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Application of Analytic Hierarchy Process (AHP) to Evaluate Maintenance Practices in TVET Institutions in Kenya

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Article info

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ABSTRACT

TVET institutions are expected to produce the bulk of Kenya's middle level manpower equipped with skills to drive the attainment of infrastructural objectives of Kenya Vision 2030. However inadequate training resources brought about by poor management practices continue to impede efforts to equip Kenyan youth with employable technical skills. A programme to re-equip the institutions has been effected but it requires maintenance practices to be aligned with the new acquisitions to ensure they are constantly available for training. A survey was conducted through a questionnaire to engineering departments to evaluate compliance with maintenance performance indicators (PIs); a 5-point rating scale was used to score responses in the questionnaire that returned a combined Maintenance Management System Effectiveness Index of 0.517. This indicated a need for improvement of maintenance practices. The Analytical Hierarchical Process (AHP) method was applied which identified predictive maintenance policy as the best one to apply.

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Introduction

Technical Vocational Education and Training (TVET) has been identified in Kenya Vision 2030 as the main vehicle that will provide the foundation for the transformation of human resource skills for technological and industrial transformation. This transformation is expected to lead to increased wealth and social well-being as well as enhancement of the country's international competitiveness.

As an alternative to traditional academic education, TVET has gained international and national prominence in the last decade (Symonds et al., 2011). In Kenya, the sector has witnessed expansion especially following the enactment of the TVET Act 2013 that established the TVET Authority. A raft of reforms have been implemented occasioning improvement of infrastructure, promotion of ICT, increased capitation among others. These measures have improved access and enhanced the quality of training.

Formal TVET programmes in Kenya are largely institution-based; the programmes are offered in public and private colleges ranging from the National Polytechnics, Technical Training Institutes (TTI), Institutes of Technology (IT) and Technical Vocational Centres (TVC). The duration of training varies from one to three years. Most of these programmes are offered in public colleges that are supervised by the Ministry of Education; however, some specialized programmes also exist in various ministries.

Despite the many reforms introduced over the last decade, the sector continues to face many challenges. The training in particular, has been criticized for being outdated and lacking relevance to industry mainly due the disparity between the skills being produced and those demanded at the workplace (TVET Policy, 2012, KAM, 2012). Various studies and government policy documents indicate high unemployment levels amidst shortage of labour; the Kenya Country Strategy Paper 2014-2018 (; Africa Development Bank, 2014 - 2018) notes that the country is short of 90,000 technicians and 400,000 artisans.

The obtaining state of affairs TVET sector could be a pointer to deep-rooted barriers in the process of human resource development. Technical institutions must therefore be supported with the necessary resources in order to deliver on their mandate. These resources include materials and equipment that exposes learners to the real work environment supported by competent human resources necessary to excel.

The processes used to impart competences and skills require informed use and maintenance of facilities and equipments; this calls for implementation of proper asset management practices that are sadly lacking as evidenced in the myriad recurring incidences of broken-down equipment in these institutions (J.W., 2009) (S.W., 2013), (MoEST 2009).

Asset management is a socio-technical discipline; the social or human aspect in technical institutions has been extensively covered in various journal articles on education while the technical aspects primarily focussed on the physical assets have not. This study aims to contribute to asset management from the technical or engineering viewpoint. Emphasis will be placed on the maintenance aspect of the equipment already acquired with a view to enhancing its availability for the training function.

The main objective of this research was to evaluate maintenance management practices in TVET institutions in Kenya and apply the Analytical Hierarchical Process (AHP) to select the best maintenance practices to employ to enhance equipment availability for training

The specific objectives of this research are:

i. To develop a framework of evaluating maintenance practices in TVET ,
ii. To evaluate the maintenance practices currently in place in TVET,
iii. To select the best maintenance practices using the Analytical Hierarchical Process

This study is limited to maintenance practices in engineering departments in selected teaching departments (mechanical/automotive, civil/building construction and electrical/electronic) in TVET institutes in Kenya.

Maintenance

Maintenance is a function inherent to productive processes. It is one of the main activities in asset utilisation and impacts heavily on operations costs. Maintenance has several definitions depending on the environment in which it is practised.

Tsang (1998) however summarizes the general maintenance objectives as the follows:

i. Ensuring the plant functions;
ii. Ensuring the plant reaches its design life. In this case, the cost of operating the plant has to be optimized to meet the desired condition;
iii. Ensuring plant and environmental safety;
iv. Ensuring cost effectiveness in maintenance and the efficient use of resources (energy and raw materials).

The modern training assets acquired through the TVET Project Phase II (Kenya Country Strategy Paper 2014-2018) sponsored by the Government of Kenya employ complex designs that demands new management and maintenance techniques. To survive in the increasingly competitive environment, TVET institutions must tailor their maintenance needs to suit their operations. In doing so, it important to put in place procedures and processes to measure, control and improve the assets performance.

Over the years, maintenance strategies have evolved into three basic maintenance policies that are widely employed to keep equipment and plant running: these are:

Reactive or Run to failure maintenance – only routine servicing is performed on an asset until it fails, the policy is suitable when the consequences of failure are minimal or when the cost of preventive maintenance far outweighs the expected benefits or value of the asset.

Preventive maintenance – where asset parts are replaced or repaired before failure occurs. Its most common forms are and condition-based maintenance (CBM) that involves continuous monitoring followed by preventive maintenance actions when failure is judged imminent.

Predictive maintenance – based on predictive techniques such as vibration analysis, tribology, thermography etc.; it is carried when a given system parameter or system condition approaches or reaches a predetermined value or situation. Also includes design out maintenance (DOM) which involves design modification of an asset part with a view to improved reliability, maintainability or the need to costs associated with routine servicing.

The attainment of the best maintenance practice is accomplished through a series actions beginning with the capture of all maintenance work in a work order. This primary tool that is used for managing and measuring labor, resources and the department effectiveness. It provides accurate and effective reports (feedback) to departments: it is also a management tool for evaluation of the maintenance function. Typical feedback includes mean time between failures (MTBF), cost of spares, compliance rates, plant maintenance overdue, labour allocation, spare parts demand and usage reports etc.

Maintenance Performance Indicators

Performance measurement employs a set of performance parameters also called Performance Indicators (PIs) that are directly linked to the overall goals of the organization. These goals determine the critical activities that must be done well for a particular operation to succeed. They are normally expressed as numerical parameters on critical activities associated with measurable physical characteristics that are tracked and measured against actual performance.

The most comprehensive performance indicators include: (Weber A., 2005), (Muchiri P., 2010) they defined these in terms of the physical asset management requirements and asset reliability process. The indicators are classified as either leading or lagging; those that indicate how tasks are performed and those that indicate outputs respectively. (Smith, 2002) defines the performance indicators in terms of standards and methods; standards being the measurable performance levels of the maintenance activity while methods deal with the tactics employed to meet the set standards.

The ideas from these authors are concerned with the following key areas (performance indicators) of maintenance practice:

i. Planned maintenance activities
ii. Work order system and Work flow
iii. Maintenance engineering development
iv. Maintenance skill training
v. Maintenance inventory and purchase integration
vi. Management reporting and performance measurement
vii. Evaluation and integration of contractors
viii. Computerized maintenance management system (CMMS).

Research Methodology

The first objective of this research is to develop a framework of evaluating maintenance practices. The eight key areas of maintenance practice identified in literature were applied to develop a questionnaire that was administered to three engineering departments (civil engineering, electrical engineering and mechanical engineering) in 35 TVET institutions. The institutions selected had earlier been used to prepare an Audit Report of 2009; the report was thereafter used as a basis to design interventions for TVET Project Phase II sponsored by the Government of Kenya.

A pilot study was done in two of the thirty-five institutions to validate the questionnaire prior to its administration. A 5-point rating scale proposed by (Jackson O. B., 2001) was used to score responses from the questionnaire which had three suggested answers rated at 5, 3 and 1 point respectively. The aggregate score from each institution is the used to determine the Asset Management/Maintenance Management System Effectiveness Index (MMEI) using the relationship defined by (Duffua S.O., 1996) as follows:

$$MMEI = \frac{\textbf{Total Earned Score}}{\textbf{Total Maximum Score(36 Questions)}}$$

$$MMEI = \frac{\textbf{Total Earned Score}}{\textbf{180}}$$

Using this method, the asset management/ maintenance management system in the organization is:

Extremely effective : MMEI ≥ 0.85
Effective : 0.70 ≤ MMEI< 0.85

Needs improvement : MMEI< 0.70

To select the best maintenance practice, the Analytic Hierarchy Process (AHP) was used. AHP is a Multi-Criteria Decision-Making (MCDM) approach that was developed by (Saaty T.L., 1980). One major advantage of AHP over other MCDM methods id that it does not require a statistically large sample size to achieve sound and useful decisional results, (Doloi H., 2008), (Chou J.S., 2013). AHP can be used for problems that have both qualitative and quantitative aspects; the method organizes the critical aspects of a problem into a hierarchical structure similar to a family tree

The Analytic Hierarchy Process uses the following three steps:

i) Hierarchy formation – the top level of the hierarchy/family tree contains the decision goal; selecting the best maintenance practices to achieve the improvement required. The successive lower levels represent the progressive breakdown of the decision criteria, sub-criteria and the alternatives for arriving at the goal. Hence, second level has the eight criterion that contribute to the attainment of the overall goal while the third level is the maintenance policies to be prioritised for each performance indicator. Fig 1 shows the decomposition of the problem into three levels.

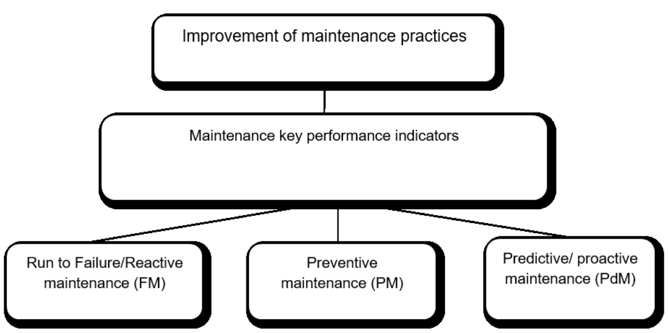

Figure 1: *Decomposition of the problem into a hierarchy*

ii) Pairwise comparisons - A pair wise comparison of elements which are assumed to be independent is made to determine the importance of each element expressed as a relative score. Every two criteria at each level are compared and so on. The pairwise comparisons are based on a nine-point scale as shown in Table 1 (Saaty T.L., 1980).

Intensity of importance (weight)	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong
9	Absolutely more important
2,4,6,8	Intermediate values between the two adjacent judgements
Reciprocals of previous values	If the activity 'i' has one of the above non-zero numbers assigned to it when compared with activity 'j' it has the reciprocal value when compare with 'i'

Table 1: *AHP pairwise comparison scale*

Verification of consistency – since AHP allows subjective judgements, their consistency is not certain. Therefore, consistency verification is necessary to ensure an optimised outcome. To control the consistency of the pairwise comparisons, the consistency index (CI) and consistency ratio (CR) are computed. These are revised if the CR exceeds 0.1 (T.L., 2000).

CI is computed using the equation

$$CI = \frac{\lambda \max - n}{n - 1}$$

Where;
CI = Consistency Index
λmax = Maximum or Principle Eigenvalue
n = Size of Square Matrix
CR is computed using the equation:

$$CR = \frac{CI}{RI}$$

Where,
CR = Consistency Ratio
CI = Consistency Index
RI = Random Index
Random Index (RI) is determined from Table 2.

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.55	0.94	1.14	1.28	1.37	1.43	1.48	1.51	1.54	1.54

Table 2: *Random Index (RI) Using Monte Carlo Simulation Method*

Response Rate

The questionnaires were administered by email to 35 Technical Training Institutions (105 technical training departments). Phone calls were made to confirm receipt of the emails and to follow up progress with a view to boost response rate. 43 responses were received in both soft and hard copies within the month of administration which translates to 40.95% response rate. Table 3 shows the profile of the respondents.

The response rate was low. It however compared favourably with other similar maintenance studies (Muchiri P., 2010).

Department	No. of respondents	%
Mechanical/automotive	19	44.19
Electrical/electronic engineering	15	34.88
Building construction/civil engineering	9	20.93
Total	**43**	**100**

Table 3: *Profile of respondents*

No.	Component	Max. score	Average scores			Grand average	%age
			Civil Engg.	Elect. Engg.	Mech. Engg.		
1.	Planned maintenance activities/work planning	35	13.86	15.91	13.92	14.56	41.6
2.	Work order system and work flow/ work identification	35	15.71	16.73	15.21	15.88	45.3
3.	Maintenance engineering development/work execution	40	18.29	21.63	20.14	20.02	50
4.	Maintenance skill training	20	11.14	14.82	14.57	13.51	67.6
5.	Maintenance inventory and purchase integration	15	9.14	11	9.64	9.93	66.2
6.	Management reporting and performance measurement	15	7.71	8.18	6.27	7.39	49.2
7.	Evaluation and integration of contractors	10	5.57	6.82	6.14	6.18	61.8
8.	Computerized maintenance management system (CMMS)	10	4.86	5.91	5.71	5.49	54.9
	Total	180	86.29	101	91.90	93.06	
	MMEI		0.479	0.561	0.511	0.517	

Table 4: *Combined results*

Criteria	a	b	c	d	e	f	g	h
a	1	2	3	6	0.5	3	5	4
b	0.5	1	2	5	0.333	2	4	3
c	0.333	0.5	1	4	0.25	1	3	2
d	0.167	0.2	0.25	1	0.2	0.333	2	.05
e	2	3	4	5	1	2	4	3
f	0.333	0.5	1	3	0.5	1	3	2
g	0.2	0.25	0.333	0.5	0.25	0.333	1	0.5
h	0.25	0.333	0.5	2	0.333	0.5	2	1
Total	**4.78**	**7.783**	**12.083**	**26.5**	**3.67**	**10.167**	**24**	**16**

Table 5: *The Criteria Matrix*

Criteria	a	b	c	d	e	f	g	h	Row total	Priority vector
a	0.212	0.257	0.248	0.226	0.136	0.295	0.208	0.25	1.832	0.229
b	0.206	0.129	0.167	0.188	0.091	0.196	0.166	0.188	1.312	0.164
c	0.069	0.064	0.083	0.151	0.068	0.098	0.125	0.125	0.784	0.098
d	0.035	0.026	0.021	0.037	0.054	0.033	0.063	0.031	0.312	0.039
e	0.414	0.385	0.331	0.185	0.272	0.196	0.166	0.188	2.144	0.268
f	0.069	0.064	0.082	0.113	0.136	0.098	0.125	0.125	0.816	0.102
g	0.042	0.032	0.027	0.018	0.068	0.033	0.041	0.031	0.296	0.037
h	0.043	0.041	0.075	0.091	0.048	0.083	0.083	0.063	0.504	0.063
Total										1

Table 6: *The Normalized Matrix*

Results

Evaluation of Maintenance Practices

The Maintenance Management System Effectiveness Index (MMEI) for departments was calculated. The combined results for the departments produced an average MMEI of 0.517, Table 4 which is way less than 0.7, the minimum value for effectiveness. The index suggests that the maintenance management systems currently in place need to be improved if the institutions are to align with the best practices.

The Application of the Analytic Hierarchical Process (AHP)

The judgment matrix for the criteria in level two of the decision tree concerning the intensity of the 8 performance indicators is shown in table 5. The letters a,b, ...,h represent the 8 criterion respectively and are arrived at with reference to Table 5

The normalised matrix is obtained by dividing each entry in the criteria matrix by its corresponding column total. The row totals are computed and divided by 8 (number of criteria items) to yield the priority vector, and is presented in Table 6.

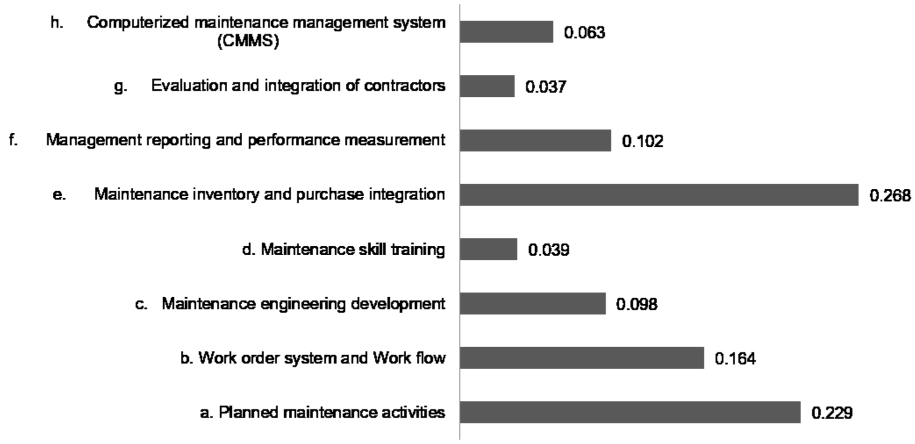

Figure 2: *Priority Vector Chart*

The vector of priorities is the principal eigenvector of the matrix. It gives the relative priority of the criteria measured on a ratio scale. In the case under consideration maintenance inventory and purchase integration has the highest priority with 26.8% of influence. It indicates the importance of record keeping in the day-to-day operations and their central place in informing future actions. Good record keeping also facilitates information flow between management and operational levels.

Planning, work order system and work flow and management reporting and performance measurement also have significant priorities of influence signifying their importance in management of maintenance practices.

The Principal Eigenvectors were calculated using the formula:

$$\lambda \text{max} = \frac{\text{original input matrix X vector of priorities}}{\text{vector of priorities}}$$

Table 7 presents the Eigenvector matrix.

Criteria	Row sums	Priority vector	Eigenvector (λ_{max})
a	1.832	0.229	8.566
b	1.312	0.164	7.778
c	0.784	0.098	8.355
d	0.312	0.039	8.387
e	2.144	0.268	8.784
f	0.816	0.102	8.326
g	0.296	0.037	8.437
h	0.504	0.063	8.245
Average λ_{max}			8.356

Table 7: *The Eigenvector Matrix*

For the criteria matrix above CR =0.036 hence the judgements are acceptably consistent.

Next the pair wise comparisons are done for the lowest level. The elements to be compared are the maintenance policies with respect to each other in satisfying each of the criterion in level 2. There are eight 3x3 matrices of judgement since there are eight criteria in level 2 and three elements to be compared with each other for each criterion. This is presented in Table 8 and 9.

The final involves establishment of the composite or global priorities of the elements. This is obtained by multiplying the priority vector for each criterion in level 2 with the column of priority vectors for each element and computing the row sums to establish the row with the highest value or global priority shown in Table 10.

Predictive maintenance has the highest priority vector and should be adopted. To make it successful, institutions need to develop relevant KPIs to define and measure performance of their maintenance activities. This task involves setting values for performance targets and milestones. The heads of departments and their assistants being experts in their fields are well placed to perform this task.

Planned Maintenance Activities					Work Order System and Work Flow				
Elements	CM	PM	PdM	Priority Vector	Elements	CM	PM	PdM	Priority Vector
CM	1	0.333	0.25	0.128	CM	1	0.333	0.333	0.141
PM	3	1	0.5	0.338	PM	3	1	0.5	0.334
PdM	4	2	1	0.580	PdM	3	2	1	0.525
λ_{max} =3.049, CI = 0.025, CR = 0.045.					λ_{max} =3.042, CI = 0.021, CR = 0.039.				

Table 8: *Comparison matrices and local priorities*

7					Maintenance Skill Training				
Elements	CM	PM	PdM	Priority Vector	Elements	CM	PM	PdM	Priority Vector
CM	1	0.25	0.2	0.098	CM	1	0.5	0.333	0.173
PM	4	1	0.5	0.334	PM	2	1	0.5	0.312
PdM	5	2	1	0.568	PdM	3	2	1	.0568
λ_{max} =3.024, CI = 0.012, CR = 0.022.					λ_{max} =3.009, CI = 0.004, CR = 0.007.				
Maintenance Inventory and Purchase Integration					**Management Reporting and Performance Measurement**				
Elements	CM	PM	PdM	Priority Vector	Elements	CM	PM	PdM	Priority Vector
CM	1	1	1	0.333	CM	1	0.2	0.143	0.074
PM	1	1	1	0.333	PM	5	1	0.333	0.283
PdM	1	1	1	0.333	PdM	7	3	1	0.643
λ_{max} =3.000, CI = 0.000, CR = 0.000.					λ_{max} =3.066, CI = 0.033, CR = 0.060.				
Evaluation and Integration of Contractors					**Computerized Maintenance Management System (CMMS)**				
Elements	CM	PM	PdM	Priority Vector	Elements	CM	PM	PdM	Priority Vector
CM	1	1	1	0.333	CM	1	0.333	0.2	0.109
PM	1	1	1	0.333	PM	3	1	0.5	0.309
PdM	1	1	1	0.333	PdM	5	2	1	0.581
λ_{max} =3.000, CI = 0.000, CR = 0.000.					λ_{max} =3.003, CI = 0.002, CR = 0.003.				

Table 9: *Comparison matrices and local priorities - expounded*

	a (0.229)	b (0.164)	c (.098)	d (.039)	e (.268)	f (0.102)	g (0.037)	h (0.063)	Global priority vector
CM	0.128	0.141	0.098	0.173	0.333	0.074	0.333	0.109	0.185
PM	0.338	0.334	0.334	0.312	0.333	0.283	0.333	0.309	0.314
PdM	0.580	0.525	0.568	0.568	0.333	0.643	0.333	0.581	0.501

Table 10: *Local and Global Priorities*

Conclusion

The maintenance practices in TVET institutions were found to be poor with a general management system effectiveness index of 0.517. The index indicates that a gap exists between industry best practices and the practices in the institutions, hence the need for improvement to put in place measures for improvement.

The finding from the questionnaire regarding the performance indicators agreed with the findings of the AHP process on the importance of maintenance inventory and purchase integration but is at variance with regard to planning and the workflow and work order system. The poor performance indicated in the questionnaire in PIs 1, 2 and 3 all which involve the generation of records upon which all others depend on clearly point towards poor practice necessitating the need for the expenditure of effort in this area. Indeed, the AHP method confirms this.

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