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Spare parts failure prediction of an automobile under criticality condition

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ABSTRACT

Many studies on spare parts planning classified items based on the levels of importance using conventional approaches. Classification of spare parts based on the stated approach without considering failure value and/or its consequence may not withstand the test of time due to continuing technological advancement or environmental degradation. This study solved the stated problem by developing a system that is capable of dynamically determining critical equipment/spare parts based on failure rates using ABC analysis. In this analysis, all operable items were considered to be non-critical and they became critical when they approached failure time. These transitions were prompted by items' failure conditional probability within the limits of 1, 2/3, 1/3 for highly critical, critical and less critical items, respectively. The most critical item(s) (A class) with highest failure value/consequence were sorted out based on specificity (one manufacturer's item) and generality (many manufacturers' item). Failure remedy was achieved by applying modified classical inventory model which considered heterogeneity in item failure. The stated conditions were integrated into a time series, linear regression model. The performance evaluation results showed that the new scheme was efficient in spare part failure criticality classification, consequence analysis and remedy. The practical implication of the findings indicated that the developed system could serve as a suitable alternative to the static classification style of the conventional approach in term of cost savings.

1. Introduction

The spare part usage in maintenance is very important but difficult to manage due to random failures [1]. The outcome of a stock-out may be disastrous due to high prices of parts [2]. If the parts are stocked out, then the defective equipment cannot be serviced when due. This will result to production loss. Besides, if the parts are overstocked, the holding costs will be high [3]. Adequate spare parts are needed to retain or restore defective industrial systems and technical installations into operable condition with minimal production time loss. One of the functions of spare parts failure analysis and planning is to assist in keeping adequate spare(s) for continuing maintenance operations. Sustainable spare part failure analysis and planning will make the industrial systems operate at high productivity [4]. There are abandonment of vehicles on the streets and garages due to non-availability of critical spare parts to correct emerging failures [5]. Besides, maintenance performance has reduced drastically in the industries because they lacked information on the newly evolved spare parts of different

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characteristics and configurations (in quality and reliability). Based on this, many maintenance companies are re-organizing, downsizing, and re-engineering vehicular failure preventive (corrective) approach. The other challenges are spare part failure data management. These include: traceability of part information; part re-use; part interaction; part duplication; and part registration [4].

There is need for a scheme that will adequately solve the stated challenges by integrating failure analysis into maintenance planning. This study develops a system that is capable of dynamically determining critical equipment/spare parts using failure criticality classification and maintenance planning approach. Many models developed on spare parts failure analysis and planning were overwhelmed with some unrealistic assumptions including spare parts failure homogeneity [6–8]; these had made the models impracticable in heterogeneous industrial maintenance environment that demands analysis of different levels of failure criticality of spare parts. A normative model based on mathematical analysis was developed to solve an ideal set of mutually consistent decisions related to sub-problem areas of the spare part paucity [9]. Widening of the scope of the study to include analysis and planning of spare parts failure would make the system robust in predicting spare parts failure remedy. Spare parts classification based on ABC analysis had been reported in standard texts [9,13,14]. Many research efforts had utilized this concept in classification of components for inventory purposes [15–19,24]. The analysis was principally used to determine those inventorying items, based on Pareto's law [14], that need: close monitoring (A class); regular review (B class); and less attention (C class). Other researches utilized the ABC analysis in product analysis and selection [20,21], design for assembly [22], and productivity improvement [23]. Research on the application of ABC approach in failure analysis is scanty. Only identified effort in this area is limited to failure consequences analysis [25]. Other important areas of failure analysis such as failure criticality, specificity, generality, and consequence values were not addressed. The stated factors are reflection of the heterogeneous nature of spare parts failure. Few efforts have addressed issues of heterogeneity of spare parts as related to criticality, specificity and generality [10,11]. These efforts would have contributed immensely in solving problems of spare parts failure planning but the address was only qualitative-based. Non-provision of quantitative-based failure analysis would make it difficult for proper assessment of its efficiency. This paper relaxes many of the assumptions made in previous works, and, at the same time provides quantitative expressions required in solving spare parts failure problems in the heterogeneous environment. The study also utilized essential components of spare parts failure analysis and planning in the previous studies [12,13] such as spare parts failure pattern, failure frequency, failure consequences, inventory, and at the same time extends failure analysis and planning to take care of heterogeneous nature of spare parts (criticality, specificity and generality).

Meanwhile, failure analysis can be carried out on equipment/material at static [26,30,40], dynamic [29,31–33], design [27,28], and operational [35] stages. Failure can be analyzed on materials (machines or components) at service/operational condition based on prediction models in order to proactively plan to prevent (correct) such failures [23,39,41]. Besides, failure can be analyzed on materials (machines or components) at design/static stages to create room for improvement on service life [36,38]. These identified failure categories in material/components were analyzed using statistical, similarity, external failure rate database, and physics of failure methods [28,34,37,43]. Statistical method of failure analysis was utilized in this study. Components (spare parts) failure frequency, failure (monetary) value, and grouping are carried out. The critical component(s) that corresponded to the highest failure value(s) were subjected to statistical ABC analysis based on Pareto's law [14]. An exponential smoothing forecasting model for predicting the critical components' failure of A class was established. From this, failure rate(s) of the critical components were determined. Failures probabilities of components based on heterogeneous failure parameters: criticality, specificity and generality were estimated under a negative exponential distribution failure pattern.

2. Methodology

The causes of failure of spare parts (components) were identified [42]. A model for spare parts failure prediction in automobile under criticality condition was developed. The model was developed based on factors such as failure pattern/trend, grouping, and failure probability exhibited by the spare parts. The control characteristics of spare parts utilized in the model were criticality, specificity, and generality. First, spare parts were grouped based on functionality, and the critical components were determined based on failure value. Second, statistical ABC analysis based on Pareto's laws was adapted for the failures analysis of the critical components [14]. The categories of rules utilized in the ABC analysis are: A class consists of 5–40% components with failure value 40–80%; B class comprises 20–40% components with failure value limit of 15–40%; and C class has 20–75% components in failure value of 5–20%. Based on this rule component(s) in A class failures are to be given close control because they are the most valuable (negligence on A class items can cause high failure consequence). Therefore failure predictive (corrective) model on A class components is pertinent. Third, simple exponential smoothing forecasting technique was adapted for failure rate prediction of the emerging critical components. The predicted failure rates based on heterogeneity of components (specificity and generally) were used for determining probabilities of failures under a negative exponential failure distribution/pattern from which failure remedy were devised based on components criticality. Failure remedy based on modified classical inventory model was applied to manage the consequence of failure. Last, sensitivity analysis was carried out on emerging regression model that related economic order quantity with scheduled failure/maintenance time. Information and data from an automotive maintenance industry located in one of the Nigerian cities were used to validate the model. The proposed framework for this study is presented in Fig. 1.