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Development of a Maintenance Management System for Primary Machinery to Enhance Productivity: A Case Study of Technology Development Workshops

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Abstract: ***The study specifically, focused on identifying maintenance factors affecting productivity of the primary machines, identifying potential causes of primary machines failures and develop Maintenance Model and Maintenance Management System (MMS). The study was conducted through adoption of qualitative approach for data collection and quantitative for quantifying the problem. The most significant factors were found to be: organization and human resources, management, material management and equipment & machinery. Model development, test and validation by using most significant identified factors were analysed using Statistical Package for Social Sciences (SPSS). Validation of the model confirmed that, the developed models are valid and reliable because the variation between actual and predicted productivities from the year 2012/13 and year 2013/14 are very small; account to 3% & 2% and 5% & 4% respectively. The researchers recommend maintenance management system for the best practise at the workshops. From the findings, the study recommends that, the responsible organization can adopt the developed maintenance model and system in order to improve productivity of the primary machines at the workshops.***

Keywords: Primary Machines, Maintenance models, Maintenance Management Systems, Technology Development Workshops

1. Introduction

Primary machines have been significant resources in the technology development workshops. The performance of workshops depends on equipment and machinery's effectiveness, which is supported by effective maintenance. Maintenance of equipment has a strong impact or contribution on achieving a fully operational model (Munuo, 2015). Maintenance practice which is currently considered at the workshops is corrective maintenance. It proves costly to the workshops since the machines/equipment are stopped during the operation in order to rectify the problems. It can be said that, planned maintenance of machines/equipment is important in the workshops to avoid direct and indirect costs involved in the corrective maintenance and other costs related to downtime (Kivugo, 2018).

The main objective of the study is to develop maintenance management system (MMS) for primary machines to improve productivity. Specific objectives of the study are; to identify maintenance factors affecting productivity of primary machines, to identify the potential causes of primary machines failure, to develop maintenance management model for primary machines to improve the productivity and to develop maintenance management system for improving productivity of the primary machines.

The study concentrated on two workshops in Kilimanjaro and Arusha regions due to the geographical locations and resources limitations. A total of 60 respondents from two workshops were selected who are based in Kilimanjaro and Arusha regions. The sample size for this study was obtained using both *purposive and convenience sampling techniques*. The study employed both primary and secondary data sources. The research instruments used in this study were questionnaires, interview guide and review of various documents including relevant textbooks, journals, manuals, internets, articles, official reports and other official documents. The data analysis was carried out by using Statistical Package for Social Sciences (SPSS).

Furthermore, the study resulted into development of MMS that will be significant to workshops and other related organizations. Likely, the research will contribute to the building of literatures base and area for future development agenda for academician and other practitioners.

2. Related Review

The demand of primary machines maintenance in most of industries is growing rapidly in order to improve productivity. Basically, maintenance operates in parallel with production and production produce products, while maintenance produces the capacity and quality of production (Ben-Daya & Duffaa, 1995).

The target accepted by the management and maintenance department may include availability, product quality, cost reduction, environment preservation and safety (Gustav & Hanna, 2012). According to Mkilania (2016) poor maintenance management of the machines results from poor maintenance strategies and policy, information and communication technology, material management, poor maintenance planning, lack of facilities, poor working environment and inadequate human resources.
Al-Hammad & Al-Zahrani (2006) classified the maintenance factors affecting productivity into six groups; material management, work planning and scheduling, management, maintenance strategies and policy, equipment

& machinery and organization & human resources. The figure 2.1 below shows maintenance factors affecting productivity of the primary machines.

Figure 2.1: Maintenance factors affecting productivity of primary machines (Source: Al-Hammad & Al-Zahrani, 2006)

Other factors Affecting Productivity of the primary machines at the workshops include:

Technical factors: Productivity mostly depends on the technology which includes layout, equipment, correct design of machines, research and development, automation and computerization. If the organization uses latest technology, productivity increases (Kalyan, 2013).

Production factors: Production of all workshops should be properly planned, coordinated and controlled. The right quality of raw materials and energy should be used for production. Production process should be simplified and standardized. Well coordination of everything increases productivity (Bao, 1989).

Personnel factors: This factor is related to productivity increase. If personnel are treated in a good manner and subjected to relevant incentives, productivity will increase but once the employees are not motivated and subjected to poor working environment and if they are not the right people production will decrease (Fernandes, 2008).

Supply chain issues: Develop strong inventory tracking systems to avoid running out, and cultivate multiple sources for the same items in case of shortages (Davis & Hikmet, 2008).

Location factors: Productivity also depends on where the production workshop is located relative to raw materials, customers, and workers. It is more productive once the production workshops are located nearby source of raw materials, customers and skilled workforce (Amiran, 1993).

Financial factors: Finance is the heart of the business; capital expenditure should be properly controlled. If there is planned finance and available the productivity will increase (Kalyan, 2013). Financial planning such as planning for replacement of the outdated machines and equipment, training the staff and salary increment is important (Foley, 1962).

Organization factors: Productivity depends highly on organizational factors such as; work timings or working hours discipline or hierarchy order policies and procedures. It also depends on the level of communication and a brand name of company (Afsharian *et al.,* 2013).

Management factors: Develop better relation with employees, encourage employees to provide their opinions and provide good working environment (Zhang, Zhang & Zhao, 2002).

Government factors: The management should have proper knowledge about the government rules and regulations and maintain good relationship with the government (Zomorodian, 2002).

The fundamental approach of maintenance management system can be viewed as a closed loop which is repeated in a continuous improvement programme of maintenance and information procedure. This approach is the concept of Plan-Do-Check-Act (Pintelon & Wassenhove, 1990).

Maintenance Management Model:
The maintenance management model consists of eight phases. The effectiveness of maintenance management depends on how well these phases are connected and work individually for coordinating maintenance goals with that of production or service. The model determines the effectiveness of the subsequent implementation of the maintenance plans, schedules, controls and improvements. Maintenance management model focuses on maintenance policies optimization, including the optimization of preventive maintenance intervals, planning of group replacements and inspection modeling (Márquez, Moreu, Gómez, Parra & López, 2009).

Development of maintenance management model facilitates decision making in the context of equipment maintenance management and organization. The techniques required are statistical analysis tools for predicting equipment's failure behavior and mathematical models to optimize the maintenance policy parameters. It also includes decision criteria concerning e-maintenance, decision aids for outsourcing and decision schemes for determining the more suitable maintenance concept (Pintelon & Parodi-Herz, 2008).

Maintenance Management System:
Maintenance Management System (MMS) is used to explore the information regarding specific machine, planning and scheduling of work to be performed and assigning work to the relevant personnel, supplier information, disposal and replacement of the machines to signal for the maintenance time. The goal of a maintenance manager is to employ a maintenance management system that optimizes the use of valuable and available resources (manpower, equipment, materials, and funds) to maintain facilities and equipment. The system provides integrated processes, giving the manager control over the maintenance of all facilities and maintainable equipment from acquisition to disposal (Sapp, 2016).

Computerized Maintenance Management System (CMMS):

The development of maintenance management system is computerized in order to facilitate proper information storage in a computer. CMMS are packaged software tools designed specifically to support companies in maintenance management. These activities are to schedule and record operation and preventive/planned maintenance activities associated with facility equipment. The CMMS can generate and prioritize work orders and schedules for staff to support "trouble" calls and to perform periodic/planned equipment maintenance. Upon completion of a work order, performance information, such as the date on which the work was performed, supplies/inventory, and man-hours expended, typically are loaded into the database for tracking, to support future operations/planning. In addition, these systems can provide the means to effectively manage both human and capital resources in a plant. It is imperative to understand that the CMMS is a tool used to assist in improving maintenance and related activities. CMMS only manages data that have been input to it or that which it has created as a result of data input. It does not manage the maintenance operation (Sapp, 2016).

3. Data Collection and Analysis

This study identified and analysed thirty factors clustered into six groups based on questionnaires results and compared to each other by using Relative Importance Index RII). Data collection and analysis for all maintenance factors in considaration are shown in table 3.1 and 3.2.

Table 3.1: Maintenance factors Affecting Productivity of the primary machines

Maintenance Factors affecting Productivity	Likert scale (%)					RII	Rank	Rating
	1	2	3	4	5			
Work planning & scheduling	0	17.5	30	25	27.5	0.73	5	significant
Maintenance strategy &policy	0	29	31	20.3	19.7	0.66	6	significant
Equipment & machine	0	12	20	25	43	0.88	1	most significant
Organization & human resource	0	3.6	27	40.5	28.9	0.79	2	most significant
Management	0	10.5	28.4	37.5	23.6	0.77	3	most significant
Material Management	0	13.2	33	26.1	27.7	0.76	4	most significant

Table 3.2: Other factors affecting productivity of the primary machines

Factors affecting productivity	Likert scale (%)					RII	Rating
	1	2	3	4	5		
Production of all workshops should be properly planned, coordinated and controlled.	0	20	33.6	10.2	36.2	0.73	5
Technical factors (include layout, equipment, correct design of machines, research and development, automation and computerization	0	27	25.6	14.2	33.2	0.7	7
Supply chain issues (develop strong inventory tracking systems to avoid running out at inopportune times, and cultivate multiple source)	0	27	30.4	10.5	32.1	0.69	8
Location factors (located relative to raw material, customers and co-workers)	0	16	32	14	38	0.75	3
Financial factors (Financial planning such as planning for replacement of the out-dated machines and equipment, training the staff and salary increment)	0	2	28	30	40	0.82	1
Government factors (proper knowledge about the government rules and regulations and maintain good relationship with the government)	5	26	22	20	27	0.68	9
Management factors (possess imagination, judgement skills and willingness to take risks)	0	20	20.4	27.5	32.1	0.74	4
Organization factors (involvement, accountability, transparency availability of materials or tools and equipment construction work)	0	20.5	35.4	24	30.1	0.72	6
Personnel factors (if personnel are treated in a good manner and subjected to relevant incentives, productivity will increase)	0	2	26	30	42	0.76	2

Table 3.1 shows that, among six group of factors affecting productivity of the primary machines, four groups ranked most significant which implied that, they have great contribution to affect primary machines productivity, and two groups were ranked significant which implied that, they have significant contribution to affect productivity of the primary machines.

Other factors affecting Productivity of the primary machines:

The researchers wanted to know the extent to which other factors as shown in table 3.2 contribute to affect productivity of the of primary machines. Their opinions are presented in Table 3.2. Two factors, financial and personnel factors ranked most significant which implied that, respondents have great concern to affect productivity of the primary machines. Other factors ranked significant which implied that, they have significant contribution to affecting productivity of the primary machines

4. Development of Maintenance Management Model for Primary Machines to Improve Productivity

4.1 Development of Multiple Regression Model

Thirty maintenance factors contribute to affect productivity of the primary machines were identified and clustered into six groups. Four factors were ranked most significant to affect productivity of the primary machines which are equipment & machinery, material management, management and organization & human resource. Other factors with less contribution to affect productivity of the primary machines were excluded from the model development.

Productivity for Workshop 1 for Year 2015/16, 2016/17, 2017/18 & 2018/19

Table 4.1 below shows the summary of productivities for four years and overall productivity for each year. By running regression analysis from data obtained in table 4.1 coefficient of respective factors were obtained and inserted into equation 4.1 to obtain the maintenance model for workshop 1 as shown in equation 4.2.

Table 4.1: Technical data for workshop1

Years	Productivity	EM	MM	M	HR
2015/16	0.69	.7400	.5800	.7000	.6900
2016/17	0.61	.7500	.6000	.7600	.6100
2017/18	0.63	.6600	.6500	.7400	.6300
2018/19	0.58	.6300	.5900	.7300	.5900

$$p_{(T)} = ß_0 + ß_2 P_{(EM)} + ß_3 P_{(HR)} + ß_4 P_{(M)} + ß_5 P_{(MM)} \quad (4.1)$$

$P_{(EM)}$: Equipment and machinery related factors

$P_{(HR)}$: Organization and human resource related factors

$P_{(M)}$; Management related factors

$P_{(MM)}$; Material Management related factors

$ß_0$; is a constant value, and

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$, and β_6 are coefficients of the predictor variables

$$p_{(T)} = 0.152 + 0.272P_{(EM)} + 0.118 \ P_{(HR)} + 0.160P_{(M)} + 0.180P_{(MM)} \quad (4.2)$$

Productivity for Workshop 2 for year 2015/16, 2016/17, 2017/18 & 2018/19

Table 4.2 summarizes productivities for four years and overall productivity for each year.

Since the effect of each maintenance factor differ to one another, it is important to observe the contribution of each maintenance factor by assigning coefficients to each and running regression analysis.

Table 4.2: Technical data for workshop 2

Years	Productivity	EM	MM	M	HR
2015/16	0.62	.6700	.6000	.7500	.6200
2016/17	0.5	.6500	.5500	.7400	.5600
2017/18	0.57	.7300	.6100	.7100	.5400
2018/19	0.62	.5800	.5500	.7000	.6000

$$p_{(T)} = ß_0 + ß_2 P_{(EM)} + ß_3 P_{(HR)} + ß_4 P_{(M)} + ß_5 P_{(MM)} \quad (4.3)$$

$P_{(EM)}$: Equipment and machine related factors

$P_{(HR)}$: Organization and human resource related factors

$P_{(MNGT)}$; Management related factors

$P_{(MTM)}$; Material Management related factors

$ß_0$; is a constant value, and

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$, and β_6 are coefficients of the predictor variables

$$p_{(T)} = 0.28 + 0.12P_{(EM)} + 0.10 \ P_{(HR)} + 0.18P_{(M)} + 0.17P_{(MM)} \quad (4.4)$$

By running regression analysis from the data obtained in table 4.2, coefficients of respective factors were obtained and inserted into equation 4.3 to obtain the maintenance model for workshop 2 as shown in equation 4.4.

Summary of Model Development for Workshop1 and Workshop 2

Equipment and machinery: positive coefficient of 0.272 and 0.12 suggests that, having unaged equipment & machinery, maintained facilities and proper use of equipment & machinery can influence maintenance performance and hence increase productivity.

Human resource: positive coefficient of 0.118 and 0.10 suggests that, having motivated, experienced, competent, skilled personnel can influence maintenance performance and hence increase productivity.

Management: positive coefficient of 0.160 and 0.18 suggests that, having effective communication among the team, management commitment, proper maintenance policy, effective maintenance system and awareness of maintenance can influence maintenance performance and hence increase productivity.

Material management: positive coefficient of 0.180 and 0.17 suggests that, having durable, quality and accessible

spare parts can influence quality maintenance and hence increase productivity.

5. Development of Maintenance Management System for Workshops

5.1 Development of Maintenance Management System

Maintenance management system is a system which is used to manage all maintenance activities with the capacity to track equipment, spare parts, timing, time required to perform maintenance and personnel. This system is developed based on conceptual model and significant element that contribute to productivity improvement as indicated below.

Maintenance planning
Maintenance planning is the process of setting priorities for various jobs and determines the time to perform maintenance, equipment, spare parts, labour, working tools and labour hour required to accomplish a certain job. The maintenance planning consists of identification of the work, estimate number of personnel, spare parts and materials required to perform a required job. When maintenance work is managed properly through setting weekly, monthly and quarterly schedules the productivity is going to increase.

Maintenance programme
Maintenance programme has nine-steps to follow; set maintenance goals-what do you want to achieve, establish priorities-what do you want to achieve first, establish performance indicators or measures-what indicators lead you into achievement, set short- and long-term plans, execute the set plans, give progress report annually (Dhillon, 2002). In order for the workshops to improve its productivities, it should set goals which eventually identify short and long terms plans, personnel, materials, and budget required through refereeing from previous years.

Maintenance controlling
Maintenance controlling deals with the releasing and monitoring of the maintenance work orders. The controlling of the maintenance work orders concentrates on scrutinise the availability of the equipment, harmonises the distribution of the maintenance tasks, monitoring the available capacity and resources and collection of the data concerning the work orders for the purpose of improving productivity.

Maintenance commitment
Maintenance management system requires great support from management side for the successful of equipment life and increase productivity of the centres. Management commitment is the major tool to facilitate productivity improvement of the equipment, its roles are to establish, implement, maintain and improve maintenance management systems on a regular basis, the management should establish a system to collect, analyse and report data related to machines maintenance activities (Tzempelikos, 2015).

Maintenance Policy
Maintenance policy is the document that guides maintenance activities which require attention during the setting due to its importance.

6. Discussion of the Results

The discussion is based on study specific objectives namely; identification of maintenance factors affecting productivity of the primary machines, identification of potential causes of primary machines failure, development of maintenance model and development of maintenance management system to improve productivity of the primary machines. Maintenance factors affecting productivity classified into six groups, the data collection and analysis were based on all factors, which consequently results into model and system development.

There are numerous types of policies such as time – based maintenance (TBM) and failure-based maintenance (FBM) policy (Duffuaa, Ben- Daya, Al-Sultan & Andijani, 2001)

Identification of maintenance factors affecting productivity of primary machines
The factors were analysed and ranked according to their significance, four group factors ranked as most significant and used in the model development and two factors were ranked as significant which implied that, they have significant contribution to affect productivity of the primary machines. Nine Other (subsidiary) factors affect productivity of the primary machines were identified, analysed and ranked. Two subsidiary factors were ranked most significant which implied that, they have great contribution to affect productivity of the primary machines which are financial and personnel factors, seven subsidiary factors ranked significant which implied that, have significant contributions to affect productivity of the primary machines which are organization, management, government, location, supply chain, technical and production factors.

Identification of potential causes to primary machines failures
The general findings of the study confirmed that, lathe machines have high rate of failure with relative importance index 0.86, followed by milling machines with relative importance index 0.76 and the last are drilling machines with relative importance index 0.71. The workshops should keep much attention on lathe and milling machines due to their great significance observed and on drilling machines requires attention as ranked as significant which implied significant efforts needed to improve productivity of the workshops. As these machines considered as a potential machine in production workshops productivity will also increases.

Development of maintenance model
The general findings of the study confirmed that, the models developed for each factor identified as well as combined outcome with productivities as dependent variables which is taken as outcome of the model development. From the model testing it shows the productivity increase as

management commitment is increased on maintenance, material management is committed, spare parts available on time, durable spare parts and quality spare parts available, aged equipment & machinery replaced and employment of qualified, competent, skilled and motivated personnel. For the workshops to improve productivity, four factors among the identified factors should be taken seriously which are; equipment & machinery, material management, management and organization & human resource.

Development of maintenance management system

The general findings of the study confirmed that, maintenance system used at the workshops is not computerized which influences improper record keeping of various documents such as work order, material requisition etc and difficult to plan and implement maintenance activities. In that aspect it was difficult to trace maintenance history for each primary machine. Therefore, it is suggested to computerise the system in order to have proper record which will exist for long time.

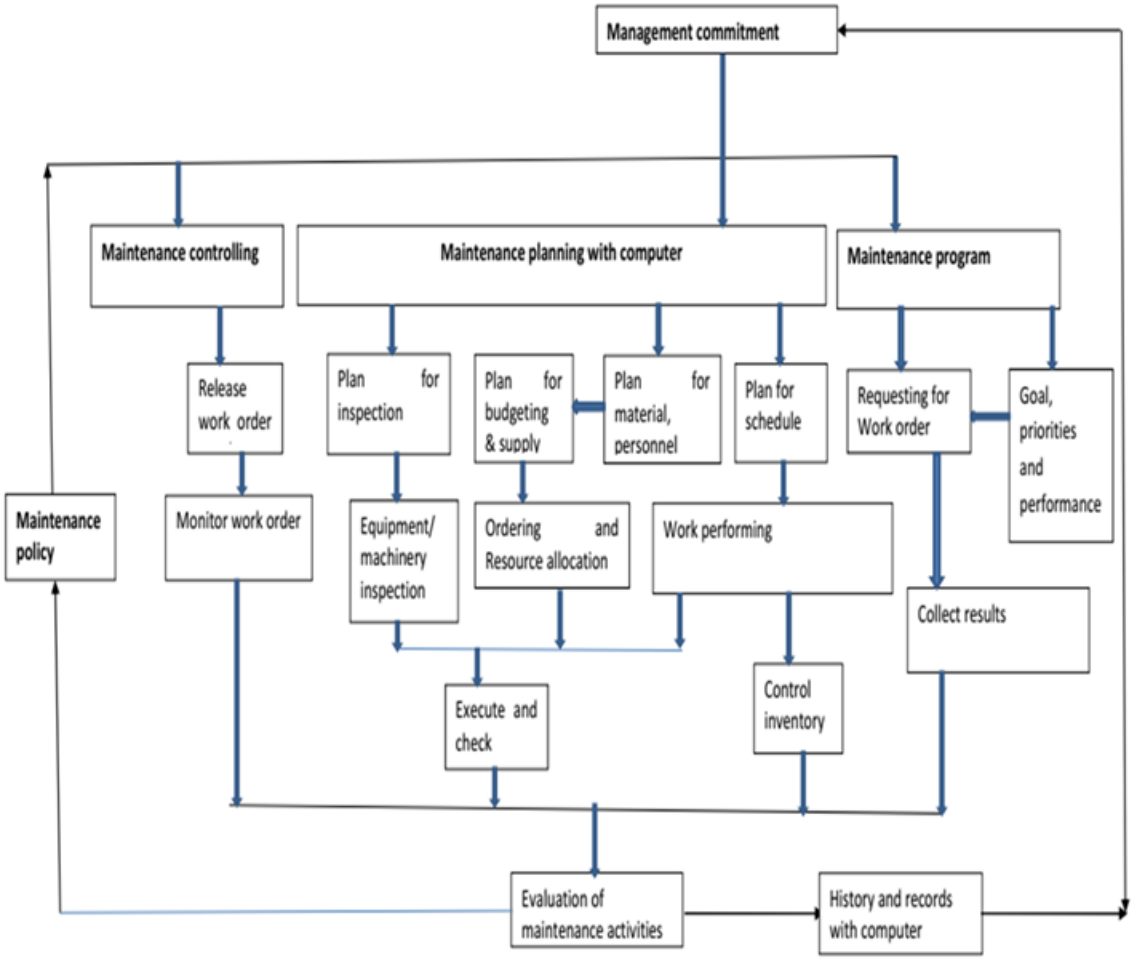

Figure 5.1: Developed maintenance management system for workshops

Also, it was confirmed that, there are no maintenance policy and strategy nor proper planning, programme and control. Therefore, due to lack of policy and strategy the maintenance type practised at the workshops is corrective maintenance but the planned maintenance is set aside and no actual implementation due to various reasons such as high costs, replacement of working spare parts which hinder productivity of the machines and eventually shorten life time of the machines and lead into costs increase, delay completing customer orders which lead to lose of customers or lose of reputations and trust from the customers.

7. Conclusion and Recommendations

7.1 Conclusion

In order to establish sustainable and best maintenance practices that are compatible with lowering maintenance costs, this paper identifies, examines and analyses maintenance factors affecting productivity of the primary machines using SPSS 21 and ranked according to their contributions. The model was developed, tested and validated, and found to be reliable and valid for improving productivity of the primary machines. It has been confirmed that, the developed models are valid and reliable because the variation between actual and predicted productivities from the year 2012/13 and year 2013/14 are very small; account to 3% and 2% for worshop1 and 5% & 4% for workshop2 respectively. The findings of the study further confirmed that, maintenance system used at the workshops was not computerized. Using the developed Computerised Maintenance Management system will improve the productivity of the primary machines in the workshops.

7.2 Recommendations

It is recommended the workshops to put more effort to most significant factors identified in order to improve productivity of the primary machines as follows:

Organization & human resource: Recommended to conduct on-job and outside trainings to capacitate personnel, to conduct maintenance sensitization awareness to staff, to increase the minimum wage to a certain level to meet the basic requirements of standard of living, and to apply Motivation scheme to retain qualified, competency and skilled personnel.

Equipment & machinery: Recommended to phase out uneconomical old technologies with sophisticated technologies, to introduce more training and use of modern diagnostic tools, to use of standard specification for repetitive works, and to ensure a well- designed and managed maintenance of equipment that can control failure rates.

Material Management: Recommended to use standard specification for repetitive works, to use reputable suppliers of genuine spare parts, and to ensure quality spare parts available in the workshop especially fast-moving items.

Management: Recommended to ensure good relationship between employees and employer, to ensure effective communication, and to ensure adequate commitment and support for maintenance by providing necessary resources.

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