Sustainable Equipment Maintenance Framework for Small-Scale Water Production Plant

*[1]Uzoma G. Okoro and [2]Shaibu Muhammed
[1]Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria
[2]Department of Mechanical Engineering, Federal Polytechnic, Idah, Nigeria
u.g.okoro@futminna.edu.ng|smuhammed@fepoda.edu.ng

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ORIGINAL RESEARCH

Abstract- The effect of the COVID-19 pandemic is still much felt in the global economy: many companies are struggling to remain competitive in business, and thus the sustainability of productions ranks high amongst research topics in manufacturing industries. While much research had focused on large scale companies, the least attention had been paid to the small and medium-scale manufacturing industries which happen to be amongst the worst hit. This paper develops a model to support maintenance decision-making in a small and medium enterprises based on AHP. A total of 8 sachet water SMEs that met the inclusive criteria were selected. Six criteria were identified; consequences of failure, Ease of repair, Downtime, Frequency of failure, Cost of repair, and Cost of replacement and considered in the pair-wise comparative analysis. The developed model is targeted at addressing the fact that different components of the production equipment have disparate need for maintenance at any given maintenance schedule. Given that resources are often limited, it is cost-effective that choices of maintenance location be made such that the value added by the maintenance activities is optimized. The highlight of the analysis is the derivation of the Maintenance Significant Factor (MSF) that reflects the maintenance location-specific values of components. The result showed that the Submersible pump at an MSF value of 0.698 should attract the utmost priority and be closely followed by the Automatic Production Machine and Modules at MSF of 0.555 and 0.447 respectively.

Keywords- Analytic Hierarchy Process, sachet water factory, Maintenance Decision.

1 Introduction

It can be argued that the possibility of the attainment of the Sustainable Development Goals (SDGs) 6 -Clean Water and Sanitation in sub-Saharan Africa significantly relies on the services of Small Scale Water Production Companies. Most National and state own water works had since gone moribund as a result of myriad of factors such as- lack of maintenance culture, dearth of expertise, Government bureaucracy and corruption- and the willingness to revise the trend is yet to be seen. This has left many cities to be solely dependent on the services of the sachet water companies for the supply of water for daily needs. The gravity of the situation became clearer during the COVID-19 pandemic when intermittent washing of hands could be what it takes to save a life. Thus, it is necessary that efforts should be geared towards sustaining the operation of these vendor companies.

From the production point of view, machine do breakdown and could cause business difficulties such as failure to meet delivery dates, poor product quality, loss of industrial reputation, and loss of profit. On the contrary, a well-formulated strategy for maintenance supports the overall company's business goals by reducing the unreliability of production plants such that acceptable failure can be anticipated (Macedo et al., 2017), reducing production cost, improving competitive advantage, and delivering benefits to the stakeholders (Campos & Simon, 2019).

*Corresponding Author

Section B- MECHANICAL/MECHATRONICS ENGINEERING & RELATED SCIENCES
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Planning a maintenance schedule for a plant involves knowing the modes and understanding the mechanism of failures of the components. This knowledge helps determine the appropriate tasks to be carried out, how often they should be carried out and the details necessary for these tasks to be accomplished and may indicate the use of various maintenance techniques. (Palma et al., 2010). In some instances, different tactics and activities could exist for a routine maintenance, giving rise to a decision problem of selecting the appropriate strategy: i.e., that which optimizes maintenance objectives. In other (but related) context, decision on strategies might have been concluded, the challenge is in the form of the inability to carry out all the identified maintenance activities in a scheduled maintenance period (such as often experienced under resource constraints). This usher in another level of decision challenge on which activities to perform first and which to leave until a later maintenance period.

Deferment of certain maintenance activities can have varied/adverse implications on the company's objectives. In this sense, the maintenance manager must quickly develop the ability to maximize the use of available resources in order to consistently advance the objectives. By ranking alternative maintenance locations and/or tasks based on numerical scores, implied priority is created. Such measurement scales are usually obvious for single criterion selection simplifying the task of choosing. Unfortunately, most real-world situations hardly have a single, simple criterion for evaluating all competing alternatives. Most often, at least one set of criteria must be taken into account, and frequently, those criteria are intricately tied to one another (Chandrahas & Mahapatra, 2015). The complexity could be further exacerbated in broad-scale participatory decision-making whereby alternative preference components and/or courses of maintenance action arise from different stakeholders with different value systems, and yet this diversity must be accommodated and integrated (Abel et al., 2015; Krejčí & Stoklasa, 2018). The use of AHP in the selection process has been reported in Srividya & Suresh (2007) to resolve the dilemma related to choice of outlet feeders for Primary Heat Transport (PHT) system in Pressurized Heavy Water Reactor (PHWR). More so, similar approach has been applied in Nyström & Söderholm (2010) and Li et al (2018) in the selection of maintenance actions. However, the nature of maintenance is such that the context under which the criteria are considered will always differ in different location even for a similar plant. The context will always capture the peculiarities of the components in the location.

Idah community in the North Central region of Nigeria use to have twenty (20) sachet water companies operating at full capacity in 2015. At the time of the study (i.e., 2019), about seven (7) of the factories (or 35%) had closed down, and the remaining ones are operating below capacity. Preliminary investigation attributed the cause to high operating expenditure orchestrated by non-optimum maintenance practice: choices of maintenance location were random, even under occasionally tight budget constraints. To provide a solution to the observed maintenance challenge, the study employs the capability of the Analytical Hierarchical Process (AHP) to resolve the decision challenge involving discontinuities of scheduled maintenance intervention arising from resource deficit in a sachet water production plant. To ensure the sustainability of operation in such conditions, this paper proposes an optimized maintenance approach that combines technical and economic perspectives to derive a value for the alternative maintenance locations called maintenance significance factor (MSF) based on a pair-wise comparison of other alternative maintenance locations scheduled for planned maintenance.

2 Materials and Method

2.1 Material

The study location is an outskirt of Idah, North-central Nigeria, known for its characteristic "sole reliance of the residents on sachet water vending for meeting daily water needs." This characteristic agrees well with the study objectives. No other factor, such as that might affect the study outcome, was considered. First, the team of researchers identified ten (10) sachet water vendor companies through random sampling of the commodity sold at the major markets in the area. The identities of the vendor companies were further confirmed at the state division of the National Agency for Food and Drugs, Administration and Control (NAFDAC) which is the regulatory agency. Out of the first ten (10) production and vendor businesses, eight (8) have been granted authority to operate by the agency, and hereafter will be codenamed A, B, C, ⋯ , H.

To this end, six criteria were identified to be utilized in order to prioritize different maintenance tasks, which otherwise could not be implemented simultaneously owing to the budget deficit. Pair-wise comparison is a method that is informed by research showing that humans are good at recognizing whether one alternative is more important than the other especially when there is no means of quantitative ratings. It has proven to be well suited for decision-making involving multiple criteria (Arunraj & Maiti, 2007; Khaira & Dwivedi, 2018). Often Saaty's table (**Error! Reference source not found.**) is adopted in quantifying these perceived differences in the level of importance. Excel spreadsheet will be employed in most of the studies.

2.2 Method

2.2.1 Analytical Hierarchical Process

Developed in the 70s, Saaty's AHP found use in aiding complex decision-making through a process that engages decision-makers in structuring a decision into smaller parts, proceeding from the goal to objectives to sub-objectives down to the alternative courses of action. Decision-makers then make simple pair-wise comparison judgments throughout the hierarchy to arrive at overall priorities for the alternatives. This thought process is presented in Table 1.

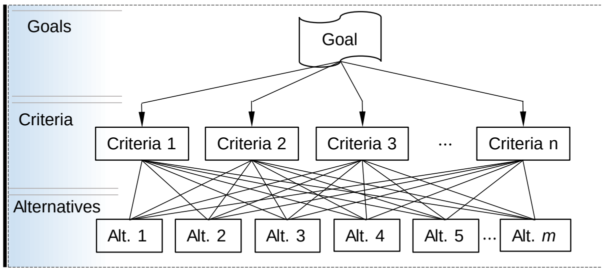

Fig. 1. The hierarchical structure of decision-making in AHP

The comparison judgments are accomplished using criteria. This could be a one-step judgment or multi-step judgment depending on the complexity of the choices and judgment. Irrespective of the route taken, the constitution of the criteria is critical. Criteria can also be inferred from secondary sources such as equipment maintenance and installation manual, journals or from primary sources such as questionnaires, interviews with stakeholders (for example, NAFDAC)

In AHP, the relative importance of the competing alternatives is made more explicit through a pair-wise judgment/comparison process which explores the knowledge of the subject area. Such a comparison process is aided by Saaty's priority table as presented in Table 1. The results of the evaluation are the decision matrices (equation 1).

The general representation of the comparison process is given by equation 1.

…where, $c_i: i = 1,2, \dots, m$, are the alternatives; $c_j: j = 1,2, \dots, m$ are the criteria, and a_{ij} are the judgements. i.e., the elements of the decision matrix. AHP pair-wise judgment is constraint by the relationship; $a_{ij} = \frac{1}{a_{ji}}; \forall i \neq j$ and $a_{ij} = 1, \forall i = j$. The pairwise comparison is done with respect to the weight (perceived or calculated from real data) of the alternatives resulting to homogeneous system of an algebraic equation with no constant terms.

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The final priority of the alternatives is derived by finding the vector $\boldsymbol{\omega}$ of order m that satisfies equation 5.

$$\begin{bmatrix} c_i \\ \vdots \\ c_m \end{bmatrix} = \begin{array}{c} \begin{array}{ccc} c_j & \cdots & c_m \end{array} \\ \hline \begin{bmatrix} & & \\ & a_{ij} & \\ & & \end{bmatrix} \end{array} \qquad (1)$$

Finding $\boldsymbol{\omega}$ derives from the study of linear algebra: a necessary condition to obtain a non-zero solution of a homogeneous system of linear equations is that the inverse of the matrix must not exist. For this to happen, the determinant must be zero.

$$[a_{ij}]^{-1} = \frac{Adj[A]}{Det[A]} \Rightarrow \nexists \qquad (2)$$

The procedure for a zero solution of the determinant begins with an evaluation of the Eigenvalue of the matrix. The relation between a matrix and its Eigenvalues is expressed in the equation;

$$([a_{ij}] - \lambda[I])\boldsymbol{\omega} = 0 \qquad (3)$$

The determinant of the matrix (in parenthesis) is a polynomial of power m and is known as the characteristic equation of $[a_{ij}]$. The roots (of order$m$) are known as the Eigenvalues, λ.For a consistent matrix, λ will be the same as the order of the matrix and substituting λ into equation 3 gives the priorities of the alternatives $\boldsymbol{\omega}$.

Table 1. Saaty's priority table: Scale constant values related to the AHP

Scale constant value	Importance for pairwise reciprocal comparison	Description
1	Equal Importance (EI)	Two *activities* contribute equally to the objective
3	Moderate Importance (MI)	Experience and judgment slightly favour one activity over another
5	Strong Importance (SI)	Experience and judgment strongly favour one activity over Another
7	Very Strong (VSI) or Demonstrated importance (DI)	An activity is favoured very strongly over another, its dominance demonstrated in practice
9	Extreme importance (EtI)	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it

(Source: Saaty, (1994)).

The weights are consistent if they are transitive: i.e., $a_{ik} = a_{ij} \times a_{jk}.(i = k, a_{ii} = 1 = a_{ij} \times a_{ji} = a_{ij} \times \frac{1}{a_{ij}})$.

For an inconsistent matrix, the largest real positive Eigenvalue that dominates the rest of the Eigenvalues (in their absolute value) and corresponds to that which solves the characteristic equation is termed the principal Eigenvalue; designated asλ_{max}. Associated with eachλ are the eigenvectors$\boldsymbol{\omega}$ (otherwise called self-vectors). The self-vectors ($\boldsymbol{\omega}$) are derived by substituting λ_{max} into equation 3. However, one of the simpler and quicker ways to evaluate the priority vectors of a consistent judgment matrix that is approximately accurate is by adding across the columns and normalizing. Another method is to normalize the mth root of the product of the values across the column.

The mathematical proof backing this assertion is beyond the scope of the work presented. Consistent judgment implies that individual decision-makers involved in the judgment capture both logical and reasonable preferences when making decisions. Where case questionnaires are used, consistency of the judgment implies that it supports empirical research conducted by researchers (practitioners or academics) to ensure that the questionnaires are not poorly answered. The judgment metric is hardly consistent especially when it involves trading off "intangible" variables that characterize most decision criteria. Inconsistency often arise from consideration of many alternatives in the same comparison process (Benítez et al., 2011).

For the fidelity of the conclusion, the judgements should be checked and ensured that consistency is within the standard limit. (Cheng & Li, 2003). AHP uses a metric called the Consistency Ratio (CR) to estimate the level of inconsistency in judgements. The formula for calculating the consistency ratio is given in equation 4 and 5, where CI is the consistency index and RI is the consistency ratio of a random matrix of the same order.

$$CR = \frac{CI}{RI} \qquad (4)$$

$$CI = \frac{\lambda_{\max} - \mathrm{m}}{\mathrm{m} - 1} \qquad (5)$$

…where $\lambda_{\max}$ is max ($\lambda_i \mid \forall i = 1, 2 \ldots$ m); m is the order of the matrix. If λ for a consistent judgement matrix is the same as the order of the matrix, it follows that from equation $5, CI = 0$. This implies CR for a perfectly consistent matrix is zero. This value increases as the level of inconsistency increases. For inconsistent matrix, $\lambda_{max} \geq m$ and the difference, $\lambda_{max} - m$ give a measure of inconsistency. By dividing the measure of inconsistency by the order of the matrix short by one (i.e., $m - 1$), an estimate called consistency index represents consistency as a function of each judgement. The consistency ratio compares the consistency index with that of a completely randomized matrix. A CR of 0 is perfectly consistent and a CR of 1 is perfectly random. Whereas a CR in the excess of 0.1 is considered too close to randomness and the judgement should be repeated. Table 2 shows the consistency ratio for a completely randomized$m \times m$ matrix.

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Table 2. Consistency ratio of a randomized square matrix of M-th order.

M	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Fig. 2. Alternative maintenance locations

2.2.2. Data Collection

Primary data were collected during the interview process aided by the use of a questionnaire. Responses were collected from machine operators and production managers at different sessions of the interview. The questions were framed to capture the thinking of stakeholders when making decisions on the alternatives location (components) for optimized maintenance impact and decision criteria.

Choice of alternative maintenance location: Beginning with the analysis of the company's core values as provided in the mission and vision statements, the combined team of researchers and the stakeholders were able to rank the production machines based on contributions toward the achievement of the company's objectives. The following equipment came top on the list as choice maintenance sites; Automatic production machine (APM), Submersible pump (SP), Surface pumping machine (SPM), Ultraviolet sterilizer (UVS), Modules (M), Cartridge filters (CF). For further analysis, it is customary to classify the criteria into benefitting (positive) criteria and cost (negative) criteria. The difference between the two classes of criteria lies in the orientation of the values: benefiting criteria are oriented in such a way that the higher the values the better, while the reverse is the case for the cost criteria. This would be applied in computing the Maintenance Significant Factor (MSF) as would be seen later. Among the six criteria mentioned, only FOF is the positive/benefitting criteria.

Identification of criteria: the questionnaire was reframed to focus on the different perspectives of objectives often considered by management and operators and how the components would aid in driving these objectives. The following features were determined to be an initiator of maintenance: The responses from the stakeholders were gathered analysed and summarised into key criteria. Which determines the reason for an alternative course of action.

a). Consequences of failure-COF: This is the result of a machine or equipment reaching functional failure. The result can be in terms of low productivity, reduced quality; market loss and reduced return on investment.

b). Ease of repair-EOR: This is defined as the probability that an equipment/ component/ system can be restored to its original/desired condition within the specified time interval.

c). Downtime- DT: Refers to a situation where a machine is not in use or productive because maintenance is needed, this is known as maintenance downtime.

d). Frequency of failure-FOF: It is concerned with the frequency with which a failure mode occurs; a higher value indicates higher criticality of the item.

e). Repair Cost CoRr: This is the monetary cost of restoring a machine or equipment to a productive state after a failure, including the cost of removing the broken part, disposing of it, replacement part cost, and cost of installation and testing.

f). Replacement Cost-CoRl: This is the cost of replacing an unserviceable machine or component. The decision to repair or replace equipment should be based on minimizing the total cost of the equipment to the business over its remaining lifetime.

The components of the production plants were compared under the criteria in a pairwise manner and guided by the provision of the Saaty table (Saaty, 1994). The comparison proceeded as described in the flow chart in Figure 3.

The consistency of the response was analysed following the completion of the comparison process. From the literature, the consistency ratio (should be less than or equal to 0.1 when using the Analytic Hieratical Process (AHP). A consistency ratio greater than 0.1 invalidates the experiment and where case it is recommended that the experiment be repeated before continuing with further analysis. The priority index (otherwise the Eigenvector) of each equipment in the set was determined. The index also forms the basis for the calculation of the MSF: the

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algebraic sum of the criterion-based priority index for each component noting that the benefiting criteria carries a positive sign while the cost criteria carry a negative sign.

Table 3. Analysis of the consistency ratios for each criteria considered showed a result of less than 0.1 (see Table 4), thus supporting the validity of the comparison process.

Table 3. Comparison matrix

Consequences of failure

	APM	SP	SPM	UVS	M	CF
ASM	1	1	3	1	1	7
SP	1	1	5	1	1	7
SPM	1/3	1/5	1	1	1/3	3
UVS	1	1	1	1	1	7
M	1	1	3	1	1	7
CF	1/7	1/7	1/3	1/7	1/7	1

Ease of repair

	APM	SP	SPM	UVS	M	CF
ASM	1	1	1	1	1	1/9
SP	1	1	1/3	1	1	1/9
SPM	1	3	1	1	1	1/5
UVS	1	1	1	1	3	1/7
M	1	1	1	1/3	1	1/7
CF	9	9	5	7	7	1

Downtime

	APM	SP	SPM	UVS	M	CF
APM	1	1	3	1	1	7
SP	1	1	3	3	3	9
SPM	1/3	1/3	1	1	1	3
UVS	1	1/3	1	1	1	5
M	1	1/3	1	1	1	5
CF	1/7	1/9	1/3	1/5	1/	1

Frequency of failure

	APM	SP	SPM	UVS	M	CF
APM	1	1	1	1	1	1/7
SP	1	1	1/3	1	1	1/7
SPM	1	3	1	1	3	1/3
UVS	1	1	1	1	1	1/7
M	1	1	1/3	1	1	1/7
CF	7	7	3	7	7	1

Repair cost

	APM	SP	SPM	UVS	M	CF
APM	1	1	5	3	1	7
SP	1	1	5	3	1	7
SPM	1/5	1/5	1	1	1	3
UVS	1/3	1/3	1	1	1/3	3
M	1	1	1	3	1	7
CF	1/7	1/7	1/3	1/3	1/7	1

Replacement cost

	APM	SP	SPM	UVS	M	CF
APM	1	1	5	3	3	9
SP	1	1	3	1	3	9
SPM	1/5	1/3	1	1	1	3
UVS	1/3	1	1	1	1	5
M	1/3	1/3	1	1	1	3
CF	1/9	1/9	1/3	1/5	1/3	1

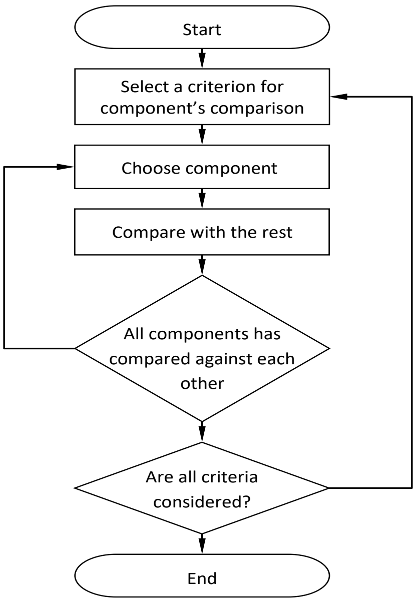

Fig. 3: Pairwise comparison process

However, the process of arriving at consistent judgement had been iterative involving several repeated interview sessions(Cheng & Li, 2003) while the priorities of each piece of equipment as compared under each criterion as represented in Table 5. Flowing from Table 5 (i.e., criterion-based priorities) is the Maintenance Significant Factor which is derived from the algebraic sum of the priority values for the component noting that the benefiting and the cost criteria have positive and negative signs respectively.

Table 4. Consistency ratio of judgement under each criterion

Criterion	ASPM	SP	SPM	UVS	M	CF
Consistency Ratio	0.030	0.024	0.033	0.035	0.046	0.034

Table 5. Maintenance criticality index

Component parts	Priority index						MSF
	CoF	EoR	Dwtn	FoF	CoRr	CoRl	
APM	0.220	0.077	0.228	0.085	0.279	0.340	1.075
SP	0.251	0.067	0.326	0.074	0.279	0.279	1.142
SPM	0.092	0.108	0.109	0.154	0.099	0.101	0.447
US	0.188	0.108	0.152	0.085	0.093	0.144	0.555
M	0.220	0.067	0.152	0.074	0.217	0.103	0.698
CF	0.030	0.573	0.032	0.528	0.032	0.032	0.083

3 Results

Two important results emanated from the AHP studies: the pair-wise comparison matrix, and the priorities vector. The pair-wise comparison matrix is shown in

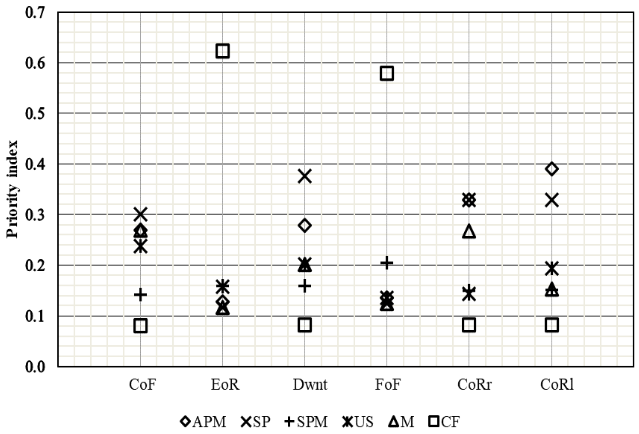

Fig. 4: Component's priority under the six criteria

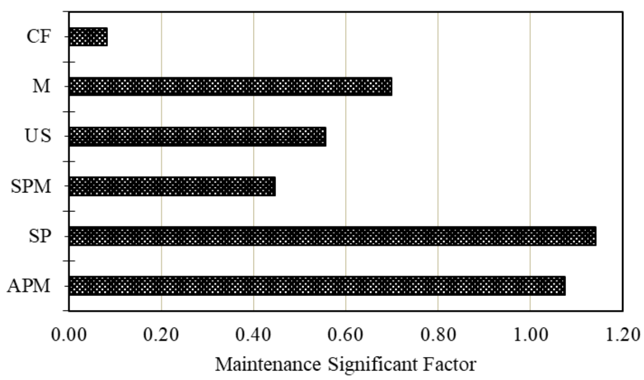

Fig. 5. Equipment Maintenance Significant Factor

4 Discussion

One of the valuable information for maintenance planning that could be available to any management team is the progress of production at any given time. Such an information often serves as an indispensable aid for decision-making. Considerations of system approach makes it possible that the overall plant performance could be broken down to buttress the contributions emanating from the subsystems/components. Thus, it is required that models for predicting plant performance should be both holistic with-respect-to the relevant system-wise influencing factors and responsive to real-time changes in the conditions. Such information becomes more visible and handier when presented in the forms that captures the equipment value.

The model presented herein prioritizes the alternative locations of a sachet water production plant based on value each component adds to the production objectives using judgements from the Production, Operations and Maintenance teams as well as the management team (herein referred to as stakeholders). Captured in the matrix is the comparative analysis of the equipment which is guided by the consistency ratio: a measure of randomness of the decision of the stakeholders. For an acceptable level of judgement consistency, the ratio has to be less than 0.1 (Table 4). The results of the comparative analysis indicate the judgement was both logical and reasonable as obtained from a consistency ratio of less than 0.1. Because the equipment performance can be quantified in all six criteria, priority weightage is determined by normalizing the quantitative factors. All judgments were aggregated across the hierarchical tree after various criterion-based equipment evaluations. Figure 1 depicts the priorities for the various production equipment under the six criteria.

Once the equipment priorities have been determined under each criterion, the final step is to evaluate the importance weights (Table 5). Hence Table 5 shows the MSF of the various equipment. The MSF assists the maintenance manager in determining the type of maintenance treatment to be applied to various components based on their criticality level. Predictive maintenance is preferred for high-critical components because it can result in significant savings by reducing failure frequency and downtime length. The submersible pump, as the most critical component in terms of maintenance in this study, requires the best maintenance policy. For the following category, a preventive maintenance strategy is recommended.

5 Conclusion

AHP has demonstrated convincing capability for prioritizing maintenance sites of machinery and equipment of small-scale sachet water production plant in a way that optimizes the overarching the plants' objective functions. A framework for selecting maintenance location/components such that optimizes the objectives is provided. Leveraging on the established principles in the system engineering, the contributory value of disparate maintenance location can be estimated based on AHP and employed to derive the priority vectors. The authors acknowledge that the conclusion of the analysis maybe affected by the size of the sample (factories) population and the other peculiarities of the sample's location and therefore advised the need for sensitivity analysis to be conducted. Furthermore, the result can be enhanced by considering factors that reflects the condition attributes of the maintenance sites/locations.

References

Abel, E., Mikhailov, L., & Keane, J. (2015). Group aggregation of pairwise comparisons using multi-objective optimization. Information Sciences, 322, 257–275. https://doi.org/https://doi.org/10.1016/j.ins.2015.05.027

Arunraj, N. S., & Maiti, J. (2007). Risk-based maintenance—Techniques and applications. Papers Presented at the 2005 Symposium of the Mary Kay O'Connor Process Safety Center The 2005 Annual Symposium, Mary Kay O'Connor Process Safety Center, 142(3), 653–661. https://doi.org/http://dx.doi.org/10.1016/j.jhazmat.2006.06.069

Benítez, J., Delgado-Galván, X., Izquierdo, J., & Pérez-García, R. (2011). Achieving matrix consistency in AHP through linearization. Applied Mathematical Modelling, 35(9), 4449–4457. https://doi.org/https://doi.org/10.1016/j.apm.2011.03.013

Campos, R. S. de, & Simon, A. T. (2019). Insertion of sustainability concepts in the maintenance strategies to achieve sustainable manufacturing. Independent Journal of Management & Production, 10(6), 1908–1931. https://doi.org/10.14807/ijmp.v10i6.939

Chandrahas, S. K. M., & Mahapatra, D. (2015). Maintenance Strategy and Decision making –AHP Method. International Journal of Advanced Engineering Research and Studies, 4–6.

Cheng, E. W. L., & Li, H. (2003). Utility of consistency measure in the analytic hierarchy process. Construction Innovation, 3(4), 231–247. https://doi.org/10.1108/14714170310814954

Khaira, A., & Dwivedi, R. K. (2018). A State of the Art Review of Analytical Hierarchy Process. Materials Today: Proceedings, 5(2), 4029–4035. https://doi.org/10.1016/j.matpr.2017.11.663

Krejčí, J., & Stoklasa, J. (2018). Aggregation in the analytic hierarchy process: Why weighted geometric mean should be used instead of weighted arithmetic mean. Expert Systems with Applications, 114, 97–106. https://doi.org/https://doi.org/10.1016/j.eswa.2018.06.060

Li, H., Ni, F., Dong, Q., & Zhu, Y. (2018). Application of analytic hierarchy process in network level pavement maintenance decision-making. International Journal of Pavement Research and Technology, 11(4), 345–354. https://doi.org/https://doi.org/10.1016/j.ijprt.2017.09.015

Macedo, R., Benmansour, R., Artiba, A., Mladenović, N., & Urošević, D. (2017). Scheduling preventive railway maintenance activities with resource constraints. Electronic Notes in Discrete Mathematics, 58, 215–222. https://doi.org/https://doi.org/10.1016/j.endm.2017.03.028

Nyström, B., & Söderholm, P. (2010). Selection of maintenance actions using the analytic hierarchy process (AHP): decision-making in railway infrastructure. Structure and Infrastructure Engineering, 6(4), 467–479. https://doi.org/10.1080/15732470801990209

Palma, J., Gómez de León Hijes, F. C., Campos Martínez, M., & Guillén Cárceles, L. (2010). Scheduling of maintenance work: A constraint-based approach. Expert Systems with Applications, 37(4), 2963–2973. https://doi.org/https://doi.org/10.1016/j.eswa.2009.09.038

Saaty, T. L. (1994). How to Make a Decision: The Analytic Hierarchy Process. Interfaces, 24(6), 19–43. http://www.jstor.org/stable/25061950

Srividya, A., & Suresh, H. N. (2007). Prioritizing feeders for maintenance activities using AHP in nuclear power plants. International Journal of Reliability, Quality and Safety Engineering, 14(3), 275–282.

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