International Journal of Sustainable Development and Planning
Vol. 18, No. 8, August, 2023, pp. 2489-2502
Journal homepage: http://iieta.org/journals/ijsdp

Improving the Maintainability and Reliability in Nigerian Industry 4.0: Its Challenges and the Way Forward from the Manufacturing Sector

Imhade P. Okokpujie[1,2*], Lagouge K. Tartibu[1], Ben Henry Omietimi[2]

[1] Department of Mechanical and Industrial Engineering Technology, University of Johannesburg, Johannesburg 2028, South Africa
[2] Department of Mechanical and Mechatronics Engineering, Afe Babalola University, Ado Ekiti 360001, Nigeria

Corresponding Author Email: ip.okokpujie@abuad.edu.ng

https://doi.org/10.18280/ijsdp.180820

Received: 26 March 2023
Revised: 22 June 2023
Accepted: 11 July 2023
Available online: 29 August 2023

Keywords:
maintainability, reliability, Industry 4.0 technologies, sustainability manufacturing system

ABSTRACT

Due to the high demand for quality goods and products, most manufacturing industries run their equipment and manufacturing teams more than expected to meet the demands. However, they do not regularly conduct maintenance and reliability checks to ascertain the industry's well-being. Operating their manufacturing systems and processes to achieve the requisite production rates of high-quality goods is a constant challenge for manufacturing industries in Nigeria due to a need for maintainability. To improve performance, this paper recently reviewed Nigeria's manufacturing industries' maintainability and reliability. The study examined articles that cut across, Maintainability scheduling in the production system with the analysis of Industry 4.0 Technologies, the reliability optimisation in the manufacturing industry in Nigeria, and the effects of sustainable maintainability and reliability implementation on manufacturing systems and the sustainability issues. Furthermore, the research highlighted the manufacturing industries' challenges regarding maintainability and reliability. Some of these challenges are insecurity, lousy infrastructure, inadequate company growth plans, and irregular taxation, which affect the day-to-day running of the industry. One of the most significant issues facing the manufacturing sector today is inventory management; nonetheless, many small manufacturers still manage their stocks by hand. Furthermore, this study provides possible suggestions for a sustainable way forward for these identified problems. Nigerian manufacturing industries might adopt Industry 4.0 technology, which will assist in successfully adopting total preventive maintenance as a strategy and culture. This article recommends a maintenance culture in the manufacturing industry. It also recommends self-auditing and benchmarking as ideal preconditions for total productive maintenance.

1. INTRODUCTION

In the industry, maintenance is a crucial part of excellent housekeeping practices. Many mechanical and mechatronic process businesses would replace outdated machinery with newer models rather than critically assess their maintenance strategies [1-3]. Maintainability and reliability are essential for the manufacturing industries, production companies, firms, etc. Farsi [4] said a physical system must be maintained to continue performing the functions for which it was created. In addition to output, product cost, and energy efficiency, its function and performance characteristics consider factors like end-product quality, production control, the need splashed convenience and safety of the hired personnel, adherence to environmental protection regulations, organisation integrity, and even the external appearance of the productive process. The profitability of a corporation is substantially impacted by maintenance quality. Safety and customer service are essential considerations in addition to plant costs and availability [5, 6]. The ability of physical systems is negatively impacted by increased downtime by reducing their average rate (i.e., speed) of production, which raises operating costs and decreases average customer satisfaction with the service. The strategic relevance of using improved and, if possible, optimum maintenance plans must be more widely acknowledged and implemented as system availability becomes increasingly important.

According to Tsarouhas [7], growing regulatory burdens, evolving technology paradigms, rising demands, and seemingly unending and pressing reorganisations characterise today's environment. It is ideal for constructing a mission concept and statement to assist maintenance employees in doing the same, much as every big organisation has done to help maintain a consistent approach despite many distractions. Maintenance benefits the system's owners, users, and society. Owners are often happy if their system produces a sufficient and ongoing financial return on their capital investment. Users expect each asset to continue performing at a level that they, at the very least, find to be adequate. Maintenance technology aims to identify and implement low-cost strategies for preventing or reversing performance degradation for the assets that investors expect. Predictive and preventative measures, failure-finding, run-to-failure, and adjustments to the physical asset's design or operation are all examples of failure-management strategies. Each category has several possibilities, some far more efficient than others. The maintenance team must know these possibilities and choose the most suitable for their situation. Making the right decision should increase the performance of the asset and cut expenses all around. Making the wrong decision might result in brand-new issues while escalating ones already present. Consequently, the appropriate mission statement should emphasise the need to maximise. The results of a reliability-cantered maintenance analysis may affect current preventive maintenance procedures, require condition monitoring, inspections, and functional testing, or result in the inclusion or removal of such methods when looking at the system via risk-based inspection (RBI). The maintenance structure is depicted in Figure 1, which the maintenance team can employ for successful operations.

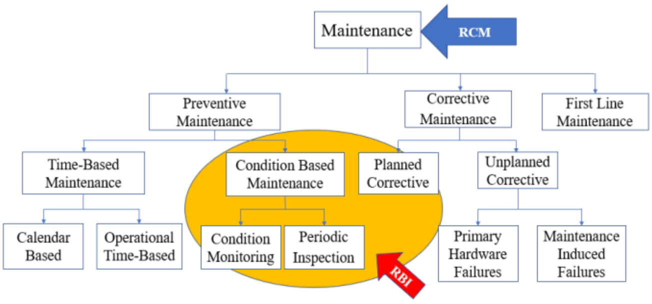

Figure 1. Structure of a maintenance operations

According to Chlebus and Werbińska-Wojciechowska [8], the operating budget for many large-scale plant-based enterprises can include up to 40% of maintenance expenditures. Therefore, increasing maintenance efficiency is a possible source of cost savings. In today's competitive climate, industries must work to maintain full production capabilities while requiring the least amount of capital expenditure. From the maintenance perspective, this means extending the equipment's life and improving equipment reliability (i.e., uptime). Wise management should base its choices on consistently high-quality, reasonably priced output that results from careful process and maintenance. Unfortunately, the implementation of PM programs has lagged in many businesses. For instance, in Nigeria, between 30 and 40 percent of PM expenditures are spent on facilities, with a mean time between failures of 30 days or fewer, which accounts for 80 percent of maintenance costs. Maintenance and spare components in industrial settings frequently comprise a significant portion of the overall production expenses. Up to a third of maintenance, expenditures may be unneeded or improperly carried out, and maintenance costs might reach sixty percent of production costs. As a result, several studies have been carried out to manage and lower maintenance costs under various maintenance strategies, including corrective maintenance, preventive maintenance, and condition-based maintenance. The number of failures can be decreased, and productivity, availability, and safety can all be improved. Signals and data are gathered from crucial components for condition-based.

Maintenance to process and monitor machine conditions. To prevent catastrophic failure, maintenance monitors and regulates deterioration based on fault detection thresholds until the new spare component is fitted; inventory and management of spare parts impact the efficiency and cost of maintenance [9]. For a maintenance and production plan to be practical, logistical issues, spotlight delivery delays, and imponent degradation during storage must be considered. Numerous studies investigated the problems with maintenance and extra components. Because there may be several dependencies between the system components in real-world systems, operation planning, maintenance, and spare component inventory management for these systems are challenging jobs. Four categories of dependencies may be made up of these: structural, resource, stochastic, and economic. These dependencies and the relationships between the various components should be considered when creating an ideal maintenance and spare parts inventory strategy [10, 11]. Therefore, this study tends to review research works on the maintainability and reliability of the manufacturing industry in Nigeria with the operation of Industry 4.0 technologies. It also discusses its challenges and how to provide sustainable suggestions to improve the nation's manufacturing systems.

2. REVIEW OF RELATED WORKS ON MAINTAINABILITY SCHEDULING IN THE PRODUCTION SYSTEM

The importance of experimental and computational approaches for comprehending various components of technology and machinery utilised in production systems has been heavily researched. The relationships between the different system configuration-derived components, such as series, series-parallel, K out of N, and so on, are referred to as structural dependency [12]. For this kind of system setup, condition-based maintenance has been thoroughly examined. Because resources are typically scarce in an industrial operation, resource reliance results. For example, three machines may share the same specified bearing as a replacement component, and there may be a need for more maintenance personnel. Other factors that may be constrained include staffing, labour, storage space, finances, suppliers, and logistics. As a result, these factors may need to be shared. This dependency should be considered at the planning stage since it might reduce system availability. Different units' deterioration and failure processes may be correlated; this correlation is known as stochastic dependency. For instance, failure of one component might result in damage to or potential loss of other members in a failure-induced damage scenario. Combined condition-based and age-based maintenance strategies may be used in this situation. However, implementing a systematic maintenance detection method can significantly improve the maintainability and reliability of engineering operations in the manufacturing industries [13-15]. These three major enabling technologies—the Internet of Things, wireless sensor networks (WSN), and ubiquitous computing—allow high-performance computing to operate efficiently and cost-effectively in the manufacturing sector to enable sustainable operations regarding maintainability and reliability.

These techniques are employed in manufacturing process performance, material design and development, structural mechanics, and automation systems' bespoke design and engineering that consider cost, performance, and the viability of industry-scale implementation [16]. The manufacturing industry has significantly developed due to societal and economic changes during the past 100 years. Manufacturing technologies and new paradigms have been established to handle financial issues and satisfy social demands because of distinct requirements in various eras [17]. Henry Ford created the moving assembly line in 1913 in response to the need for cost-effectiveness, which launched the mass production paradigm. Consistent product quality has been a primary focus since the Japanese industrial sector began developing lean manufacturing methods in the 1970s [18, 19]. The advent of flexible manufacturing systems (FMS), which allowed the production of a range of goods on the same manufacturing system, was helped by the development of computer numerical control (CNC) equipment in the late 1970s [20-24]. This analysis is to assist sustainability in improving the availability of the machines via maintainability and reliability operations, as presented in Figure 2. The synchronisation of standardisation, interchangeability, fault isolation, diagnostics, and repair with the accessibility of modularisation significantly affects the tooling, test equipment, human actors, and lifecycle of the facilities in the manufacturing industries.

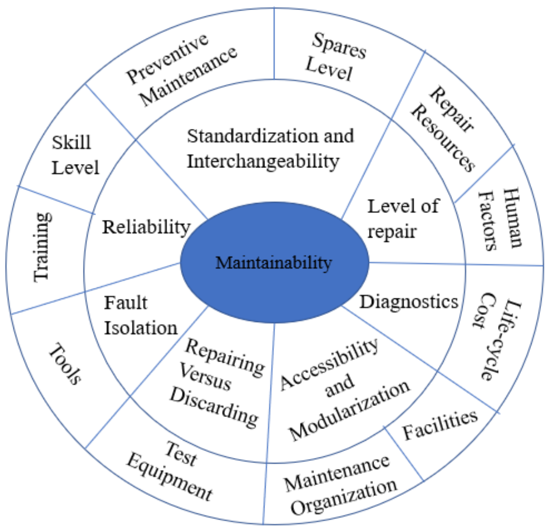

Figure 2. A structural system for improving availability via maintainability and reliability for manufacturing industries

2.1 Maintainability scheduling in the production system with the analysis of Industry 4.0 Technologies

Maintainability is the chance at which a malfunctioning machine, component, or entire manufacturing system will be brought back into operational efficiency during the restoration period when done by the prescribed protocols. A specific time frame [25-28]. To put it another way, maintainability is an assessment of how easily product maintenance and repair are possible. Consequently, a product's good maintainability will Increase the capacity to be repaired and serviced, lower the maintenance cost, and provide assurance that the item would be suitable for the intended use. This should maintain the components so they may continue to fulfil their purpose. However, the equipment's continued operation depends on its creators, as well as its builders and operators, i.e., not only the maintainers [29-31].

A maintenance strategy is created and implemented in three steps: (1) Create a plan outlining the tasks for each component. (Ex., work identification); (2) Obtain the resources (skilled workers, spare parts, and equipment) required to manage the suggested method successfully (3) Put the plan into action by acquiring and deploying the systems needed to manage the using resources wisely). The goal is to enhance equipment uptime while minimising expenses [32]. Tsarouhas [33] calculated the reliability, availability, and maintainability (RAM) study based on historical information obtained over a year. The data were subjected to a Pareto analysis, descriptive statistics, trend, and serial correlation test. Each machine's failure and repair data parameters and the ice cream-producing system were calculated. The RAM analysis evaluates the present operations management and enhances the line's quality, productivity, and efficiency performance. Preventive maintenance times for each machine and finished system for various dependability periods were discovered. The packing machine and freezer tunnel are the two machines with the lowest reliability rates. This equipment is essential; careful maintenance is required to prevent quality and productivity losses. The exogenous machine, the ice cream machine, and the entire production system have the poorest maintainability and productivity. Furthermore, because the RAM indicators were developed to measure and improve machine performance, production managers and engineers can quickly assess the choices made in the system's operation.

Systems for autonomous manufacturing that can run smoothly, effectively, and qualitatively are required due to global competitiveness. Unexpected production machine failures in an automated system with multi-stage, fast manufacturing processes can be costly. Failure of equipment to perform as required is a common reason for manufacturing machine breakdowns. This immediately adds to production waste, such as preparing for unanticipated downtime or product returns [34]. Therefore, significant dependability information is essential to forecast the cost of unplanned downtime, identify spare parts, and suggest the ideal maintenance intervals. A good reliability program will ensure the gathering of crucial data about the system's reliability performance throughout the operating stage. It will direct the use of this data in analytical and management techniques. Valid data collection and analysis are necessary for good, effective reliability programs and maintenance development and the creation of reliability models to support decision-making processes [35]. Most industrial systems are highly complex, although they are frequently repairable. In those conditions, strong reliability, availability, and maintainability (RAM) research might play a crucial role in the design phase and in any necessary modifications to attain the optimal performance of these systems. However, assessing the RAM characteristics of such systems with the desired level of precision takes work, using both accessible and unreliable data.

The need for high-quality produced goods is rising today [36]. Companies must ensure their interests work well, which entails high availability, safety, and minimal maintenance costs, to remain competitive in the global market. A product's inherent capacity to be maintained significantly impacts the user experience throughout the service phase. Maintainability is a property of goods essentially decided during the design phase. A product's ability to be maintained depends on several factors: visibility, reachability, available space, maintenance safety, and customer demands. The ultimate objective of these components is to expedite maintenance and guarantee that it proceeds safely.

Product Lifecycle Management (PLM) software like Digital Enterprise Lean Industrial Interactive Application, Dassault Structures and JACK allows designers to design maintainability in the early design stages digitally (Siemens Tecnomatix Jack). However, this design approach has several significant areas for improvement, contributing to the maintainability design's low efficiency and accuracy. First, the designer needs to be an expert in creating maintainable designs. A real engineering difficulty is having a designer with such expert maintainability expertise, however. Second, while some PLM Software has tools for maintainability models and analysis, engineers must spend much time creating simulation animations using a key-frame controller, which does not match the demands of rapid turnaround times. Maintainability design is the process of the closed loop and iteration, which is last but certainly not least. Design, verification, assessment, and feedback are all components of the complete maintainability layout process. However, the current approach to creating maintainability is open-ended and only relies on the PLM software's features. The visual cone and the envelope ball are two examples of functionalities too basic to fulfil the design requirements.

Model of a serial-parallel multistage manufacturing system's production, quality control, and preventive maintenance [37]. Each stage has many machines to achieve productivity and line balance requirements. The devices become less effective with us, affecting the final output's quality. To safeguard stock against unpredictability, a make-to-stock manufacturing approach is implemented. Each level of processing involves quality inspections on every item. Non-conforming goods are discarded while conforming things are transported to the following step for additional processing. Preventive maintenance is carried out during production runs to increase the machines' dependability and, as a result, the quality of the final output. Machines are examined and, if required, serviced after manufacturing runs. The suggested maintenance plan is unusual because productivity and the machine's important structural measure are considered when choosing which machines to maintain. To reduce the average cost rate, it seeks to identify the production run duration, quality control threshold, and maintenance threshold concurrently. A simulation-based optimisation strategy combining Monte Carlo Simulation and evolutionary algorithms solves a stochastic mathematical problem.

A proactive, profit-driven strategy is needed to close the gap between actual expenditures and desired expenses. The ability of Nigerian industries to create goods could be improved by downtime, which lowers average output rates, increases operating costs, and degrades customer service [38]. Lean total-quality management (TQM) and misused just-in-time (JIT) strategies can significantly increase downtime. Implementing total productive maintenance (TPM) and reliability-centred maintenance (RCM) as organisational improvement initiatives is therefore highly desired. TPM calls for a collaborative effort between operators and maintainers to save waste, lessen downtime, improve product quality, and increase equipment efficiency. RCM entails figuring out what must be done to keep any physical component functioning as its user wants it to. Determining the maintenance requirements and ensuring they are satisfied as inexpensively as feasible are the two goals that must be accomplished. RCM focuses on a small, multidisciplinary team employing the appropriate abilities to operate and maintain equipment. Such teams have been used to resolve and eliminate sporadic, catastrophic, and recurring failures thanks to several root-cause analysis (RCA) methodologies. The key to success is ensuring everyone involved once employees have received the necessary training in these strategies. The company should build the organisational disciplines and processes to guarantee usage whenever the circumstance calls for them. It is crucial that everyone concerned accepts responsibility for the issue.

Bush [39] pointed out that managing people entails more than simply regulating their behaviour. Effective management calls for competent leadership with a distinct vision and goal and the provision of the money required to carry out the program that all parties have agreed to. TPM was created due to TQM, lean management, and JIT developments. Unfortunately, in Nigeria, these ideas have not yet gained much ground. A quality maintenance program's fundamental tenet must permeate the whole company if it is to be successful. What is required is a factual, enumerated approach to decision creating, respect for other organisations, promotion of creativity, and emphasis on constant development rather than placing fault when errors happen. These are the required things, i.e., signs that a company is evolving.

Machine wear and tear increase over time during production cycles, significantly influencing product quality and system dependability. The use of the machine degradation status, the structure importance measure, and the quality information feedback for helping maintenance decision-making describe a novel integrated maintenance method that is introduced [40].

More particularly, due to technological limitations, the machines can only be examined to assess their states after manufacturing runs, after which any necessary maintenance is carried out. An opportunistic maintenance technique is used using quality information feedback during production runs. The goal of concurrently improving production, quality control, and maintenance procedures is to reduce the anticipated total cost rate. A stochastic mathematical model is constructed and solved using a simulink optimisation technique. (1) A serial-parallel multistage production system is evaluated for jointly optimising manufacturing, quality assurance, and maintenance strategy; (2) Condition tracking and effective data feedback are both integrated into the maintenance choice procedure; and (3) Because there is a limited amount of maintenance time between two sequential production runs, the structure importance is also evaluated, furthermore to the forecasting reliability. For the flexible multistage manufacturing system in multi-specification and small-batch production, a maintenance scheduling approach has been developed [41].

The key factors are the unpredictable nature of future production demands and the bidirectional linkages between production and station decay. The dynamic production schedule causes each station's workload to fluctuate, significantly affecting how well each station holds up over time. The choice of the station to carry out the production activities will, in turn, be influenced by the station's degradation condition. A cost-effective maintenance schedule model is then suggested for the system based on the load-integrated degradation model created due to this interaction. Because future production demands are unclear, the system's best preventive maintenance plan is achieved by reducing the anticipated total maintenance cost per unit of time within the next unknown production period. A greedy constraint method is created with the time of preventive maintenance as the constraint to streamline the solution procedure. According to numerical comparisons, the projected total maintenance cost under the suggested maintenance schedule model is consistently less than that under the full and average load models.

Equipment maintenance is crucial for increasing production efficiency, and how to incorporate maintenance into production to deal with ambiguous situations has drawn much interest [42]. The topic of this study is the preventive maintenance (PM) integration into production planning of a complex manufacturing system based on availability and cost. The suggested strategy is divided into two parts. First, this study uses an extreme learning machine algorithm to forecast the needed capacity of each machine. Based on an analysis of historical data, the optimal times for executing PM tasks are determined to minimise their negative effects on productivity and determine the PM interval and length. Second, this study uses an enhanced ant colony optimisation method to determine the schedule planning and the least amount of maintenance workers. Finally, this strategy's viability and advantages are examined. Based on empirical research using actual manufacturing execution system and equipment maintenance system historical data. Experimental findings show the viability of the suggested strategy, which reduces human requirements while maintaining maintenance responsibilities. Consequently, the suggested strategy helps to increase the business's production efficiency. Small quantities of goods may be produced in the manufacturing sector to save inventory costs, albeit this may unintentionally raise setup costs [43].

This presents a difficulty in optimising the lot size to increase the manufacturer's economic gain, a topic that has been extensively researched for a long time. The best lot sizes are often achieved by minimising the total inventory storage and setup cost. In real life, a production system might malfunction, necessitating maintenance. This presents even another difficulty in determining the best maintenance plan to minimise the likelihood of system failure in the future. For manufacturers, issues include increasing manufacturing costs and stricter efficiency standards. Enhancing maintenance effectiveness is a key strategy for overcoming these obstacles, and several publications are on this subject. Before creating a fresh batch of product items, a multi-product system might need to be reset. To lessen the disruption brought on by the maintenance procedures in this situation, the set-up epoch might be used as a maintenance window.

One of the cornerstones of the fourth industrial revolution is smart manufacturing (Industry 4.0) [44]. It is not only opens up positive prospects for highly reliable, available, maintainable, and safe manufacturing processes, but it also makes the systems more complicated to analyse for health. To address these issues, it is necessary to have a solid strategy for tracking and evaluating the system's health. The manufacturing sector greatly impacts societal and economic progress [45].

Since the term "Industry 4.0" is widely used by universities and research organisations, it has generated much attention from both the commercial and scientific sectors. Although the idea is not novel and has been discussed from various angles in academic circles for many years, the term "Industry 4.0" has only recently been coined and is already gaining some traction outside of the academic community and in the industrial society. Whereas academic research focuses on comprehending and defining the concept and attempting to develop related technologies, business models, and respective techniques on the other, industry, on the other hand, focuses its attention on the evolvement of industrial machine suits and intelligent products as well as potential customers. Businesses first need to understand the features and content of Industry 4.0 to prepare for a future change from manufacturing dominated by machines to digital production. Nigerian industrial industries must carefully assess their situations and individual potentials in relation to the fundamental criteria outlined for the Industry 4.0 standard if they are to transition successfully. They will be able to create a clear road map as a result.

Modern marketplaces are characterised by quick requirements changes and emerging client needs [46]. Therefore, quick changeable production is a key objective of the Industry 4.0 strategy, which intends to increase manufacturing's adaptability and efficiency by integrating different factory components and virtualising the industrial assets in digital twins. The use of scenario-based evaluation to investigate the changeability capabilities of Industry 4.0. We arrive at three possible change scenarios that a plant can experience: Product flow might change depending on product kind, quality, and the launch of a new product. Based on the impact of the resulting transformation, we compare the third industrial revolution (Industry 3) with Industry 4.0 designs using these scenarios.

The Architecture-Level Modifiability Analysis (ALMA) technique is what we use for our evaluation, and Presenting ALMA 4.0, a guideline for Industry 4.0 Maintainability scenario-based evaluation, describes its instantiation to the provided situation. Manufacturing firms must implement more sustainable production and facility control techniques in response to growing worries about climate change and energy deficit [47].

Such methods necessitate operational procedures prioritising sustainability by concurrently considering economic, energy, and environmental factors. To concurrently solve the issues of energy consumption, intelligent maintenance, and throughput enhancement, a novel combined production scheduling model that considers energy control and maintenance implementation is suggested in this work. Several measures are combined and assessed to achieve a single goal: cost minimisation. The cost minimisation issue is solved using particle swarm optimisation with a local optimal avoidable mechanism and a time-varying inertial weight to discover a close-to-optimum solution for production and maintenance schedules. A complicated network that stretches from oil and gas fields to demand nodes is known as the hydrocarbon supply chain (HCSC) [48].

Since the petroleum industry is the most important sector of the global economy and any interruptions or changes in the supply of hydrocarbon products would impact the whole global economy, it is imperative to integrate operation and maintenance operations throughout this intricate network. Therefore, thorough and efficient maintenance increases the reliability of an asset and extends its lifespan. The maintenance tasks are preferably carried out during periods of low demand to minimise significant losses in production and, ultimately, to fulfil client demands. Operating planning and maintenance scheduling decisions are interdependent and should be optimised together [49-55].

3. RELIABILITY OPTIMISATION IN THE MANUFACTURING INDUSTRY IN NIGERIA

Despite using TBM in its PM programs, the Nigerian electric power sector still has high downtime and significant maintenance costs [56]. These are not attempts to imitate the proactive measures now practised in industrialised nations. According to past research on this sector, its maintenance processes must incorporate reliability, availability, maintainability, supportability (RAMS), and risk analysis. This might be done gradually and in phases, with feedback to track the results. The risk will be reduced, and the system's dependability and availability will be improved by including RAMS and risk analysis in the maintenance operations. Controlling the flow and analysis of information will need to be done effectively and efficiently. The company must implement a training program with a particular emphasis on incorporating RAMS and risk analysis into maintenance procedures. According to Jakkula et al. [57], load haul dumpers (LHDs) are a common equipment used for transportation operations in many underground mines. Due to several technical and managerial practices, this equipment frequently experiences breakdowns, which raises maintenance costs and reduces production and productivity. Reliability, Availability, and Maintainability (RAM) analysis focuses on improving availability and performance while ensuring equipment operates as efficiently as possible. In light of this, the current study estimated the equipment's performance using RAM investigation. Field studies were used to gather the necessary failure and repair data for LHDs. To verify the Independent and Identical Distribution (IID) nature, statistical studies using the Statistic-U test and graphical analyses utilising trend and serial correlation tests were also carried out—a data collection. The renewal process was used to do the RAM analysis based on the results of the aforementioned tests. The Kolmogorov-Smirnov (K-S) test was used to determine which dataset approximation was the best match. Additionally, it was predicted that the reliability-based preventive maintenance time intervals would increase the dependability percentage.

$$R_t = Exp.\left(\frac{-T}{MTBF}\right) = Exp.\left(\frac{-T}{MTBF}\right) \tag{1}$$

where it is simpler to comprehend R, which stands for continuous failure rate, and *MTBF*, or mean time between failures. For failure models with exponential distributions. A fundamental measure of reliability is the mean time between failures (MTBF). R is the reliability and might sum several separate reliability terms.

3.1 Application of FMEA/FMECA

Failure mode effect analysis (FMEA) approaches are widely utilised in business for a wide range of applications, and the flexible analytical approach may be applied at different phases of the product life-cycle [54]. Failure mode effect integration (FMECA) analysis may support design, manufacturing, maintenance, and other policies to increase reliability, maintainability, and supportability. For instance, RCM methods include FMEA and a key element of the analysis (Figure 3) [55]. Additionally, the FMEA reporting may be utilised to give information about the reliability of a consolidated location.

Based on Adenuga et al. [56], despite using TBM in its PM programs, the Nigerian electric power sector still has high downtime and significant maintenance costs. These are not attempts to imitate the proactive measures now practised in industrialised nations. According to past research on this sector, its maintenance processes must incorporate reliability, availability, maintainability, supportability (RAMS), and risk analysis. This might be done gradually and in phases, with feedback to track the results. The risk will be reduced, and the system's dependability and availability will be improved by including RAMS and risk analysis in the maintenance operations. Controlling the flow and analysis of information will need to be done effectively and efficiently. The company must implement a training program with a particular emphasis on incorporating RAMS and risk analysis into maintenance procedures.

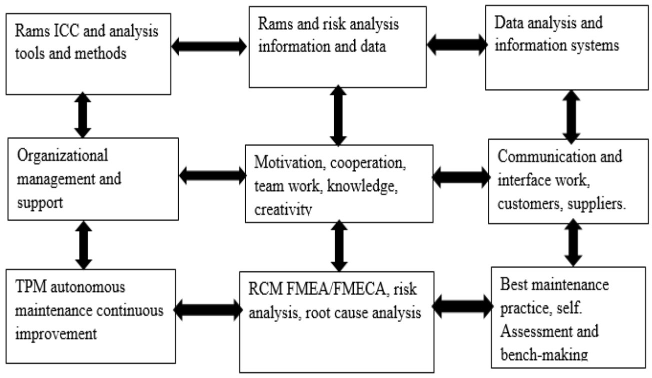

Figure 3. The flexible analysis method and FMEA techniques can be used in a variety of applications and at different stages of the product life cycle

According to Jakkula et al. [57], load haul dumpers (LHDs) are a common equipment used for transportation operations in many underground mines. Due to several technical and managerial practices, this equipment frequently experiences breakdowns, which raises maintenance costs and reduces production and productivity. Reliability, Availability, and Maintainability (RAM) analysis focuses on improving availability and performance while ensuring equipment operates as efficiently as possible. In light of this, the current study estimated the equipment's performance using RAM investigation. Field studies were used to gather the necessary failure and repair data for LHDs. To verify the Independent and Identical Distribution (IID) nature, statistical studies using the Statistic-U test and graphical analyses utilising trend and serial correlation tests were also carried out—a data collection. The renewal process was used to do the RAM analysis based on the results of the aforementioned tests. The Kolmogorov-Smirnov (K-S) test was used to determine which dataset approximation was the best match. Additionally, it was predicted that the reliability-based preventive maintenance time intervals would increase the dependability percentage.

Modelling and analysing the dependability of manufacturing systems is a difficult procedure [58]. Their behaviour frequently resembles that of multi-state systems. High reliability/availability will be provided via multi-state system architectures, with load sharing and other structural dependencies. As a result, this plan can assist businesses in increasing productivity and lowering operational expenses. Maintenance and part replacement are carried out while used and operated to maintain their functionality. The relationship between spare parts inventory and maintenance plan, ordering spare parts might be challenging. This study examines the characteristics of spare parts inventory management and maintenance policies for manufacturing systems with multiple machines and various interdependencies (economic, load-sharing, and multi-state configuration). Preventive maintenance, as well as condition-based maintenance, are taken into consideration. The interactions between maintenance policies and spare parts management are considered to assess a manufacturing system's cost and availability. Investigated is how these elements affect things. The ordering time and load-sharing factor have a greater impact than the other factors.

As the foundation of the irrigation system [59], tube wells integrated with underground pipelines (TIUP) require reliability, availability, maintainability, and dependability (RAMD) assessment. This work aims to estimate the Steady-State Availability (SSA) of the TIUP through the performance of RAMD analysis, Failure Modes and Effects Analysis (FMEA), and constructing a unique stochastic model utilising the Markovian technique. To confirm the theoretical and practical findings of the proposed model, a genuine case study of a traditional TIUP system has been conducted. All subsystems' failure and repair rates have an exponential distribution, and their effects on system/subsystem availability and other reliability metrics have been studied. The random factors affecting failure and repair rates are independent and identically distributed; every repair is perfect. Regarding dependability and maintainability, the centrifugal pump and energy supply systems are the most important parts. The TIUP system depends heavily on labour to function properly.

Micro-grid electrification is gaining popularity in illuminating rural areas in developing nations [60]. Yet selecting the optimum local supply option is a difficult problem that requires considering different generation technologies (such as solar PV, wind, or diesel) and system designs. Most currently available decision support systems to evaluate this design only combine technical and economic factors into one optimisation procedure. However, it has become clear that social and environmental concerns are crucial to ensuring the projects' long-term viability. This study aims to provide a multicriteria approach that will enable comparisons of electrification schemes using on-grid or isolated micro-grids and various technologies while considering various factors. This multicriteria process is included in a two-phased methodology to help promoters of electrification design the system in a structured manner. An open-source techno-economic optimisation model is used to generate various electrification options, which are then evaluated and ranked using the multicriteria method, which considers 12 criteria representing economic, practical, socio-institutional, and ecological factors. A genuine case study of 26 population settlements in Nigeria's Plateau State serves as the basis for validating the whole design technique. To balance the criteria and customise their evaluation for the particular case study, experts in rural electrification within the context of Nigeria have been engaged. Results indicate that solar-powered photovoltaic (PV) systems are the most suited electricity solutions for Nigerian villages. In contrast, grid connection feasibility relies on the neighbourhood’s size and the separation from the nearest national grid consumption point.

Based on Babatunde et al. [61], renewable energy is crucial when it comes to enhancing and promoting environmental sustainability in agricultural-related activities. This study assesses the environmental, technological, and economic advantages of installing PV battery systems in a farmstead housing livestock. A walkthrough energy audit of the farmhouse is done to ascertain the farm's energy needs. Southern Nigeria is where the farm chosen for this study is situated. The program Hybrid Optimisation Modeling for Electric Renewable (HOMER) from the National Renewable Energy Laboratory was modified for the techno-economic study. In terms of total net present cost, it is discovered that a freestanding PV/battery-powered system for farmhouse applications is more economically viable than its diesel-powered counterparts (TNPC). It is possible to save 48% over the Cost of Energy and TNPC with no emissions. The outcomes demonstrate the advantages of switching from diesel generators to renewable energy sources like PV-battery systems in agricultural applications. The study's site receives a moderate solar brightness of around 6.16 kWh/m^2/day and 6 hours or so of daily sunlight. The monthly irradiance and clearness index are displayed in Figure 4 and were taken from the NASA website. This information establishes the operational capability of the PV panels and serves as a metrological input to HOMER.

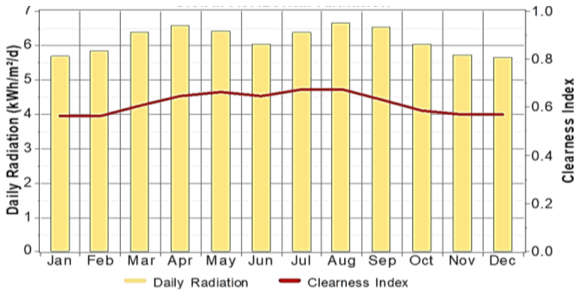

Figure 4. Monthly on-site global irradiance [61]

The optimisation procedure is the foundation for the study utilised to select the PV-battery arrangement. The Hybrid Optimisation Modeling for Electric Renewables (HOMER) program from the National Renewable Energy Laboratory is used for this. The national renewable energy laboratory's (NREL) HOMER design and optimisation software for microgrids and distributed energy generating systems were used to assess the system's technical and financial feasibility. Ensuring that the system's aim and restrictions are met can stimulate the system's behaviour for 8760 hours every year. After comparing the costs of many potential configurations, the system with the lowest TNPC is the most feasible.

Furthermore, Rokhforoz and Fink [62] say products may have advantageous externalities that influence consumers' choices in social networks. Suppliers might include these externalities in their pricing plans to boost their income. Suppliers need to optimise the reward while considering their manufacturing and maintenance expenses. The possible benefits of predictive maintenance include lower maintenance costs and increased system availability. One can present a bi-level optimisation approach based on game theory to deal with the simultaneous optimisation of pricing with market imperfections and proactive maintenance scheduling depending on the system's current state. The manufacturing company determines the items' pricing and the units' predictive maintenance schedule at the first level. Customers make decisions about their consumption at the second level using an optimisation strategy where the goal is to Maintenance is a key component of good housekeeping practices in a business. Instead of rigorously evaluating their maintenance methods, many mechanical and mechatronic process companies would rather replace obsolete equipment with newer versions.

4. EFFECTS OF SUSTAINABLE MAINTAINABILITY AND RELIABILITY IMPLEMENTATION ON MANUFACTURING SYSTEMS

Sustainable manufacturing processes are crucial for production industries, but individuals putting production systems in place need help achieving this reliability objective. In this manner, a production system is modelled using a fundamental economic-production paradigm with a storage restriction and demand-dependent unit production cost under carbon emissions [63]. More reliable manufacturing companies create fewer faulty goods than an unreliable production system. A geometric programming technique is the best to create a quasi-closed form of the ideal solution since the model includes a power function. Geometric programming is a suitable analytical method to tackle this issue in a production system. The production system is considered dependable when waste created during the manufacturing process is controlled or reduced while maintaining product quality and mitigating any unfavourable environmental consequences. The production model is new since it depicts a dependable method for producing goods while minimising carbon emissions and faulty product manufacture. To build a dependable manufacturing system while reducing carbon emissions, waste must be managed while product quality is preserved. A reliable production system model that included reliability as a decision variable under carbon missions was built on the foundation of a basic economic production system. The model aims to save costs and enhance current manufacturing processes by adding dependability as a quantifiable attribute under carbon emissions. The following fundamental premise is applied to construct a trustworthy production system model: Fewer faulty items are produced by more reliable production processes. The main objective is to create a carbon-controlled production system that is 100% dependable, defect-free, and operates with regulated carbon emissions, which is a sign of an ideal environment for green manufacturing.

Demand is what determines the cost of unit production under carbon emissions, and high demand for dependable items corresponds to lower unit output; as a result, if demand rises, production must also rise to avoid shortages. As a result, without considering shortages, an increased production rate results in lower unit production costs. As a result, the unit production rate and the demand rate must be inversely related.

Figure 5 provides a graphic representation of the relationship. The cost per unit of production for carbon emissions is regarded as $p = \alpha D{-}\beta$, where α is the capital investment's yearly fractional cost. And β measures price elasticity ($\alpha > 0$, $\beta > 1$). Modern technology may be used to produce goods more effectively. Although managers may create large quantities when there is considerable demand for a reliable product, small batches have lower storage costs. So, a storage space restriction is taken into account. Another reliability restriction is used since no product can be completely dependable [63].

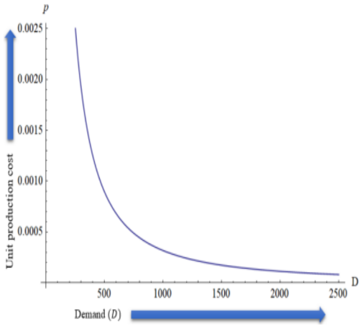

Figure 5. Demand and unit production cost relationship

Digitalisation and sustainability affect every step of the production process [64]. Digitalisation and sustainability are crucial issues for the manufacturing sector. Businesses are adopting the fourth industrial revolution's sustainability-related ideas through several different projects and strategies. One of the recurrent themes in smart and sustainable manufacturing is the application of contemporary maintenance techniques, such as Maintenance 4.0. From the standpoint of the difficulties presented by the fourth industrial revolution and the difficulties associated with sustainable growth on the economic, environmental, and social fronts, the most recent developments in maintenance management in Nigeria should consider intelligent and sustainable maintenance from three angles. The first is the historical viewpoint, which highlights how the maintenance method has evolved in line with the advancement of production engineering. The development perspective, which offers historical insights on maintenance data and data-driven maintenance technology, is the following: The third viewpoint discusses maintenance about the elements of sustainable development and potential ways to use data-driven maintenance technology to address the financial, environmental, and social issues associated with sustainable production. Many businesses are looking to rethink their production practices and philosophies in light of the increasingly unstable political, economic, environmental, and societal environments, as well as the pressures of globalisation, rising competition, and manufacturing systems, products, and technologies with very short lifespans. Their goal is to increase the number of product variations while maintaining manufacturing efficiency. Consequently, manufacturing systems must be extremely adaptable and reconfigurable to flourish and meet these demanding objectives. The idea of reconfigurable manufacturing systems (RMS) originated in this setting in the late 1990s to get beyond the constraints of traditional production and to adjust quickly and economically to shifting market and societal situations. Due to its fundamental qualities, including scalability, convertibility, diagnosability, customisation, modularity, and integrability, RMS is seen as a catalyst for Industry 4.0. Moreover, reduced energy use and carbon footprints are essential in the industrial sector due to rising fuel prices, increasing electricity usage fees, and environmental laws. Therefore, considering sustainability while developing an RMS is essential to meeting the demands put forward by the environmental and societal surroundings [65].

4.1 Sustainability issues relating to the effects of reliability and maintainability

According to Dahmani et al. [66], engineering, manufacturing, and design are just a few of the many fields that sustainability has touched. Companies now consider sustainability to be a major problem. Statistics show that over 37%, if not 50%, of the world's total greenhouse gas (GHG) emissions come from manufacturing that uses energy sources, including electricity, coal, oil, and gas. Because of this, businesses have begun to take action to reduce GHG emissions from their products and services. Sustainability has been described as the reorganisation of technical, scientific, environmental, economic, and social resources to allow for the regulation of the causing system in a condition of temporary and spatial balance. In a sustainable future where human life quality is consistently increased in terms of enjoyment and prosperity related to sanitation, education, food, shelter, and employment, the need for healthcare, work happiness, etc., arises swiftly. At the same time, limitations on sustainable growth are set by local and global socioeconomic and statistical settings. Many aspects of sustainability evolution exist, including the economy, environment, and society. Sustainability is the evolution that satisfies the demands of the present without compromising the capacity of future generations to satisfy their own needs. These several factors were acknowledged as the cornerstones of sustainable development, and the sustainability model took them into account. The competitive worldwide environment is impacted by similar issues, such as scheduling and loading challenges, expensive tooling and equipment costs, abundant scrap availability, challenging quality control, and lengthy setup times. To increase firm profitability and improve product support design, a higher level of connection between design and manufacturing processes is needed in Nigeria's production industries. Poor dependability in any manufacturing company results in failure and availability at every level, including design, construction, planning, maintenance, etc. Figure 6 shows the relative analysis of reliability and maintainability when it pertains to the issue of sustainability in the manufacturing industries. The art of maintaining the reliability of a machine through maintainability leads to quality availability, which significantly affects the product's cost.

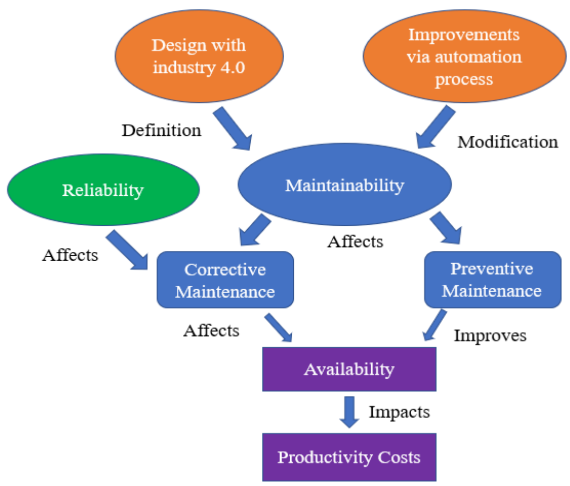

Figure 6. Relational study of the effects of reliability and maintainability as regards sustainability issues

The dependability measurement lowers the overall failure rates in Nigerian-producing organisations by quantifying prospective performances [67]. Failure lowers total revenue and production. For businesses aiming to increase dependability, failure must have a clear meaning. Most of the manufacturing process has been centred on scheduling and short-term production planning in Nigerian production enterprises over the previous 20 years. Due to the intense competition around the globe today, manufacturing companies in Nigeria are under pressure to meet the constantly changing needs of their customers quickly. Because the business climate is so fiercely competitive, improving product quality while keeping costs as low as feasible is important. Maintenance service is one of the most often utilised elements, particularly in a manufacturing line that constantly needs repair. To get the best management of production rates, the manufacturing sectors are attempting to improve the operations existing in the production lines. The installed machine in the production line directly impacts the product's performance. It becomes necessary to analyse the maintainability and reliability to give ideal strategies if the machine introduced into the production lines is not predictable and trustworthy. Failures in the manufacturing lines result in unintended outcomes like lengthened delivery times, subpar products, and negative.

Financial effects like excessive production costs. Maintenance management activities are crucial in lowering the amount and quality of goods produced, the number of faulty components produced and the loss of system running time. They also lower the production system, product quantity, and quality losses. In the past, manufacturing line process failures were eliminated by upgrading functional and operational excess or replacing and evaluating important systems. The high maintenance costs and limited availability introduce a decrease in support time, high dependability, and maintainability in the manufacturing process. Each system component's effective preventative maintenance over time lowers total unforeseen costs and makes it easier for the business to operate within its budget. A manufacturing system or equipment must first be evaluated for performance and upkeep requirements before being acquired by an industrial firm. The maintenance procedure used to keep a system or component at a specific level of dependability and availability is also used to keep product quality at a specific level [68].

Businesses in Nigeria with poor maintenance procedures will incur high production expenses. The dependability analysis, which also provides suitable maintenance methods, should be employed to determine the system's efficacy. The reliability indices and RAM principles are universally recognised technical methods for identifying production bottlenecks, issues with critical components, and optimising maintenance activities [69].

The mean-time-to-repair (MTTR), mean time-between-failures (MTBF), and failure rates influence the dependability of the equipment on the production line. As a result of enhanced maintainability and reliability initiatives, the system will have high availability. Production availability is always tightly associated with the maintenance and reliability of the equipment and components. Any one of the following three criteria can be used to gauge a system's effectiveness: availability, reliability, and maintainability [70]. The RAM analysis would help the Nigerian manufacturing system identify the correct degree of operation and particular safety concerns for continuous development. Ineffective production systems, optimisation and prediction algorithms play a key role.

Sousa et al. [71] argue that the corporate world constantly changes. Dynamic complexity, ambiguities, and uncertainties call for quicker and more assured judgments. Industry 4.0 is a crucial option to remain competitive in this climate. Manufacturing dependability in this context is crucial for businesses to make wise decisions. In the literature, several Industry 4.0-related technologies, such as the Internet of Things (IoT), cyber-physical systems (CPS), blockchain, and data mining, have increased equipment availability. However, survey research still needs to demonstrate how reliability has partnered with support for organisational decision-making in the context of Industry 4.0. Most applications still primarily concentrate on the efficiency and condition of certain pieces of machinery. However, in today's volatile environment, local decisions are no longer adequate in complicated enterprises; an organisation's whole structure must be analysed.

The necessity for trustworthy data on the long-term performance of building materials-producing industries in Nigeria, especially the anticipated service lives of building materials, components, and assemblies, is at the core of sustainable building practices [72]. Given the predicted effects of climate change on the built environment and the numerous global government initiatives to ensure that structures are resilient at construction and can maintain their resilience over time, this need is becoming increasingly obvious. Key climatic factors projected to change and impact how long construction materials last are described, allowing for the specification of goods given the impacts of climate change. Lower heating loads, as seen by quieter heating degree days, and higher cooling loads, particularly in most parts of Nigeria where heat island effects may predominate over climate change for months, will result from rising world temperatures. Inattention to intense heat events may result in overheating in structures, which raises health risks for the most vulnerable members of society, including the elderly, physically ill, and very young people. Buildings may need to be able to operate efficiently in terms of heating or cooling, depending on the season. This might result in inefficient energy usage.

4.2 Maintainability implementation

Zhu et al. [73] investigated and stated that design for maintainability is becoming better known. Unfortunately, there is no comprehensive examination of the numerous connected problems and studies. Meier and Russell [74] found that while maintainability can significantly impact project costs, most businesses need a systematic mechanism for addressing it during the completion of projects. The Building Projects Institute established the Maintainability Study Team to address the potential available to companies by effectively implementing maintainability concepts. Although maintainability can significantly affect project costs, most companies need a structured strategy to handle it throughout the project delivery process. The Construction Sector Institute created the Maintainability Researcher to explore the potential that organisations can take advantage of by effectively using maintainability concepts.

The maintainability research team at the Construction Industry Institute (CII) has created a model method for implementing maintainability with six milestones [75]. Commit to establishing maintainability, set up a maintainability program, get its capabilities, plan for it, carry it out, and update corporate programs. The six benchmarks are divided into corporate and project levels via the CII's milestones for maintainability. Gao et al. [76] provide a conceptual illustration of serverless computing-based WSN maintainability implementation. The ability to meet the minimum resource requirements for the WSN product with a higher likelihood during the setup, trial production, testing, batch production, deployment, operations, and maintenance stages is referred to as the "maintenance-ability implementation.

Saghatforoush et al. [77] examined that, with appropriate and timely inputs into the first phases of the design and planning of a project, the constructability idea unifies individual building functions and experiences. It tries to make the construction process easier to achieve the overall project objectives more effectively and efficiently. Similarly, the operability and maintainability ideas include O&M (operation and maintenance) tasks, project planning, and design knowledge. Several studies claimed that infrastructure projects could have been delivered at their best by implementing these ideas independently.

5. THE CHALLENGES FACED IN MAINTAINABILITY AND RELIABILITY OF THE MANUFACTURING INDUSTRY AND THE WAY FORWARD

It is crucial to incorporate this expense in the annual budget as companies with significant expenditures on tangible assets become more conscious of the strategic value of the maintenance function. In other words, reliability has become a substantial issue in capital-intensive firms. Sadly, many Nigerian businesses frequently place little emphasis on adequate maintenance, and as a result, the expense of failures as a share of the total cost is rising. Innovation is necessary to challenge today's enterprises' entrenched behavioural norms and embedded perceptional patterns. Reliability should take precedence over repair in organisational culture. Therefore, to "build in" commitment, the established goals must provide "something in it for us" to everyone inside the business. As a result, the leader should consider the requirements of the organisation’s employees while formulating these goals and utilise them to guide the organisation’s future. A person's compensation must be in line with the accomplishment of the organisation’s strategic objectives. These benefits may be both monetary and non-monetary. The leader is responsible for developing collaborative and organisational learning opportunities. Finding the proper techniques is only one of the challenges Nigerian maintenance managers face today. Another is comprehending how these approaches work together. The financial return on a company's fixed assets is a crucial factor in investment decisions involving the return on fixed assets. Asset management is focused on achieving the lowest total cost during the production or provision of a desired service. To manufacture goods or services cheaper than rivals, one must outperform them regarding return on fixed assets. Maintenance expenses comprise a sizable portion of production costs, so maintenance management influences the return on fixed assets. The efficacy of maintenance should be investigated to determine why the maintenance cost as a proportion of manufacturing cost varies. The Nigerian manufacturing industry, however, has several difficulties, including:

1. inadequate finance and insufficient funding.
2. insecurity, lousy infrastructure, and inadequate company growth plans.
3. irregular taxation, which affects the day-to-day running of the industry.
4. One of the most significant issues facing the manufacturing sector today is inventory management. Nonetheless, a lot of small manufacturers still manage their stocks by hand.

While the final mission statement should clarify how the vision is to be realised, the vision statement should outline the company’s aspirations. The current best practice (CBP) standard should serve as the guideline for the maintenance vision statement. Fixed-time maintenance (FTM) overhauls or component replacements are most PM models' foundation.

Due to the relatively high costs associated with implementing PM and the fact that less than 20% of all components fail within the typically allowed intervals, this strategy is rarely justifiable. Therefore, if adopted, PM operations should focus mainly on the state of each individual component and be carried out using a more carefully planned corrective maintenance approach. By contrasting the sectors in the USA and Nigeria, it is determined that more than one-third of the costs are due to the inefficient use of maintenance resources, and the latter wastes all maintenance expenses.

One of the best ways to implement automated systems in the manufacturing industries that can assist in automatically detecting faults, giving comprehensive information on the equipment life span, and developing organisational operations structures. Figure 7 presents a structural formulation that helps improve manufacturing industries' operational systems. This covers the implementation of sensors and the employment of automated machines for manufacturing processes. Reduce the use of maintenance parts, implement discard-at-failure maintenance, design built-in test points, and always apply troubleshooting manuals to the maintenance process. All these applications are embedded in Industry 4.0 technologies. However, more research should be done to properly incorporate Industry 4.0 technology into maintainability issues for sustainable manufacturing processes.

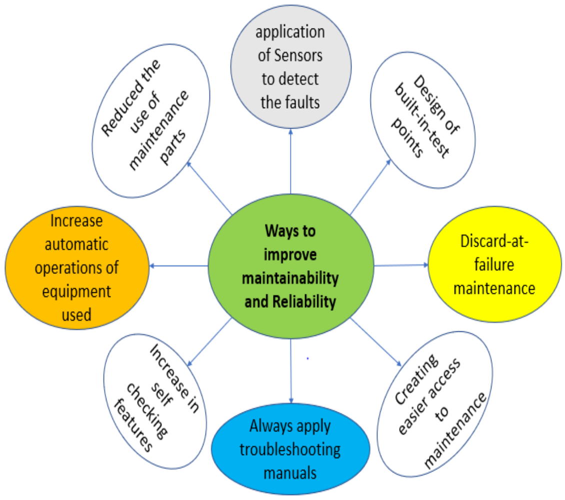

Figure 7. Comprehensive structure for maintainability and reliability improvement for manufacturing industries

6. CONCLUSIONS

This study reviews the current literature on the maintainability and reliability of the manufacturing industry in Nigeria with the operation of Industry 4.0 technologies. The study also highlighted its challenges and the way forward. It is worth knowing that Nigerian industrial managers need a culture that can deal with quick changes more successfully if they want to instill a competitive mindset in their manufacturing sectors. To do this, total preventive maintenance (TPM) should be introduced. The challenge of trying to do things better is the foundation of TPM, so coping successfully with change, which frequently requires quick alteration, needs to become ingrained in manufacturing organisations. To successfully adopt TPM, personnel within an organisation must be prepared to accept "change" for the better. The speed at which they move toward that aim depends on how keen they are to accept "change." Only an organisation that provides the required training and time to monitor its success can implement TPM successfully. Or the failure of the subsequent measures for change. With the utilisation of the suggested models and tactics, there should be a new mindset and recalibration of what is anticipated in current organisations. This should be self-assessed and compared to world-class industries with comparable product lines to achieve sustainability in terms of maintainability and reliability in Nigeria's manufacturing industries. The following are signs of the implementation of this study, they are:

i. The industry will be able to achieve a Lengthen asset lifespan of their equipment for sustainable production.
ii. Reduced the risk of a constant equipment breakdown leading to excess idea time. Which, in return, it will increase efficiency and decrease unplanned downtime in the industry.
iii. It will promote the safety and health of the workers. And boost customer satisfaction and increase profitability.

The operational process of industrial 4.0 is very significant to enable the industry to automate many operations while reducing stress on the staff.

7. RECOMMENDATION

Poor maintenance practices in Nigerian businesses would result in excessive production costs. The dependability analysis, which also offers appropriate maintenance techniques, should be used to gauge the system's effectiveness. The RAM principles and reliability indices are generally accepted technical strategies for locating production bottlenecks and critical component problems and maximising maintenance activity. Equipment dependability on the production line is impacted by the mean time to repair (MTTR), the mean time between failures (MTBF), and failure rates. The system will have high availability due to improved maintainability and reliability actions resulting from incorporating Industry 4.0 technology. The upkeep and dependability of the machinery and components are always closely correlated with the product's availability. A system's efficacy should be determined using one of the following three factors: accessibility, dependability, and maintainability. The Nigerian manufacturing system should consider the RAM analysis in selecting the proper level of operation and specific safety considerations for ongoing development. The study will recommend the following:

i. A sustainable prediction model using the industrial 4.0 techniques should be developed to help manufacturing industries predict the set time to carry out Maintainability and Reliability process in the industry.
ii. A benchmarking procedure should be operated upon to comprise different maintenance techniques to enable performance improvement.

REFERENCES

[1] Senisek, J., Wild, N., Wolfartsberger, J. (2021). Investigating the potential of smart manufacturing technologies. Procedia Computer Science, 180: 507-516. https://doi.org/10.1016/j.procs.2021.01.269

[2] James, A.T., Kumar, G., Bhalla, M., Amar, M., Jain, P. (2021). Analysis of challenges for automobile service garages in India: A structural modelling approach. Journal of Advances in Management Research, 18(3): 392-413. https://doi.org/10.1108/JAMR-04-2020-0059

[3] Tolio, T., Bernard, A., Colledani, M., Kara, S., Seliger, G., Duflou, J., Battaia, O., Takata, S. (2017). Design, management and control of demanufacturing and

remanufacturing systems. CIRP Annals, 66(2): 585-609. https://doi.org/10.1016/j.cirp.2017.05.001
[4] Farsi, M.A. (2022). Reliability, availability and maintainability modelling of multi-state systems with load-sharing structure. Journal of Computational & Applied Research in Mechanical Engineering (JCARME). https://doi.org/10.22061/jcarme.2022.7962.2059
[5] Holgado, M., Macchi, M., Evans, S. (2020). Exploring the impacts and contributions of maintenance function for sustainable manufacturing. International Journal of Production Research, 58(23): 7292-7310. https://doi.org/10.1080/00207543.2020.1808257
[6] Lezoche, M., Hernandez, J.E., Díaz, M.D.M.E.A., Panetto, H., Kacprzyk, J. (2020). Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture. Computers in Industry, 117: 103187. https://doi.org/10.1016/j.compind.2020.103187
[7] Tsarouhas, P. (2020). Reliability, availability, and maintainability (RAM) study of an ice cream industry. Applied Sciences, 10(12): 4265. https://doi.org/10.3390/app10124265
[8] Chlebus, M., Werbińska-Wojciechowska, S. (2016). Issues on production process reliability assessment-review. Research in Logistics & Production, 6(6): 481-497. https://doi.org/10.21008/j.2083-4950.2016.6.6.1
[9] Temer, E., Pehl, H.J. (2017). Moving toward smart monitoring and predictive maintenance of downhole tools using the industrial Internet of Things IIoT. In Abu Dhabi International Petroleum Exhibition & Conference. OnePetro. https://doi.org/10.2118/188382-MS
[10] Farsi, M.A., Zio, E. (2019). Industry 4.0: Some challenges and opportunities for reliability engineering. International Journal of Reliability, Risk and Safety: Theory and Application, 2(1): 23-34. https://doi.org/10.30699/IJRRS.2.1.4
[11] De Jonge, B., Scarf, P.A. (2020). A review on maintenance optimisation. European Journal of Operational Research, 285(3): 805-824. https://doi.org/10.1016/j.ejor.2019.09.047
[12] Ruwaida Aliyu, A.A.M. (2021). Research advances in applying flexsim: A perspective on machine reliability, availability, and maintainability optimisation. Journal of Hunan University Natural Sciences, 48(9). http://www.jonuns.com/index.php/journal/article/view/758.
[13] Guo, Z.Y., Zhou, D., Zhou, Q.D., Zhang, X., Geng, J., Seng, S.K., Lv, C., Hao, A.M. (2020). Applications of virtual reality in maintenance during the industrial product lifecycle: A systematic review. Journal of Manufacturing Systems, 56: 525-538. https://doi.org/10.1016/j.jmsy.2020.07.007
[14] Kumar Sharma, R., Gopal Sharma, R. (2014). Integrating six sigma culture and TPM framework to improve manufacturing performance in SMEs. Quality and Reliability Engineering International, 30(5): 745-765. https://doi.org/10.1002/qre.1525
[15] Gupta, G., Mishra, R.P. (2018). Identification of critical components using ANP for implementation of reliability-centered maintenance. Procedia CIRP, 69: 905-909. https://doi.org/10.1016/j.procir.2017.11.122
[16] Gargini, P.A. (2017). A brief history of the semiconductor industry. Nanoelectronics: Materials, Devices, Applications, 1-52. https://doi.org/10.1002/9783527800728.ch1
[17] Fukuda, K. (2020). Science, technology and innovation ecosystem transformation toward society 5.0. International Journal of Production Economics, 220: 107460. https://doi.org/10.1016/j.ijpe.2019.07.033
[18] Koren, Y., Gu, X., Guo, W. (2018). Reconfigurable manufacturing systems: Principles, design, and future trends. Frontiers of Mechanical Engineering, 13: 121-136. https://doi.org/10.1007/s11465-018-0483-0
[19] Phuyal, S., Bista, D., Bista, R. (2020). Challenges, opportunities and future directions of smart manufacturing: A state of art review. Sustainable Futures, 2: 100023. https://doi.org/10.1016/j.sftr.2020.100023
[20] Gu, X., Koren, Y. (2018). Manufacturing system architecture for cost-effective mass-individualisation. Manufacturing Letters, 16: 44-48. https://doi.org/10.1016/j.mfglet.2018.04.002
[21] Erdil, A. (2021). Manufacturing-production systems and their importance: Evaluation of flexible manufacturing systems (FMS). Avrupa Bilim ve Teknoloji Dergisi, (29): 331-342. https://doi.org/10.31590/ejosat.1024198
[22] Setchi, R.M., Lagos, N. (2004). Reconfigurability and reconfigurable manufacturing systems: State-of-the-art review. In 2nd IEEE International Conference on Industrial Informatics, pp. 529-535. https://doi.org/10.1109/INDIN.2004.1417401
[23] Kuzgunkaya, O., ElMaraghy, H.A. (2007). Economic and strategic perspectives on investing in RMS and FMS. International Journal of Flexible Manufacturing Systems, 19: 217-246. https://doi.org/10.1007/s10696-008-9038-8
[24] Shnits, B., Rubinovitz, J., Sinreich, D. (2004). Multicriteria dynamic scheduling methodology for controlling a flexible manufacturing system. International Journal of Production Research, 42(17): 3457-3472. https://doi.org/10.1080/00207540410001699444
[25] Bhushan, K., Chattopadhyaya, S., Sharma, S., Sharma, K., Li, C., Zhang, Y., Eldin, E.M.T. (2022). Analyzing reliability and maintainability of crawler doser BD155 transmission failure using markov method and total productive maintenance: A novel case study for improvement productivity. Sustainability, 14(21): 14534. https://doi.org/10.3390/su142114534
[26] Chung, I.H. (2022). Exploring the influence of the parameters' relationship between reliability and maintainability for offshore wind farm engineering. Energies, 15(15): 5610. https://doi.org/10.3390/en15155610
[27] Cevasco, D., Koukoura, S., Kolios, A.J. (2021). Reliability, availability, maintainability data review for the identification of trends in offshore wind energy applications. Renewable and Sustainable Energy Reviews, 136: 110414. https://doi.org/10.1016/j.rser.2020.110414
[28] Tian, Q., Wang, H. (2022). Optimisation of preventive maintenance schedule of subway train components based on a game model from the perspective of failure risk. Sustainable Cities and Society, 81: 103819. https://doi.org/10.1016/j.scs.2022.103819
[29] Abbassi, R., Arsaghi, E., Yazdi, M., Aryai, V., Garaniya, V., Rahnamayiesekavat, P. (2022). Risk-based and predictive maintenance planning of engineering infrastructure: Existing quantitative techniques and future directions. Process Safety and Environmental

Protection. https://doi.org/10.1016/j.psep.2022.07.046
[30] Casini, M. (2022). Extended reality for smart building operation and maintenance: A review. Energies, 15(10): 3785. https://doi.org/10.3390/en15103785
[31] Eti, M.C., Ogaji, S.O.T., Probert, S.D. (2006). Development and implementation of preventive-maintenance practices in Nigerian industries. Applied Energy, 83(10): 1163-1179. https://doi.org/10.1016/j.apenergy.2006.01.001
[32] Oztemel, E., Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. Journal of Intelligent Manufacturing, 31: 127-182. https://doi.org/10.1007/s10845-018-1433-8
[33] Tsarouhas, P. (2020). Reliability, availability and maintainability analysis of a bag production industry based on the six sigma DMAIC approach. International Journal of Lean Six Sigma, 12(2): 237-263. https://doi.org/10.1108/IJLSS-09-2019-0101
[34] Khan, A., Turowski, K. (2016). A survey of current challenges in manufacturing industry and preparation for industry 4.0. In Proceedings of the First International Scientific Conference "Intelligent Information Technologies for Industry" (IITI'16), pp. 15-26. https://doi.org/10.1007/978-3-319-33609-1_2
[35] Gherghea, I.C., Bungau, C., Indre, C.I., Negrau, D.C. (2021). Enhancing productivity of CNC machines by total productive maintenance (TPM) implementation. A case study. In IOP Conference Series: Materials Science and Engineering, 1169(1): 012035. https://doi.org/10.1088/1757-899X/1169/1/012035
[36] Guo, Z., Zhou, D., Zhou, Q., Mei, S., Seng, S., Yu, D., Chen, J. (2020). A hybrid method for evaluation of maintainability towards a design process using virtual reality. Computers & Industrial Engineering, 140: 106227. https://doi.org/10.1016/j.cie.2019.106227
[37] Gharoun, H., Hamid, M., Torabi, S.A. (2021). An integrated approach to joint production planning and reliability-based multi-level preventive maintenance scheduling optimisation for a deteriorating system considering due-date satisfaction. International Journal of Systems Science: Operations & Logistics, 1-23. https://doi.org/10.1080/23302674.2021.1941394
[38] Cheng, G., Li, L. (2020). Joint optimisation of production, quality control and maintenance for serial-parallel multistage production systems. Reliability Engineering & System Safety, 204: 107146. https://doi.org/10.1016/j.ress.2020.107146
[39] Bush, T., Jackson, D. (2002). A preparation for school leadership: International perspectives. Theories of Educational Leadership and Management, 30(4): 417–429. https://doi.org/10.1177/0263211X020304004
[40] Alimian, M., Ghesavati, V., Tavakkoli-Moghaddam, R. (2020). New integration of preventive maintenance and production planning with cell formation and group scheduling for dynamic cellular manufacturing systems. Journal of Manufacturing Systems, 56: 341-358. https://doi.org/10.1016/j.jmsy.2020.06.011
[41] Zhou, X., Zhu, M., Yu, W. (2021). Maintenance scheduling for flexible multistage manufacturing systems with uncertain demands. International Journal of Production Research, 59(19): 5831-5843. https://doi.org/10.1080/00207543.2020.1791998
[42] Li, L., Wang, Y., Lin, K.Y. (2021). Preventive maintenance scheduling optimisation based on opportunistic production-maintenance synchronisation. Journal of Intelligent Manufacturing, 32(2): 545-558. https://doi.org/10.1007/s10845-020-01588-9
[43] Gao, T., Xu, M. (2022). Cost control and efficiency optimisation in maintainability implementation of wireless sensor networks based on serverless computing. arXiv Preprint, arXiv:2210.15831. https://doi.org/10.48550/arXiv.2210.15831
[44] Lauria, M., Azsalin, M. (2019). Project and maintainability in the era of Industry 4.0. TECHNE-Journal of Technology for Architecture and Environment, 184-190. https://doi.org/10.1016/j.ress.2020.106996
[45] Kamble, S.S., Gunasekaran, A., Ghadge, A., Raut, R. (2020). A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs-A review and empirical investigation. International Journal of Production Economics, 229: 107853. https://doi.org/10.1016/j.ijpe.2020.107853
[46] Esper, K., Schnicke, F. (2020). Evaluation of the maintainability aspect of Industry 4.0 service-oriented production. In 2020 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT), pp. 8-14. https://ieeexplore.ieee.org/abstract/document/9172010
[47] Sun, Z., Dababneh, F., Li, L. (2018). Joint energy, maintenance, and throughput modeling for sustainable manufacturing systems. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 50(6): 2101-2112. https://ieeexplore.ieee.org/abstract/document/8350310.
[48] Ghaithan, A.M. (2020). An optimisation model for operational planning and turnaround maintenance scheduling of oil and gas supply chain. Applied Sciences, 10(21): 7531. https://doi.org/10.3390/app10217531
[49] Vianna, E.A., Abaide, A.R., Canha, L.N., Miranda, V. (2017). Substations SF6 circuit breakers: Reliability evaluation based on equipment condition. Electric Power Systems Research, 142: 36-46.
[50] Dunmade, I., Udo, M., Akintayo, T., Oyedepo, S., Okokpujie, I.P. (2018). Lifecycle impact assessment of an engineering project management process-A SLCA approach. In IOP Conference Series: Materials Science and Engineering, 413(1): 012061. https://doi.org/10.1088/1757-899X/413/1/012061
[51] Fayomi, O.S.I., Okokpujie, I.P., Udo, M. (2018). The role of research in attaining sustainable development goals. In IOP Conference Series: Materials Science and Engineering, 413(1): 012002. https://doi.org/10.1088/1757-899X/413/1/012002
[52] Onawumi, A., Udo, M., Awoyemi, E., Okokpujie, I.P. (2018). Alternate maintainability evaluation technique for steering system of used automobiles. In IOP Conference Series: Materials Science and Engineering, 413(1): 012062. https://doi.org/10.1088/1757-899X/413/1/012062
[53] Chibu, O.R. (2018). Integration of reliability, availability, maintainability, and supportability (Rams) in maintenance decision policies in Afam electric power station in rivers state Nigeria. International Journal of Electrical and Electronics Engineering (IJEEE), 7: 1-16. https://www.academia.edu/37819702.
[54] Filz, M.A., Langner, J.E.B., Herrmann, C., Thiede, S. (2021). Data-driven failure mode and effect analysis (FMEA) to enhance maintenance planning. Computers in Industry, 129: 103451.

https://doi.org/10.1016/j.compind.2021.103451
[55] DeLuca, R.C., Schwartz-Watjen, T., Tomczykowski, W. (2022). Challenges of and lessons learned from implementing an MBE FMECA in the DoD. In 2022 Annual Reliability and Maintainability Symposium (RAMS), pp. 1-6. https://doi.org/10.1109/RAMS51457.2022.9894009
[56] Adenuga, O.D., Diemuodeke, O.E., Kuye, A.O. (2022). Maintenance in marginal oilfield production facilities: A review. World Journal of Engineering and Technology, 10(4): 691-713. https://doi.org/10.4236/wjet.2022.104045
[57] Jakkula, B., Mandela, G.R., Chivukula, S.M. (2022). Reliability, availability and maintainability (RAM) investigation of load haul dumpers (LHDs): A case study. International Journal of System Adenuga Engineering and Management, 13(1): 504-515. https://doi.org/10.1007/s13198-021-01154-3
[58] Farsi, M.A. (2022). Reliability, availability and maintainability modelling of multi-state systems with load-sharing structure. Journal of Computational & Applied Research in Mechanical Engineering (JCARME). https://doi.org/10.22061/jcarme.2022.7962.2059
[59] Kumar, A., Saini, M., Patil, R.B., Al-Dahidi, S., Mellal, M.A. (2022). Reliability, availability, maintainability, and dependability analysis of tube-wells integrated with underground pipelines in agricultural fields for irrigation. Advances in Mechanical Engineering, 14(8): 16878132221115931. https://journals.sagepub.com/doi/pdf/10.1177/16878132221115931.
[60] Juanpera, M., Blechinger, P., Ferrer-Martí, L., Hoffmann, M. M., Pastor, R. (2020). Multicriteria-based methodology for the design of rural electrification systems. A case study in Nigeria. Renewable and Sustainable Energy Reviews, 133: 110243. https://doi.org/10.1016/j.rser.2020.110243
[61] Babatunde, D.E., Babatunde, O.M., Emezirinwune, M. U., Denwigwe, I.H., Okharedia, T.E., Omodara, O.J. (2020). Feasibility analysis of an off-grid photovoltaic-battery energy system for a farm facility. International Journal of Electrical & Computer Engineering (2088-8708), 10(3): 2874-2883. https://doi.org/10.11591/ijece.v10i3.pp2874-2883
[62] Rokhforoz, P., Fink, O. (2022). Maintenance scheduling of manufacturing systems based on optimal price of the network. Reliability Engineering & System Safety, 217: 108088. https://doi.org/10.1016/j.ress.2021.108088
[63] Moon, I., Yun, W.Y., Sarkar, B. (2022). Effects of variable setup cost, reliability, and production costs under controlled carbon emissions in a reliable production system. European Journal of Industrial Engineering, 16(4): 371-397. https://doi.org/10.1504/EJIE.2022.123748
[64] Jasiulewicz -Kaczmarek, M., Legutko, S., Kluk, P. (2020). Maintenance 4.0 technologies-new opportunities for sustainability driven maintenance. Management and Production Engineering Review, 11(2): 74-87. http://dx.doi.org/10.24425/mper.2020.133730
[65] Fernando, Y., Halili, M., Tseng, M.L., Tseng, J.W., Lim, M.K. (2022). Sustainable social supply chain practices and firm social performance: Framework and empirical evidence. Sustainable Production and Consumption, 32: 160-172. https://doi.org/10.1016/j.spc.2022.04.020
[66] Dahmani, A., Benyoucef, L., Mercantini, J.M. (2022). Toward sustainable reconfigurable manufacturing systems (SRMS): Past, present, and future. Procedia Computer Science, 200: 1605-1614. https://doi.org/10.1016/j.procs.2022.01.361
[67] Kumar, S., Singh, R. (2020). Rank order clustering and imperialist competitive optimisation based cost and RAM analysis on different industrial sectors. Journal of Manufacturing Systems, 56: 514-524. https://doi.org/10.1016/j.jmsy.2020.07.014
[68] Dalzochio, J., Kunst, R., Pignaton, E., Binotto, A., Sanyal, S., Favilla, J., Barbosa, J. (2020). Machine learning and reasoning for predictive maintenance in Industry 4.0: Current status and challenges. Computers in Industry, 123: 103298. https://doi.org/10.1016/j.compind.2020.103298
[69] Xu, L.D., Xu, E.L., Li, L. (2018). Industry 4.0: state of the art and future trends. International Journal of Production Research, 56(8): 2941-2962. https://doi.org/10.1080/00207543.2018.1444806
[70] Djeunang Mesafack, R.A., Di Mascolo, M., Simeu-Abazi, Z. (2022). Systematic literature review of repair shops: Focus on sustainability. International Journal of Production Research, 60(23): 7093-7112. https://doi.org/10.1080/00207543.2021.2002965
[71] Sousa, M.L.H., da Costa, C.A., de Oliveira Ramos, G., da Rosa Righi, R. (2020). A survey on decision-making based on system reliability in the context of Industry 4.0. Journal of Manufacturing Systems, 56: 133-156. https://doi.org/10.1016/j.jmsy.2020.05.016
[72] Lacasse, M.A., Gaur, A., Moore, T.V. (2020). Durability and climate change—Implications for service life prediction and the maintainability of buildings. Buildings, 10(3): 53. https://doi.org/10.3390/buildings10030053
[73] Zhu, L., Shan, M., Hwang, B.G. (2018). Overview of design for maintainability in building and construction research. Journal of Performance of Constructed Facilities, 32(1): 04017116. https://ascelibrary.org/doi/full/10.1061/%28ASCE%29CF.1943-5509.0001116.
[74] Meier, J.R., Russell, J.S. (2000). Model process for implementing maintainability. Journal of Construction Engineering and Management, 126(6): 440-450. https://ascelibrary.org/doi/abs/10.1061/(ASCE)0733-9364(2000)126:6(440)
[75] Moua Her, B., Russell, J.S. (2002). Maintainability implemented by third-party contractor for public owner. Journal of Management in Engineering, 18(2): 95-102. http://dx.doi.org/10.1061/(ASCE)0742-597X(2002)18:2(95)
[76] Gao, K., Peng, R., Qu, L., Wu, S. (2020). Jointly optimizing lot sizing and maintenance policy for a production system with two failure modes. Reliability Engineering & System Safety, 202: 106996. https://doi.org/10.1016/j.ress.2020.106996
[77] Saghatforoush, E., Trigunarsyah, B., Too, E. (2012). Assessment of operability and maintainability success factors in provision of extended constructability principles. In Proceedings of the 9th International Congress on Civil Engineering [Civilica-Encyclopedia of Civil Engineering Series], pp. 1-10.