Process Optimisation Regarding Overall Equipment Effectiveness of Tyre Manufacturing Using Response Surface Methodology and Grey Relational Analysis

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Abstract. *Although overall equipment effectiveness (OEE) is positively associated with customer retention, profit growth and enhanced customer relationship, the existing evidence, however, is largely limited. Yet, extending this line of inquiry to a wide variety of optimization methods and industrial settings is compelling for maintenance progress since no study has addressed this concern using the response surface methodology (RSM) and grey relational analysis (GRA) and this paper addressed this gap. This paper presents approaches based on RSM and GRA to optimise the OEE for the tyre manufacturing process using literature data. The results obtained from using the RSM showed an OEE metric of 59.09% as the optimal solution and 90.9%, 65.04% and 99.4% of availability, performance rate and quality rate, respectively. Furthermore, the GRA revealed ranges of coefficients for availability, performance ratio and quality ratio is from 0.062 to 46.2, 0.196 to 4.528, and -0.002 to 1, respectively. Consequently, availability has the highest grey relational grade of 49. 33 and quality rate has the least value of 0.02. The outcome of the study establishes that the methods are effective and may serve as to detect variance of the OEE component factors during actual operation by referring to the predictions.*

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1. Introduction

In the tyre industry globally, the outbreak of COVID-19 has negatively influenced the economy in the industry and the global economy at large and the world is currently confronted with an unprecedented economic predicament. This global challenge has forced operators in the tyre industry to a partial or total lockdown pending a situation where the COVID-19 curve is flatted. But as success is achieved to flatten and contain the transfer curve of COVID-19 in the global business environment, tackling the economic problem remains a challenge and opportunities using scientific tools of improvement should be exploited. One of the avenues of correcting this economic weakness is the introduction of optimisation measures for the overall equipment effectiveness programme in the tyre industry.

Furthermore, extensive studies in the domain of overall equipment effectiveness (OEE) have demonstrated that superior results and enhanced efficiency are the principal benefits of implementing optimisation studies in manufacturing concerns [1, 2, 3, 4, 5, 6, 7]. Optimisation refers to the choice of the superior element from a group of obtainable options [6, 7, 8]. Although optimisation exists in a range, significant research on the OEE has applied some methods, including response surface methodology (RSM) [6], nonlinear optimisation technique [7] and design of experiments [1]. This research theme often minimizes or maximizes the OEE function to obtain the optimal solutions to the set objective functions [6, 8]. In this paper, it is argued that the central composite design-oriented RSM is moulded substantially to compete with alternative methods in the OEE tyre manufacturing literature [9], including genetic algorithm, experimental design and non-linear optimisation methods abundant in the literature [9, 10, 11, 12, 13]. This viewpoint enables us to reap the benefits of central composite design RSM that needs a very limited number of experiments for testing.

In the manufacturing industry, tyre manufacturing is an old and increasing industry in importance because a tyre is central to automobiles [14, 15, 16]. It offers grip to braking and acceleration and establishes the control of the steering. Tyres are vital to drive safely and offer a direct linkage between the automobile and the road [15, 17, 18]. Tyres affect our lives on the wheel as they dictate our safety [19, 20, 21]. Thus, tyre manufacturing is a fundamental industry that should be managed for efficiency, quality and productivity [22, 23]. Maintenance is the central and perhaps the most important driving element of the tyre industry [24]. Though maintenance is important, unfortunately, very scarce research is available and the optimisation of the maintenance process in terms of the OEE of the systems [8, 25].

Further, because of the unique features of the tyre industry, optimisation of the tyre industry's maintenance OEE factors may not be completely understood using the existing models of failure mode and effect analysis where the search for the root causes of incessant breakdown is made in the tyre production process [26, 27]. Although the idea of a risk priority number is useful and promotes an understanding of the OEE practices, it may not fully help to tackle the optimisation problem concerning some defined tyre manufacturing parameters [27].

With the extensive use of quantitative approaches in the tyre industry, this requirement to understand the industry restricts the process engineers to appreciate the workers' potentials and abilities [28, 29]. Therefore, in this paper, the central composite design RSM is used to optimise the parameters of the tyre industry in terms of availability, performance ratio and quality ratio [9]. The gap in the tyre industry is bridged to analyse how the optimisation of the parameters of the system affects the outcome of the tyre industry in terms of process optimisation and efficiency. By doing this, the tyre industry literature is extended from different perspectives:

1. Highlighting evaluation parameters and features uncertain in previous OEE research with potentials to expand the frontier of comprehension of investigators on the evaluation parameters and the procedure for evaluation.
2. Employing the theory regarding central composite design in RSM may trigger new thinking and improvement of the current knowledge in the area of OEE for the tyre industry.
3. Instituting research deficiencies on optimisation of OEE in the tyre industry to adequately position new research endeavours.

Furthermore, regarding the research area presented in this paper, optimisation of OEE in tyre manufacturing, there is only one optimisation method that has been proposed in the literature closely related to the present study; the genetic algorithm was proposed in [8] to tackle the optimisation problem in tyre manufacturing from the lens of OEE metric. However, the genetic algorithm involves multiple steps, requiring some knowledge of non-traditional optimisation procedures which appear too cumbersome for the process engineer and the engineering team with limited knowledge of computerisation and restricted time to compute due to the pressing need to tackle equipment faults.

Consequently, this situation calls for an alternative method, and the central composite design of the RSM appears as an appropriate tool to bridge this gap. In the context of OEE optimisation, the RSM is used as a novel approach to the development and practical application of response surface theories and principles to the tyre production industrial practice [1]; it solves the manufacturing loss problem, reducing the manufacturing losses or eventually eliminating it for sustained industrial gains in tyre production.

2. Literature Review

2.1 General

The OEE metric is a mandatory best practice tool in the tyre plant, to lower or avoid the most widespread sources of equipment-oriented productivity loss, popularly labelled as the six big losses that and streamlined into three groups, consisting of availability, quality and performance [25, 30, 31]. The argument behind the OEE philosophy is that it should be benchmarked, improved and the improvement should be sustained. Diverse scholars have utilised OEE to monitor and control processes [1, 32]. In this work, the deployment of a response surface model is intended to first optimise the parameters to control and improve the tyre production system [9].

The principal objective of this report is to seek a proper OEE metric for the tyre manufacturing process beyond the conventional measurement to a rank where utmost results are obtained that truly enhance the performance of the system reduce and eliminate losses in the tyre production process. Although several scholars have extensively discussed the OEE metric in manufacturing plants, very little efforts have been made on tyre manufacturing and extremely loss efforts have been committed to the optimisation of the tyre manufacturing process using the OEE metric [27, 33, 34, 35]. This paper is then one of the frontline efforts in this regard.

The proposed RSM offers preferable results over the traditional outcomes that are presented in previous papers such as in [14, 26, 36, 37, 38]. Although the concern for optimisation at present is unsatisfactory, nonetheless, some research efforts and implementations have been reported optimisation concerning the OEE, in the literature with very little contribution to tyre manufacturing. A research was conducted in [7] to declare an optimisation model to evaluate the least cycle time from a mathematical function with linear constraints. While the study projected insights on how optimisation may be initiated in manufacturing systems, the seemingly complicated task of computation displayed in the report may not be substantially attractive to the practitioner. Hence, the simplicity of an optimisation model such as the RSM that is offered to the OEE community.

Andersson and Bellgran [36] revealed how to methodically join productivity metrics with OEE metrics to aid production enhancement. It further proposed two novel productivity indices for shop floor activity enhancement with application in the automotive industry. Sharma [5] established the OEE metric in a chosen auto-manufacturing plant characterised by flexible manufacturing, improving the reliability of the plant through loss avoidance strategies. The results revealed a substantial enhancement in the OEE assessment of the proposed model regarding the party-automated cell by tackling the six big losses of manufacturing.

Shahin and Isfahani [3] contributed an approach to calculate the OEE when the production system is of the continuous type. Data were collected to validate the model from an Estahan Steel producing plant and the groupings of data are on the aspects of production rate, waste rate and stoppage rate. Substantial savings and equipment usage was achieved concurrently using the proposed method.

Singh et al. [4] evaluated the OEE to examine the operational efficiency within a manufacturing system. Results of plant improvement were indicated before and after the implementation of OEE for a case study plant. Yuniawan et al. [2] modified the OEE metric by adding details of OEE approximation, cost of value addition and non-value added cost using Taguchi Scheme and simulation exercise. Roessler and Abele [39] proposed two methods to enhance the OEE and reliability of a shop floor by subjecting the condition of measurement to uncertainty and applying fuzzy set theory. The unique applications of OEE at production planning and shop floor activities were demonstrated with results that ascertain the critical contribution of OEE to attain success in production plan development and implementation as well as incorporate planning.

Cesarotti et al. [40] considered the influence of single losses of OEE regarding energy utilization. The study implemented the approach in a thermoforming plant. Braglia et al. [41] conducted a fuzzy oriented study to evaluate the OEE of a plant. The triangular fuzzy numbers were deployed, preferred to the stochastic representation of the system and application made in a case study. Tantanawat et al. [42] considered OEE measures and financial indices to appraise palm oil mills. Simulation of data was considered in verifying the proposed model. Chiarini [43] improved OEE in an Italian plant by deploying a lean six sigma approach. The author established variability in the process using the root cause method. Eventually, the plant's performance through OEE enhanced by 21%. Additional tools, including 5S, poka-yoke and single minute exchange of die method were implemented in the plant for performance enhancement.

2.2 Literature Observations and Gaps

1. The tyre manufacturing process maintenance job is an important part of the global tyre industry with a complicated arrangement of man, machine and activity interactions. However, understanding the association among the three main losses, availability, quality rate and performance rate has excluded the use of RSM [9].
2. Compared to the food industry and other manufacturing systems, the use of the term OEE from the perspective of tyre manufacturing is comparatively new. However, the new economic dimension of turbulence, forcing companies to shut down brought the requirement to tackle OEE in a tyre manufacturing environment. The OEE is brought into sharp focus, requiring all participants in production and maintenance to respond to the reduction of the six big losses in manufacturing, therefore calling for optimization. Unfortunately, very little efforts on optimisation have been invested in tyre manufacturing and at present, no model on RSM has been contributed in this regard. Thus, this is a research gap in the direction of testing the robust RSM and using it to optimize the manufacturing process performance.
3. At present, many authors dealing with RSM have developed experimental runs, regression models and stopped at surface plots; very few authors have further analysed the regression model for the prediction of performance. In tyre research, there appears no report on the RSM and particularly the predictive performance analysis of regression model to solving performance problems related to OEE.
4. The literature on OEE is expanding. Though uncertainty is recognised in operations and maintenance activities in the engineering literature, uncertainty treatment has not been extended to the literature on OEE and regarding tyre manufacturing.
5. In an article, the issue related to data mining was explored outside the tyre plant domain. However, the tyre plant generates a huge volume of data but the advantages of such computations have not been exploited in the tyre manufacturing industry and this gap is critical and should be closed.

3. Methodology

3.1 Research Problem

The conventional practice of evaluating the OEE in the tyre plant is related to the evaluation of the component parameters of availability, performance rate and quality rate as three main loss control parameters [39]. However, in adopting the traditional OEE model, which is the product of availability, quality rate and performance rate, the process engineer may be at the risk of planning based on the sub-optimal values, controlling industrial losses sub-optimally [36]. But losses must be controlled and optimisation tools are adequate to control them. Unfortunately, the viewpoint of OEE parametric optimisation has received very little attention in the tyre industry. Yet there is tremendous pressure on the process engineer to drastically reduce losses and sustain the tyre plant. Scholars in maintenance management emphasize that the emerging lean tradition where loss avoidance is the order of the day should be maintained. However, no scientific leads are available at present to resolve this problem in the tyre manufacturing plant. To resolve this problem RSM is conceived as an appropriate tool to use [9].

Furthermore, in the definition of the problem treated in the present work, it is understood that several dimensions optimizing the OEE metric are possible. However, some variables can be evaluated in a meaningful way while others are complicated to implement practically at the tyre production floor. It is known that highly skilled maintenance workers will indirectly yield high effectiveness at work. Similarly, the experience of workers and environmental conditions where the work is carried out are contributors to the effectiveness of the system. But all these are in an indirect manner and complicated to measure. Though surrogate measures may be attempted for such they are subjective. But data concerning downtime and uptime, for instance, are objective and could be evaluated in a meaningful way to reflect the effectiveness of the equipment since humans will be the driving force to attain this effectiveness. Thus, it was determined to optimise the OEE metric using the RSM, where the response is the OEE metric, and the parameters are the availability, quality rate and performance ratio that reflects the outcome of the OEE metric.

Next, the section on literature review reveals the incapability of the OEE literature to answer the research question on how to optimise the OEE parameters of the tyre manufacturing process with practical ease. So, one may ask at this point “What is the association between availability, performance ratio and quality rate such that measures of optimal values may be obtained for effectiveness using the OEE measure?

3.2 Research Scope

In this work, the focus of our argument is that losses in the tyre manufacturing plant should be eliminated. These six big losses, which are reduced to three, are represented by the parameters, namely the availability ratio, performance ratio and quality rate [39]. It is argued that the three parameters cover the wide scope of processing obtained within the tyre plant and that they capture the important details necessary for the tyre manufacturing plant to attain effectiveness. To attain the goal of loss elimination two frameworks were developed based on the classical models of RSM and grey relational analysis (GRA)[44]. Thus, the scope of this paper cover three main dimensions (1) optimisation of the OEE response using RSM (2) selection of the best parameter using the GRA and (3) optimisation of the OEE parameter using the GRA.

The first aspect of the scope was motivated by the need to enhance the availability of the system, its performance ratio and the quality rate for the tyre products delivered to the customers. At present, the OEE evaluation is based on the product of availability (AV), performance (PR) and quality rate (QR) and this does not allow for utmost performance of the system's parameters. Though results on availability are delivered, are they at the maximum speed of the equipment? Performance results are given but are they at the utmost operating rate? Are the cycle time (throughout) and takt time optimised? At sub-optimal levels, are they not giving the operator freedom to work as desired and not at the operator utmost performance and skill levels? These are gaps that exist in the current system of OEE evaluation. However, optimisation using the RSM and GRA is set to bridge these gaps. Thus, the first and third aspects of the current research scope address the optimisation gap in the OEE literature.

The second aspect of the scope relates to the selection of the best parameter in the OEE framework. This is necessary to offer direction for the disbursement of resources for the tyre plant. For instance, if the quality rate was elevated as the first rank, it means that it is the most influential parameter to the customer and intensive efforts to sustain the quality of the product should be made by directing most resources to this parameter. However, the values attached to the rank may reveal the level of significance that is given to the topmost parameter and used as a multiplicative factor in the sharing of resources during the budgetary process.

3.3 Response Relating to Big Losses in Manufacturing

From the previous section, the problem solved in this work is regarding optimisation of the OEE metric in a tyre manufacturing plant. However, to use the RSM there is a need to specify the responses. A close look at the system suggests the OEE metric as the response since responses are defined based on the problem to be solved. The OEE metric is often evaluated in crisp numeric value.

3.4 Factor Definition for the OEE Response

The extant literature on OEE and TPM has established three factors as representatives of the OEE metric [45]. These include availability, performance rate and quality rate [2].

3.4.1 Availability

Availability measure was developed to understand the ratio of the uptime to the sum of uptime and downtime [25]. The uptime refers to the period in which the equipment is in good operating condition and delivered to the production team for productive work [42]. However, the converse of uptime is downtime, which refers to the period that the machine is denied operation either by breaking down resulting from failed components or imposed downtime by the maintenance and overhaul activates [42]. The term availability has several descriptions. It is often desired by an investor willing to purchase new equipment to know the designed availability of the plant to plan for spare parts. So, the terms inherent availability and achieved availability are often used in maintenance.

Mathematically, availability is defined as follows [3, 4, 5]:

$$\text{Availability} = \text{Uptime}/(\text{Uptime} + \text{Downtime}) \qquad (1)$$

The principal question answered by the availability parameter is whether the equipment is operating or not [4]? In tackling availability, we compare theory with practice. Theoretically, the management knows that the equipment is given to the production department for the whole working period. However, practically, all the time is not available to the production department. Some of the periods are shared by the maintenance crew for preventive maintenance while the trade union may forcefully stop production as a result of a trade dispute between the management and the union. The time that equipment stops work will reduce the availability of the plant.

3.4.2 Quality Rate

The quality rate is another factor used to compute the OEE metric [16, 39]. In quality literature, quality is defined as the whole features of a tyre that meets the expectations of the customer. Traditionally, the outcome of a quality assessment exercise is often described in terms of rework rate, scrap rate and reject rate or quantities of scrap, reject and rework [16]. A scrap product is an or for which the quality attributes fall below the accepted threshold and cannot be remedied but thrown back as raw material for remanufacturing. In rejection, the degree of defect is not strongly pronounced as the scrap but still outside the acceptance of the customer. In most cases, rejects may not be repaired but also treated as a re-manufacturing product. Reworks are unacceptable tyres but could be amended and resold. This group of defects need not undergo re-manufacturing but may require extremely few modifications before customer acceptance. However, in the OEE metric, the computation of all the three categories is not separated and treated as not meeting up. Some reports classify them as scraps.

Mathematically, quality rate is defined as follows [16]:

Quality rate = (No of tyres manufactured – No of good (acceptable) tyres)/(No of tyres manufactured) (2)

In the tyre manufacturing process, the operations of the equipment involve yields and losses obtainable from the material inputs. Losses are to be minimised or eliminated as the central objective of an OEE programme. Losses are obtained from the subtraction of yields from the materials used as inputs. They are the number of materials the process utilises to produce the output to offer for the corresponding losses for the planned period. The main question answered by the quality rate is how many of the tyre products meet the given specifications by the quality department? Quality rate associates the number of tyres produced with tyres produces, which agrees with the standard set by the company.

3.4.3 Performance Ratio

The mathematical expression for performance is as follows (Equation 3) [16]:

Performance = (Standard Cycle Time × Aggregate Tally) / Run Time (3)

Performance relates to the proportion of the net run time to the run time of the tyre processing equipment [16]. In mathematical terms, performance is defined as the product of the standard cycle time and aggregate tally divided by the run time. The standard cycle time is the best cycle time that the tyre manufacturing process can attain an optimal situation. Cycle time is the time it takes the production of the crew to work on producing a unit of the tyre in the process. This commences from when the raw materials are mixed up to the time the produced tyre is prepared for shipment. It may be summarised as the time taken to complete the production of a unit of tyre products. Another name for the cycle time is the throughput time. It involves time for all the production processes to produce a unit of the tyre.

The use of the term cycle time depends on the interest of the investigator. Instead of considering the whole tyre as a product, the investigator may define the cycle time to finish certain processes therein. For instance, one may ask what is used to make the tyre. The makeup of the tyre's body is a calendared sheet that may be separated into a stratum of rubber, a stratum of fortifying fabric and another stratum of rubber. The investigator may be interested only in the cycle time for the first stratum of rubber or the second stratum of rubber instead of the whole process, consisting of calendaring, bead making, tyre building and vulcanizing. The cycle time is often measured with a stopwatch.

A related technical name to the cycle time is the takt time, which describes the time between the commencement of work one a unit of the tyre and the real-time of commencing on the production of another one. The next important term is the most run time. The real-time taken by a task in the tyre production process to be completed in its totality is called the run or running time. It could be a function of other parameters in the system. For instance, if the tyre equipment considered processes only a product at a time or two/multiple products are produced. It may also be a factor in the age of the equipment in the plant. Earlier models of tyre equipment are manual-based with significant running time. However, with a trade-off concerning the cost and output of equipment, newer versions produce multiple outputs with less running time per unit. Another factor that dictates the running time is the speed the equipment operates with. Furthermore, the arrangement (physical) of the machine also dictates the running time; if outputs are delivered without disrupting the next output the running time will be low. Otherwise, it will be high. Another factor is the type of tyre inputs (i.e. the size of materials) that is fed into the equipment.

In summary, the performance parameter of the OEE answers the question of how fast the equipment is running [30, 31, 38]. The performance rate considers the theoretical output. This refers to the equipment's output that may have been produced if had operated with the maximum speed of operation. In reality, the actual output is less. Consider equipment in a group being slowed down when other equipment is stopped because of a near-miss situation. The equipment is slowed down to accommodate the build-up of products to a controllable level. This will affect the actual output obtained for the whole process at the end of the eight hours of work.

3.5 Data Extraction from [8]

An earlier study on the optimisation of OEE in a tyre plant in India is credited to [8]. The data from the work is used to validate the current model proposed on the RSM (Fig. 1). Table 1 of the paper, which details the availability, performance, quality and OEE data, forms the foundation of the analysis of the present paper. In the work, five processes in the tyre manufacturing plant were analysed in terms of the OEE outcome and input parameters and a genetic algorithm was used to optimize these process parameters. Furthermore, some essential descriptive statistics of the analysed data, extracted from [8] are described as follows. The size of the tyre studied is 3.5 in x 10 in while its weight is roughly 3.65 kg. The scrap is roughly 0.06kg. For the production figures, the value is often limited to 8,000 units for the 3.5 in x 10 in. However, for all the sizes of tyre produced by the plant, the production figure is roughly 25,000 units. To further understand the industry, we mention the materials used are inputs as a compound having 85%. This is made up of 50% rubber, 5% chemical, 35% carbon and 10% oil. Apart from the compound, 10% fabric is involved and the remaining 5% is the beading wire [8].

3.6 Decision to Use the Central Composite Design

There are many variants of the RSM and each variant may apply to the specific data considered. From a search of the literature, several advantages were attributed to the different variants of the RSM. However, by comparing these advantages and the nature of data used in this work, the central composite design was found as the best model variant for this particular study and hence adopted to optimise the tyre plant OEE optimisation problem.

3.7 Experimental Trials for Optimal Value Determination

Based on the knowledge from a literature search on the application of RSM to engineering problems, twenty experimental trials were made based on data from [8]. The trials are distinguished by run orders. Run 20 was taken as the optimum run and the values of the parameters availability, quality rate and performance rate noted.

3.8 Regression Model

The software is used, Minitab 16 offered to opportunity to linking up the experimental design with the development of a regression equation. The regression menu of the Minitab 16 revealed a regression equation of the maximum power of 2 for some terms. This is the representative equation with which further tests may be conducted to determine whether all the terms are significant or not.

3.9 Adoption of ANOVA Test Principles

The analysis of variance, ANOVA is a test conducted on the data to establish which of the terms relating to the tyre manufacturing plant are significant and which are otherwise. The level of significance was fixed at 5% while the significant p is of interest. The hypothesis formulated is of two types: The null hypothesis and the alternative hypothesis. It was hypothesised that the terms representing the OEE metric in the regression model are significant (null hypothesis). The alternative hypothesis is that the terms are not significant. It is observed that if the significant p is less than 0.05, the term(s) is/are regarded as significant. Otherwise, the term(s) is/are regarded as insignificant.

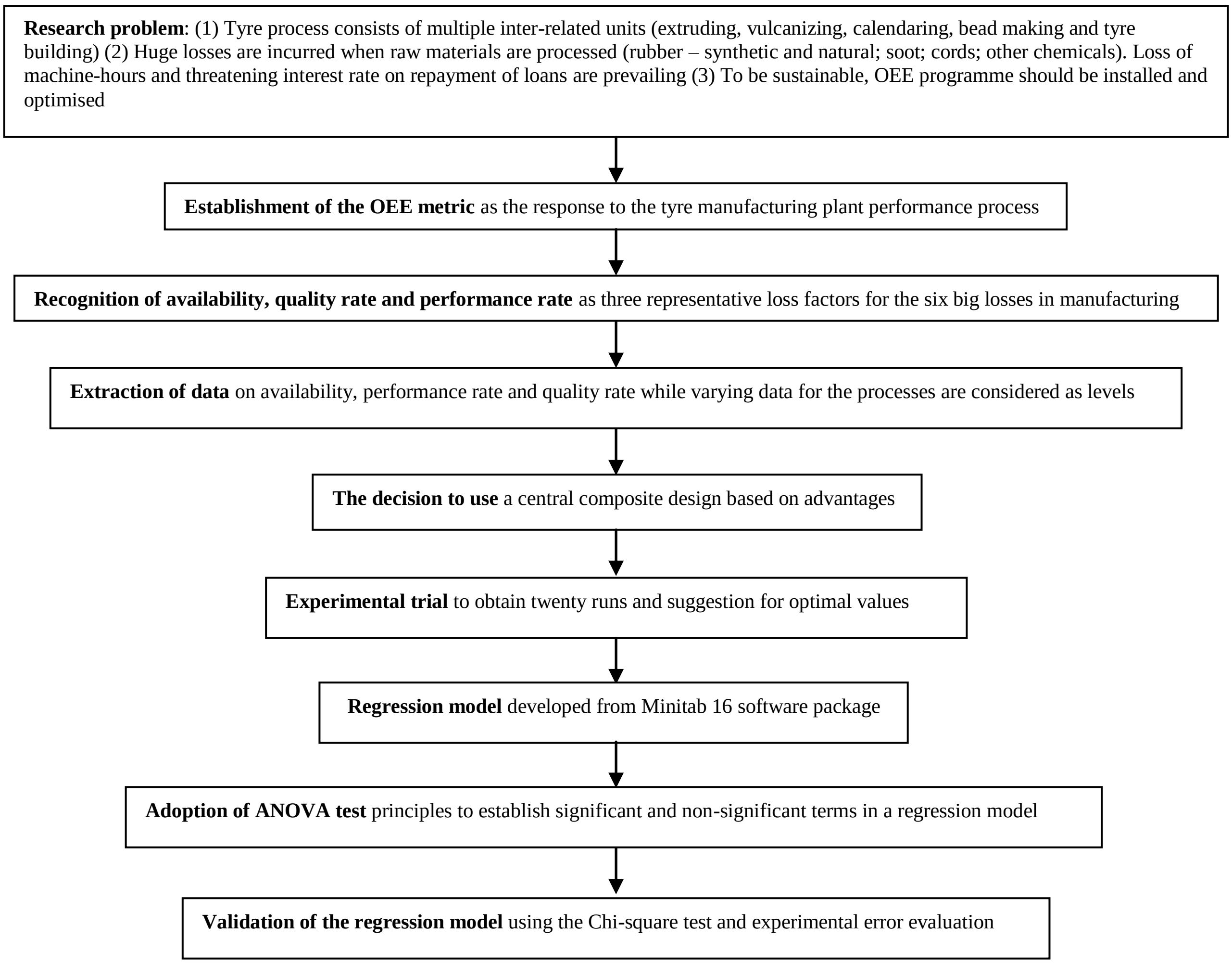


Fig. 1 Methodology to implement the central composite design of RSM for tyre plant's OEE optimisation

3.10 Validation of Regression Model using Experimental Error Values

It should be noted that the regression model provides a predictive model with which actual values can be compared. The original data Table 1 of Vivekprabhu et al. [8] was referred to and values of each of the parameters for each serial number were substituted into the revised regression model for the computation of the predicted values of the RSM. The revised RSM is the new equation obtained after removing the non-significant terms. Now that predictions are obtained, the difference between the actual and experimental values offered in [8] is noted and referred to as the error. The average of this represents the predictive error for the RSM.

3.11 Grey Relational Analysis

The idea of grey relational analysis, developed from a larger idea of grey system theory (GST), began with the famous Chinese Professor Julong Deng that held a faculty position at the Huazhong University of Science and Technology. The GST also branched from the system theory that became very popular in the 1980s [44]. The origin of systems theory research in modern times may be linked to the perception of Aristotle, a philosopher in ancient Greek. This towering figure declared that knowledge is acquired from a deep insight into the whole instead of analysis of individual components [46, 47].

Consequently, systems theory and its offshoot were defined. Within the family of grey system theory, the GRA is perhaps the most extensively applied member in research and practice throughout the world. The GST works on the notion of a random process, as a grey quantity variable within a defined space, with a specific amplitude and time zone [44]. Either considering the GST or GRA, the term grey carries the idea of being uncertain, poor or incomplete [44]. So a system referred to as a "grey system" means that insufficient information is contained in it. Deng [48] argued that a system with entire information is best described as a "white" system. It is also possible to have a system whose information is entirely unclear. This negative unclear state is called a "black" system. In real situations, it is often experienced that no system may be white or black but in between these two extremes, thus, they are referred to as grey systems [44].

The popularity gained by the GRA is its usefulness to monitor the correlations that are present among the factors that influence a system. Considering the benefit side, GRA permits the quantitative and qualitative union to be recognised from separate factors that possess incomplete or insufficient information [44]. The GRA discussed in the following mathematical terms is in a way of grey system theory to probe discrete data series [44, 48, 49]. Concerning [49], the procedure that accounts for GRA is discussed herein steps [44]:

- Introduce the reference data series x_0.
  $$x_0 = p_{01}, p_{02}, \ldots, p_{0q}) \quad (4)$$

; where q may be regarded as the number of respondents. The x_0 reference data series contains q values that reveal the responses having superior outputs.

- Introduces the comparison data series x_e.
  $$x_e = p_{e1}, p_{e2}, \ldots, p_{eq}) \quad (5)$$

; where $e = 1, \ldots, t$ may be regarded as the number of scale elements. It then shows that t comparison data series occurs and each comparison data series shows q values.

- Evaluate the difference data series Δ_e,
  $$\Delta_e = (|p_{01}-p_{e1}|, |p_{02}-p_{e2}|, \ldots, |p_{0q}-p_{eq}|) \quad (6)$$

- Compute the global maximum value $\Delta_{\max}$ and minimum value $\Delta_{\min}$ in the difference data series.
  $$\Delta_{\max} = \max_{\forall e}(\max \Delta_e) \quad (7)$$
  $$\Delta_{\min} = \min_{\forall e}(\min \Delta_e) \quad (8)$$

- Modify each data point in each difference data series to grey relational quantity. If $\gamma_e(f)$ be the grey relational quantity of the f^{th} data point in the e^{th} difference data series, then,
  $$\gamma_e(f) = \frac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_e(f) + \xi\Delta_{\max}} \quad (9)$$

  where $\Delta_e(f)$ signifies the e^{th} value in the Δ_e difference data series. ξ signifies a value between 0 and 1. The quantity ξ is applied to compensate for the impact of $\Delta_{\max}$ if $\Delta_{\max}$ is an excessive quantity in the data series. The quantity of ξ can be put at 0.5.

- Evaluate grey relational grade for each difference data series. If Γ_e signifies the grey relational grade for the e^{th} scale element and suppose that data points in the series are similar in weights, then,
  $$\Gamma_e = \frac{1}{q}\sum_{r=1}^{q}\gamma_e(r) \quad (10)$$

  Equation (10) reveals Γ_e which is an indicator of the ground level of standardised deviance for the e^{th} original data series from the reference data series. An element showing a scale of high values Γ reveals that the respondents completely approve it to an elevated level on particular elements.

- Sequence the Γ values calculated such that they ascend or descend to aid reasonable implications for management decisions.

- Calculate the maximum grade for grey relations, Γ_{tr}, using the mean of all the entries. The expression to attain this is in Equation (11),

$$\Gamma_{tr} = \frac{1}{t}\sum_{e=1}^{t}\Gamma_e \quad (11)$$

This value reveals a level upon which an item having a grade not less than it is declared as "crucial".

Furthermore, this research modelled the OEE metric optimisation problem as a grey relational problem where limited information is available but a dependable selection of the best parameter is needed. Also, the optimised values of the OEE parameters are desired. The GRA attains success to search for the best parameter by first establishing normalisation of the parameters to bring analysis to a fair judgement. This stage is referred to as the normalisation/data pre-processing phase. The stage that follows is to establish the grey relational coefficient and the development of the grey relational grade. These are the stages to establish ranks for the parameters. However, to establish the optimal parameter setting using the grey relational method, further analysis to ascertain the response table, response graph and analysis of valance is made in optimising the OEE metric for the tyre manufacturing plant.

The optimal values of A for availability, B for performance ratio, and C for quality rate are obtained. Consequently, it is ascertained that the GRA impacts positively on the OEE optimisation of the tyre production process [44]. The superiority of the GRA to the existing genetic algorithm and linear/non-linear model in the evaluation of tyre plant OEE metric optimisation is that little information about the tyre plant is transformed into a substantial solution to help reduce the losses in the tyre plant.

4. Results and Discussion

According to [8], tyre process optimisation is an area of concern in a process plant. Optimising promotes judicious resource utilisation and effectiveness of the type plant in the process plant; inappropriate skills of workers, poor training and the use of inexperienced workforce may lead to wastage of time and resource. This has an impact on the overall profit of the organisation. However, the result of this study has the potential to be employed to increase the consciousness of tyre plant workers. It could potentially offer information to tyre plants, many of which embark on OEE prefects to install the programme with optimisation as the central focus. In so doing, tyre plants that are exceeding wasteful in resource management could potentially avoid waste and become sustainable.

Moreover, this study may offer tyre plants the information that potentially can be used to tackle labour disparities between the trade unions and the management of the plant. The trade union has a history of frequent agitations on productivity gains incentives. However, it respects scientific intervention in the settlement of disputes. So, the robust optimisation made offered here could serve as a yardstick and benchmark on performance measurement and reward system for the tyre production workers.

4.1 Response Surface Analysis

By using Minitab 16 Software, the following regression equation was obtained, Equation (12).

Regression Equation in Uncoded Units

$$OEE = 0.59 - 0.6501\,AV - 0.9035\,PR - 0.59\,QR + 0.00000\,AV^2 - 0.000000\,PR^2 + 0.00\,QR^2 + 0.994000\,AV(PR) + 0.6540\,AV(QR) + 0.9090\,PR(QR) \quad (12)$$

Furthermore, ANOVA was run to know the significant and non-significant terms that contribute to the model development. The results revealed two sets of values, with certain model components assuming a value of 0 and others, 1. From the interpretation, all the values obtained at 0 for significant p reveals the significance of terms whereas those with values more than 0.05, and in this case, 1, were deemed to be non-significant and removed from the regression equation. Thus, the revised regression equation (13) was obtained.

Regression Equation in Uncoded Units

$$OEE = 0.59 - 0.6501\,AV - 0.9035\,PR - 0.59\,QR + 0.994000\,AV(PR) + 0.6540\,AV(QR) + 0.9090\,PR(QR) \quad (13)$$

Equation (13) is the predictive model valid to evaluate the OEE of the tyre plant. The values of availability, performance rate and quality rate were substituted into Equation (13) and the OEE is optimised. Thus, given the factors, levels need to be developed. The OEE quadratic model has a power of two and the literature recommends three levels for it.

It interested the authors of this article to know the percentage of precision of the regression model, which was used in the paper. To know this, Equation (13) was used and the data representing the OEE metric from the field results was substituted into the regression Equation (13) while the errors for each of the processes were evaluated. In all, five substitutions were made and the include those for extrusion, calendaring, bead making, tyre building and vulcanizing, respectively. To explain the procedure adopted, consider the extruding process whose availability, performance ratio and quality rate data are 0.857, 0.894 and 0.992, respectively, from the field data. This yielded an OEE of 0.76356 against what was recorded from the field data calculations as 0.76003. The error is 0.353%, which is showing an accuracy of 99.647%. By following this procedure, the errors between the field data and the prediction by the regression model for calendaring, bead making, tyre building and vulcanizing are 0.355%, 0.354%, 0.355% and 0.357%, respectively. On the average, the regression model shows an error of 0.355%, which is good performance for the regression model.

In this study, the central composite design-oriented responses surface is considered to design the experiments. It achieved success by searching for optimum OEE situation and analyse the influence of tyre manufacturing process parameters, primarily availability, performance ratio and quality ratio on the effectiveness yield results. The regression equation that accompanies the RSM to optimise the OEE for the tyre manufacturing plant was produced using the experimental results of 20 experiments. The utmost OEE metric of 59.09% was obtained as the optimal solution of availability of 90.90%, the performance ratio of 65.40% and the quality rate of 99.40%. Consequently, it is established that the response surface model impacts positively on the OEE optimisation of the tyre production process. The response surface approach is superior to the traditional method of computing the OEE of the tyre plant that uses a product analysis of the OEE component parameters. The traditional method to compute the OEE metric from the experimental data yields 47.74%, a value less than our optimal value by 11.69%; optimal values, therefore, showcases superiority over the traditional method of OEE metric computation.

Process	Availability	Performance ratio	Quality ratio
Extruding	0.857	0.894	0.992
Calendering	0.854	0.428	0.993*
Bead making	0.844	0.427	0.994**
Tyre building	0.974	0.508	0.995***
Vulcanizing	0.971	0.414	0.996****

Note: *,**,***,****Data used here has an increment of 0.001, 0.002, 0.003, and 0.004 for each of the original values displayed in [8] to be suitable for illustration of the methodology proposed in this work

Table 1 Data on availability, performance ratio and quality ratio [8]

After completing the central composite method of the response surface, the following summary Table 2 was obtained from the RSM analysis using MINITAB software

StdOrder	RunOrder	PtType	Blocks	Availability	Performance Ratio	Quality Ratio
19	1	0	2	0.909	0.654	0.994
20	2	0	2	0.909*	0.654*	0.994*
16	3	-1	2	0.909	1.000	0.994
18	4	-1	2	0.909	0.654	0.997
13	5	-1	2	0.803	0.654	0.994
14	6	-1	2	1.000	0.654	0.994
17	7	-1	2	0.909	0.654	0.991
15	8	-1	2	0.909	0.262	0.994
6	9	1	1	0.974	0.414	0.996
10	10	0	1	0.909	0.654	0.994
5	11	1	1	0.844	0.414	0.996
4	12	1	1	0.974	0.894	0.992
11	13	0	1	0.909	0.654	0.994
3	14	1	1	0.844	0.894	0.992
7	15	1	1	0.844	0.894	0.996
9	16	0	1	0.909	0.654	0.994
8	17	1	1	0.974	0.894	0.996
12	18	0	1	0.909	0.654	0.994
2	19	1	1	0.974	0.414	0.992
1	20	1	1	0.844	0.414	0.992

* Optimal values of parameters

Table 2 Experimental trials by the central composite method of response surface method

The following Design Table 3 is also provided by the software. Tables 4 and 5 representing the two-level factorial: Full factorial point types and design table (randomised), respectively also relates to the tyre plant analysis.

Factors:	3	Replicates:	1
Base runs:	20	Total runs:	20
Base blocks:	2	Total blocks:	2

$\alpha = 1.633$

Table 3 Central composite design summary

Cube points:	8
Center points in a cube:	4
Axial points:	6
Center points in axial:	2

Table 4 Two-level factorial: Full factorial point types

Run	Blk	A	B	C
1	2	0.000	0.000	0.000
2	2	0.000	0.000	0.000
3	2	0.000	1.633	0.000
4	2	0.000	0.000	1.633
5	2	-1.633	0.000	0.000
6	2	1.633	0.000	0.000
7	2	0.000	0.000	-1.633
8	2	0.000	-1.633	0.000
9	1	1.000	-1.000	1.000
10	1	0.000	0.000	0.000
11	1	-1.000	-1.000	1.000
12	1	1.000	1.000	-1.000
13	1	0.000	0.000	0.000
14	1	-1.000	1.000	-1.000
15	1	-1.000	1.000	1.000
16	1	0.000	0.000	0.000
17	1	1.000	1.000	1.000
18	1	0.000	0.000	0.000
19	1	1.000	-1.000	-1.000
20	1	-1.000	-1.000	-1.000

Table 5 Design table (randomised)

Analysing the response surface design produces the following data (Table 6) while the Coded Coefficients are shown in Table 7.

Source	DF	Adj SS	Adj MS	F-Value	p-Value
Model	9	0.652744	0.072527	93132522.58	0.000
Linear	3	0.650819	0.216940	2.78574E+08	0.000
Availability	1	0.023806	0.023806	30570039.17	0.000
Performance Ratio	1	0.626994	0.626994	8.05126E+08	0.000
Quality Ratio	1	0.000019	0.000019	24203.84	0.000
Square	3	0.000000	0.000000	0.00	1.000
Availability*Availability	1	0.000000	0.000000	0.00	1.000
Performance Ratio*Performance Ratio	1	0.000000	0.000000	0.00	1.000
Quality Ratio*Quality Ratio	1	0.000000	0.000000	0.00	1.000
2-Way Interaction	3	0.001925	0.000642	824039.98	0.000
Availability*Performance Ratio	1	0.001924	0.001924	2470090.00	0.000
Availability*Quality Ratio	1	0.000000	0.000000	74.26	0.000
Performance Ratio*Quality Ratio	1	0.000002	0.000002	1955.69	0.000
Error	10	0.000000	0.000000		
Lack-of-Fit	5	0.000000	0.000000	*	*
Pure Error	5	0.000000	0.000000		
Total	19	0.652744			

Table 6 Analysis of variance on the response surface regression

The model summary is S = 0.0000279, R-sq = R-sq(adj) = R-sq(pred) = 100.00%,

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.590919	0.000011	52069.17	0.000	
AV	0.069002	0.000012	5529.02	0.000	1.00
PR	0.354118	0.000012	28374.75	0.000	1.00
QR	0.001942	0.000012	155.58	0.000	1.00
AV*AV	-0.000000	0.000020	-0.00	1.000	1.01
PR*PR	0.000000	0.000020	0.00	1.000	1.01
QR*QR	-0.000000	0.000020	-0.00	1.000	1.01
AV*PR	0.041351	0.000026	1571.65	0.000	1.00
AV*QR	0.000227	0.000026	8.62	0.000	1.00
PR*QR	0.001164	0.000026	44.22	0.000	1.00

Key: Availability – AV; Performance Ratio – PR; Quality Ratio – QR

Table 7 Coded Coefficients

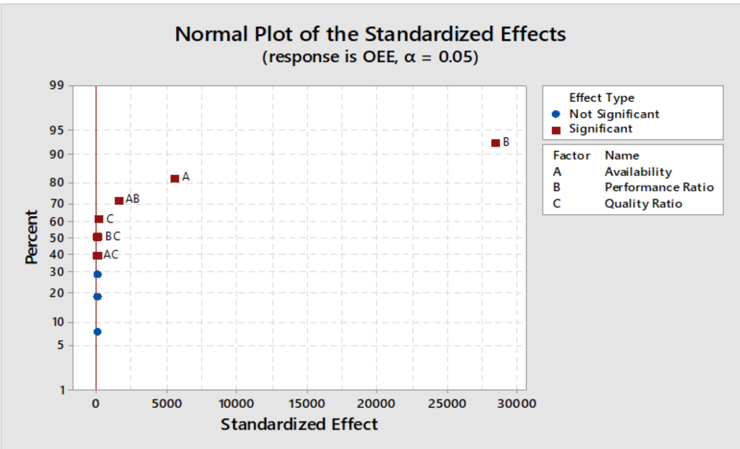
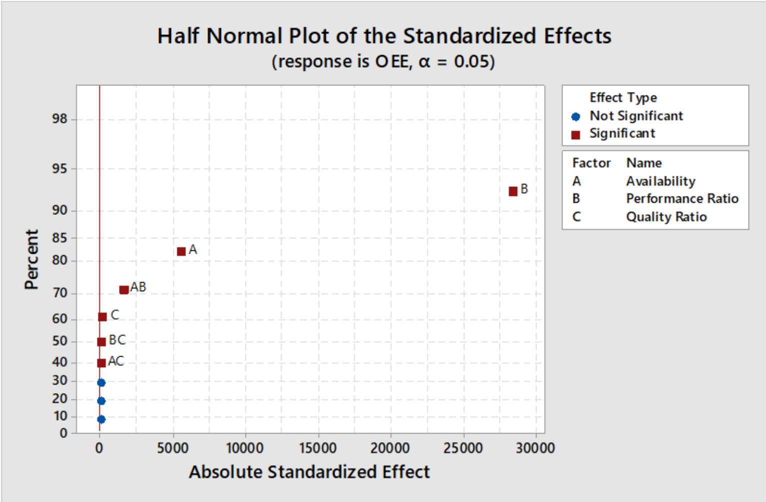
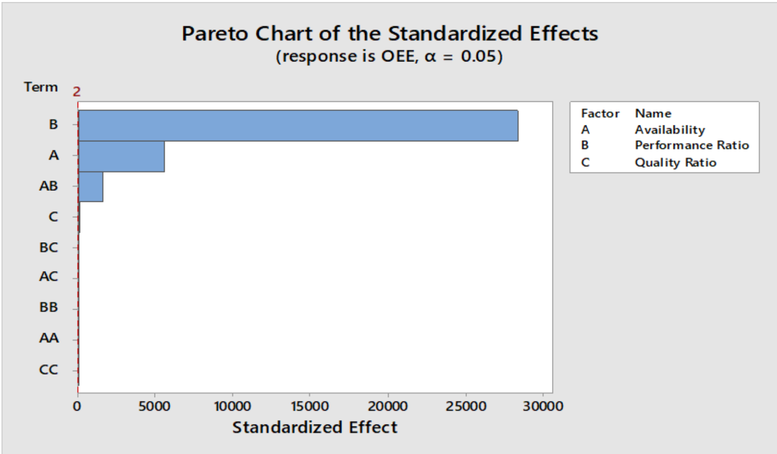


Fig. 2 Half normal plot for the OEE parameters

Fig. 2 is the half-normal plot for the OEE parameters, which applies a pre-arranged predictable influence to assist in appraising the parameters of the OEE that are important distinguished from those that are not important. The figure shows that factor A, AB, C, BC and AC are significant. However, other terms are not significant at 10, 20 and 30%.





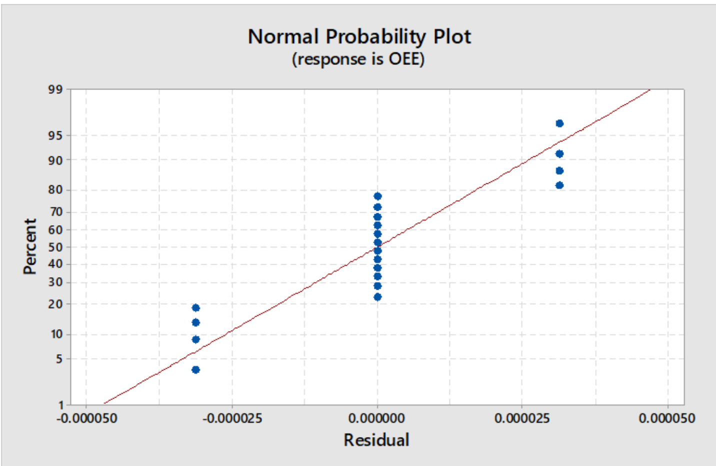


Fig. 3 Normal probability plot for the OEE parameters

In the instance shown in Fig. 3, a plot of the Z score is made against the tyre plant's data set. Although for some data characteristics where a straight line occurs, it may be interpreted that the tyre plant's data fits a normal probability distribution, in our specific case that the line is skewed, the data is not normal, interpreted as the inability of the data to fit a bell curve.

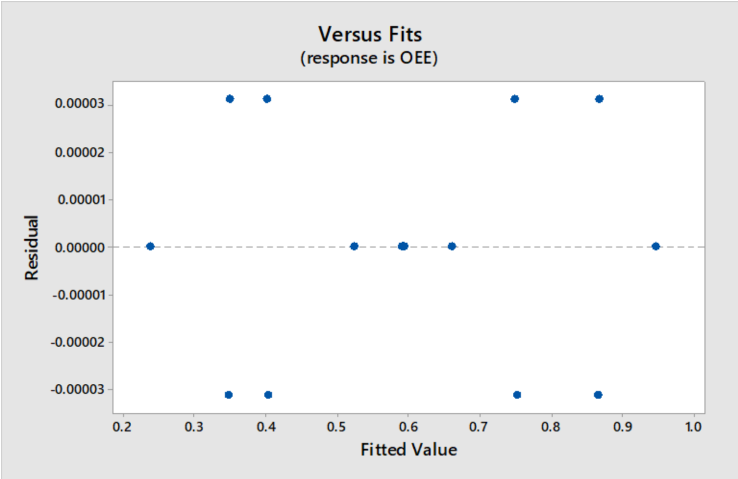


Fig. 4 Residual vs fitted values

In carrying out an analysis based on residual, it is very common to see residuals being plotted against fits plots. This represents a scatter plot containing residual along the y axis while the x axis always carry the fitted values which are sometimes called the projected responses. The usefulness of the plots is to find out non-linearity, outliers and unequal errors in variance. Regarding our data (Fig. 4), there are exhibits of non-linearity therein.

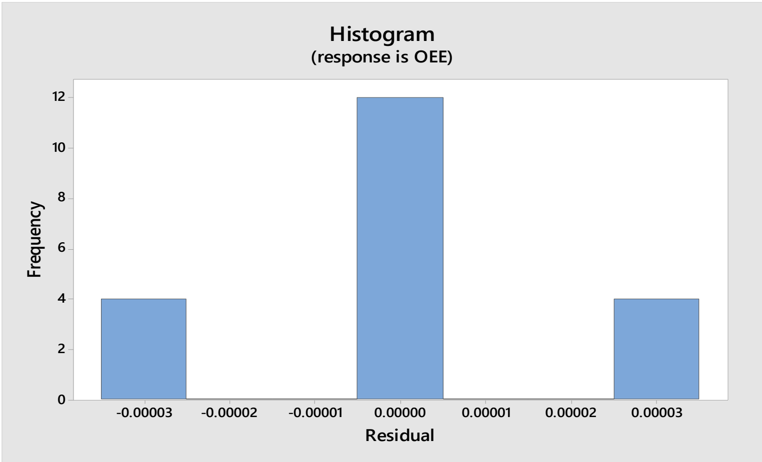


Fig. 5 Histogram for the OEE parameters

In Fig. 5, the y axis of the histogram shows the frequency of the OEE response against residual. When the residual is zero, the value of the histogram is the highest, indicating good results.

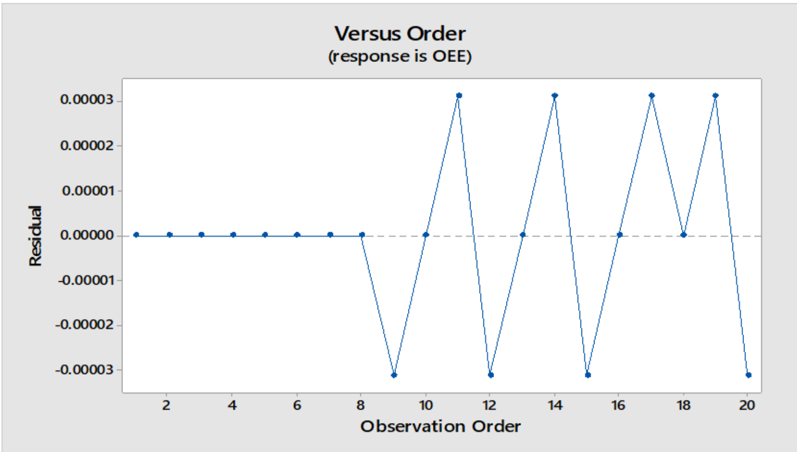


Fig. 6 Observation order vs residual for the OEE parameters

Fig. 6 shows a plot of observation order against residual for the OEE parameters. In this plot, the positive residuals seem to appear at the inner bands of the |X| values, as declared in [50]. Similarly, also, the outer bands majorly comprise negative residuals. Though by removing the residuals the statistical parameters such as R^2 may be enhanced, nonetheless, the real-world representation of the tyre production plant OEE attributes would be lost. We, therefore, conclude similarly to [50] that the results may be judged as satisfactory since it exhibits little deviation from the normality and hence acceptable.

OEE(Pred)	OEE(Act)	Error
0.708629	0.76024	6.788841
0.050939	0.36238	85.94321
0.048795	0.3578	86.36259
0.185655	0.49093	62.18301
0.034371	0.39883	91.38212

Table 8 Predicted and actual OEE values

Table 8 is obtained, which shows the predicted values, actual values and errors in prediction. In this paper, the experience contained in a research endeavour to use RSM to increase the availability of a tyre manufacturing plant in India, and concurrently enhancing the performance rate and the quality rate of tyre manufactured products is shared. By using the RSM, the experimental design aspect of the RSM interacted with the regression analysis method to produce a reliable model of optimisation for the tyre manufacturing plant. A regression model was developed using the Minitab 16 software that receives the input data of the overall equipment maintenance parameters with details of the levels for each of the parameters. Through the ANOVA method, which is a tool for experiments design, it was possible to obtain significant and non-significant parameters in the regression equation generated by Minitab software. The level of significance was fixed at 0505 (significant *p*). While some terms from the ANOVA computations were lower than 0.05, others, including AV2, PR2, QR2 were noted to be above o.05, and hence proved insignificant and removed from the regression equation. For the RSM, [9] argued that it is used to establish the association between at least one variable and a group of parameters (i.e. availability, performance rate and quality rate) that are conceived to affect the responses (i.e. the OEE). The authors further elaborated that the first phase of RSM development was to understand its components, notably the sequential progress, mapping the experimental details to the complication involved in developing the regression model. Furthermore, a quick advancement to the extremely interesting aspect of the factor space is made as to the next step. In this work, the RSM has been explored in the context of OEE optimisation for a tyre plant in India and used to search for optimal parametric setting for the parameters to attain particular values of the OEE response, for instance, the largest value. By exploiting the RSM the performance of each parameter is analysed to characterise the OEE and to design an effective maintenance policy to enhance the effectiveness of the plant. The results reveal an estimate of the OEE for the tyre pant to plan in the next budgetary period. With the information obtained from the OEE optimised values, the understanding of the process engineer concerning the tyre plant is deepened.

The idea of the OEE metric evaluated is the best practice in the industry. Vivekprabhu et al. [8] declared OEE as a fundamental metric to help in the attainment of world-class performance and the competence of OEE in attaining world-class achievements is well discarded. Research also promotes the development of new insights from old principles for enhanced best practices. This innovative way of optimising the OEE through the RSM is unique and promises to expand the knowledge domain on OEE and practices toward reducing or eliminating the six big losses of manufacturing. The findings from this study will lead to some important changes in the way the OEE metric is evaluated. It will then change the perception of both the process engineer and the workers concerned with implementing the OEE programme in the type of manufacturing plant.

Furthermore, existing knowledge on the OEE metric regarding the tyre manufacturing process is limited but needs an extension. A wider scope of OEE metric knowledge is a path to be more operationally efficient for the tyre plant, which is expanding because of increased vehicular demand. At present, knowledge of optimisation of OEE is restricted to the use of genetic algorithm [8] and linear/non-linear models. The innovative use of RSM on OEE metric evaluation, to optimise parameters, including availability, quality rate and performance ratio will substantially revise the present knowledge on OEE metric optimisation. The revision will potentially create opportunities for process engineers to prepare more robust budgets based on the predicted values of OEE parameters for the next budgets implementation period.

In developing countries, tyre manufacturing plants producing tyres are encountering obstacles in achieving efficient manufacturing equipment and material wastage is lingering. This hinders the progress of the plant in expansion plans and customer patronage is declining. Research has at present been conducted on the installation of OEE in tyre manufacturing in a developing country, India and data are in the public domain on the OEE metric of the plant. However, further studies are needed to improve the results. Hence, the objective of this article is to use the RSM as optimisation and predictive tool for operations of the tyre plant.

The optimal setting for the optimised parameter of the OEE metric could be determined from the response table obtained, which consists of three parameters and five levels. The optimal parametric level for the availability parameter, AV, is AV_n. This is obtained at level n and the value obtained at level n and the value is N. Correspondingly, the optimal level for the performance ratio, PR is PR_n. This is achieved at level n and the values are N, furthermore, the optimal level for the quality rate is QR_n and the Value is achieved at level n. By considering all the parameters, the optimal setting is defined as $AV_n\ PR_N\ QR_n$.

4.2 Grey Relational Analysis Results

The GRA was conducted on the experimental data in [8] (i.e. Table of the paper) using the three steps as follows. The first step is to normalise the parameters (Table 9).

	OEE parameters		
Experimental trial	AV	PR	QR
1	0.0250	1	0
2	0	0.0292	0.2500
3	-0.0833	0.0271	0.5000
4	1	0.1958	0.7500
5	0.975	0	1

Table 9 Normalised values of OEE parameters for tyre production process loss minimisation

It was noticed that the three parameters have various unit and a direct comparison is difficult as the researcher will not understand the relative performance of the parameters. So, normalisation of the parameters to a scale ranging between 0 and 1 was adopted according to literature guidance. For the availability measure, experimental trial 3 has the least (-0.08333). However, if we are to disregard the negative sign the experimental trial 2 becomes the least with a zero value while experimental trial 4 has the highest value of 1. For the performance ratio, the least value (experimental trial 5), which yielded and the highest value (experimental trial 1) that gives 1 were obtained. The quality rate provided the least value (experimental trial 1) to be 0 and the highest value (experimental trial 5) to be 1. All other experimental trials outside the mentioned boundaries fall within zero and one apart from the one earlier mentioned. The second step to actualize GRA was to complete the coefficients for the GRA (Table 10).

	Coefficients	Weights				
Experimental trial	AV	PR	QR	AV	PR	QR
1	0.0623	4.5283	0.0020	0.0136	0.9860	0.0005
2	0.0656	0.3466	0.0007	0.1590	0.8394	0.0016
3	0.0756	0.3481	-0.0020	0.1792	0.8256	0.0048
4	4.6154	0.1960	-0.0102	0.9613	0.0408	0.0021
5	46.2000	0.3670	1	0.9713	0.0077	0.0210

Table 10 Coefficients and weights of a grey relational model

The result for availability coefficients ranges between 0.062 and 46.2 with the experimental trial 1 having the least while experimental trial 5 has the highest. The performance ratio range is from 0.196 to 4.528 with experimental trial 4 revealing the least and experimental trial 1 showing the highest values. For the quality rate, the coefficients range from -0.002 to 1 with experimental trials 3 and 5 holding the least and highest values of the coefficients, respectively. The next stage is the computation of the grey relational grade. The outcome reveals the parameter named availability as the highest with a value of $\gamma_1 = 49.33$ while the parameter performance ratio has $\gamma_2 = 5.05$ as the next in the rank and quality ratio has $\gamma_3 = 0.02$ as the least in the rank. The response table is in Table 11.

	OEE parameters		
Level	AV	PR	QR
1	0.0136	0.9860*	0.0005
2	0.1590	0.8394	0.0016
3	0.1792	0.8256	0.0048
4	0.9613	0.0408	0.0021
5	0.9713*	0.0077	0.0210*
Delta	0.9577	0.8317	0.0205
Rank	1	2	3

*optimal values

Table 11 Response table for OEE parameters

4.3 Comparison of OEE with Literature Values

As the OEE promotes benchmarking, it was decided that the values obtained in this work should be compared with those in [51]. The case study by the author dealt with automotive components, and precisely the production of brake systems and turbochargers and this makes the comparison with work on tyre manufacturing relevant. The OEE was obtained as 74% while for the current paper, a value of 59.09% was reported. Our system seems to perform slightly worse than the case study compared by 14.91%. However, compared to the world class value of OEE, the two values appear less and below standard. An effort to enhance the OEE further needs to be intensified. However, compared to the world-class value of OEE, the two values appear less and below standard. An effort to enhance the OEE further needs to be intensified. In [51], the stated sources of losses to address for correction of availability's low values are planned maintenance, shutdown and large failure. The suggestion here is that more time should be devoted to planned maintenance. All these factors may need to be checked by the process engineer.

4.4 Novelty and the Advantages of this work

The key objective of this article is to optimise the parameters of the OEE performance scheme in a tyre manufacturing plant using RSM. Although a few researchers have studied the OEE of manufacturing plants, very few scholars have reported on its optimisation. But optimisation is a critical idea in the planning; implementation and control of an OEE programme in a tyre plant. The tyre plant process becomes more efficient and the assessment of OEE and losses at instants is done with greater clarity. Besides, the OEE metric is easier to enhance and increase with optimisation. Reducing the six big losses in manufacturing is regarded as a pillar of OEE and loss reduction will be helpful to the tyre plant in a drive to enhanced plant performance. If results are not optimal then they are sub-optimal. So working at sub-optimal levels encourages losses and incapable of adequately tracking all the losses available in the system. Yet is known that incompetence of the system to properly track and control the six big losses of manufacturing threatens the existence of the plant, sustainable manufacturing is possible only if the process engineer is accountable for the losses and brings them under control. Unfortunately available models, particularly the linear and non-linear algorithms which prevail in the OEE literature are not competent to control losses. In a tyre manufacturing plant, OEE is a measure, which is used to control losses regarding natural and synthetic rubber, among others. It was found that the six big losses of a tyre manufacturing process can be compressed to three, including availability, performance rate and quality rate. In [8], it was asserted in an optimisation model using a genetic algorithm that optimisation is essential to enhance the performance of the tyre plant. The data generated by the authors are extremely valuable in a modification effort to the tyre plant.

The RSM used in this work has the potential to be an influential instrument for determining the performance concerns and enhancing maintenance outcomes in a tyre manufacturing plant. The advantages of using the RSM to tackle the performance optimisation problem when implementing the OEE programme, as opposed to non-linear/linear models and genetic algorithms, which prevails in the OEE literature are stated as follows. Firstly, it has a mathematical advantage since as the parameters are measured they can be improved. Secondly, the RSM offers the process engineer in the tyre plant the benefit of the economy in the data collection process, adaptability in experimental method and competence in managing detrimental fluctuations. According to [52], the RSM has additional advantages of being used to weigh designs against their level of rotatability. It was further argued by the author that RSM is helpful to build a design that meets up with particular attractive measure. Furthermore, the author [52] declared that RSM is helpful to amend rotatability by appending an adequately selected experimental run for a particular design. Furthermore, the GRA has the potential to transform the OEE performance with its benefit of the capability to appraise quantitative and qualitative associations between the parameters of the OEE by employing a comparatively small quantity of tyre production data.

4.5 Practical Implications

Tyre manufacturing today has rapidly expanded in advanced technologies such that manually controlled operations in the past years are replaced with at least semi-automated systems if the cost of full automation is prohibitive. These systems have in-built monitoring and corrective test equipment. In many plants, total replacements of equipment with the most updated systems are unattainable because of cost issues. Thus, the requirement to maintain old equipment and the new equipment acquired in a simultaneous mode requires the process engineer to increase in knowledge more than previously experienced. Knowledge on how to optimise using the RSM and the GRA by the process engineer offers an important contribution to practice in the use of OEE metrics in tyre manufacturing.

Furthermore, in developing countries, tyre certification is mandatory and challenging. However, a solution option for the challenge of meeting up with the quality of tyre products demanded by regulatory bodies is the installation of the OEE programme in the plant. OEE programme is an extremely appealing option to reactivate the conscious utilisation of resources by the employees of a manufacturing plant. Though domiciled in maintenance, OEE principles may be envisioned for applications in other departments of the tyre plant, including supply chain, stores and production. Among others, the three essential factors that will dictate the sustenance of the plants are availability, performance ratio and quality ratio. Since a holistic measure assures global optimal solution instead of locally optimal solutions, the RSM and GRA were found to be effective tools to optimise these factors. Two optimisation processes for tyre manufacturing were developed. The superior operational situation was established for superior performance achievement regarding availability, performance ratio and quality ratio.

4.6 Social Contributions of the Study

Maintenance engineers in tyre factories have a political mandate from both the society of professional engineers and the council for the registration of engineers in their countries to maintain ethics while working in their plants to protect the environment as well as see to the wellbeing of both humans and non-humans in the environment. Thus, the quality rate component of the OEE metric has a social contribution that makes engineers responsible for their actions. Undeniably, the engineer who manages the technology of the tyre plant could carelessly, if not monitored by legislation, harm the environment in some ways. Heat, water, noise and air pollution can be triggered to affect the community if regular and effective control of the negative influence of the machines is not pursued. The tyre factory may contaminate the environment by blowing vapours of chemicals into the air as well as pollution from smoke-out rents. Our model, therefore, serves as a control tool to maintain and/or restore an environment that is not negatively affected by factory activities.

Furthermore, the health burden and cost through weak environmentally–conscious factory practices is disturbing to governments. The quality rate mechanism of our model, therefore, provides a social contribution by alerting professional bodies on their responsibilities to impose restrictions on their subjects, which are the companies registered with them. They are to advise governments on legislations. For example, with the adoption of the OEE metric, the society of engineers may detect a strong deviation of a tyre company from environmentally-conscious practices and may sanction such.

5. Conclusion

Optimisation of OEE factors in tyre plants is extremely necessary to obtain highly effective parametric information used to correctly and vigorously appraise the operational efficiency of plants. Presently, very scanty effective models are available to assess and optimise the OEE metric used to drive the tyre plant towards reducing or avoiding losses regarding labour, materials and machines in the plant. Consequently, in this research, the authors offered a novel approach to optimising the OEE metric using the RSM. The result revealed that the proposed approach could be used to optimise the OEE metric in a tyre plant and offers a useful guide to operating a tyre plant based on predicted parametric information.

Modelling work has been conducted using the life data of a tyre manufacturing plant obtained from [8]. Our study focused on the use of central composite design RSM to determine the maximum values for availability, performance ratio and quality ratio. A regression equation of the highest power of two was developed, which was later reduced to a power of one since the factors having the power of two appear not to be significant in the significant *p* test carried out using analysis of variance results. However, arising from the analysis and the results, the following conclusions are valid. The factors AV, PR, QR, AV(PR), AV(XR) and PR(QR) contribute significantly to maximize the OEE of the tyre manufacturing plant. This was observed from the predictive model of regression analysis which yielded values of $p < 0.05$ for the mentioned factors.

Furthermore, this study incorporates the development of RSM as a process model capable of optimising the factors that drive the six big losses of tyre manufacturing but compressed into three: availability, quality rate and performance rate. The tyre produced has the size and weight of 3.50 inches x 10 inches and 3.65 kg, respectively [8]. The regression equation obtained from the RSM was used as a tool that can predict the features of the plant regarding the optimization of the component parameters of the OEE and the OEE metric itself. The regression model was then used to appraise the tyre manufacturing process performance from its operational perspective. The results offered a directive on how to operate the tyre plant and reveal the utility of the response surface model as a process support instrument.

As the study was conducted, indications of the limitations of the study were clarified, which may be improved in future studies. It will be noted while id the idea of fuzzy theory be introduced into the work as several activities within the maintenance system is uncertain and imprecise, necessitating the adoption of relevant furry elements. The parameters of the model may be studied for sensitivity to know which of the three parameters of availability, performance ratio and quality ratio is the most sensitive to focus energy on the robust design of the model through a concentration of efforts on the identified parameters of the model.

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