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MODELLING OF DETENTION PERIOD OF COAL WAGON RAKES IN MEDIUM CAPACITY THERMAL POWER PLANTS

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Abstract

The function of any industrial unit largely depends on its material handling system. The material handling system of the unit primarily deals with receipt of raw materials from the source, in-house handling for their proper use and processing required, if any, delivery of the products to the distributors and the end users and carrying out bye products and waste materials/affluents to ecologically safer destination. The coal based thermal power plants, which lead production of effectively usable form and efficiently transmissible nature of energy for catering to the need of an industrial unit, its development as well as meeting the domestic requirements; indispensably depend on rakes of coal received and their unloading. In this paper a model has been evolved to correlate different parameters of material handling system pertaining to the coal based thermal power plant of medium capacity (i.e. 1000 MW) by making use of response surface methodology to analyze the haphazardly distributed and random nature of data.

Keywords:

period of detention;

interarrival time;

wagon rake;

response surface method; coefficient of determination; F-test;

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1. Introduction

Thermal power plants play a pivotal role as driving and guiding force to maintain a harmonious relationship among the e-trinity combination of energy, economy and environment required for economy boosting as well as environment safeguarding nature of industrial growth on one side and energy conservation and its quality upgrading on the other side. The production of useful form of energy in thermal power plants finds involvement of bulk material handling process in different stages like receipt of coal as raw materials from the different source stations, its in-plant handling for processing and use and handling of wasteful product /bye-

product for further profitable use and/or their disposal to the befitting and safer destination in every nation irrespective of its state of being either developed or developing or underdeveloped. The first stage of inflow

parameter deals with the coal handling which appears to be the prominent factor in deciding the cost of energy whereas the second stage involves in-plant handling of materials and the third stage which deals with the monitoring, control and processing of outflow parameters like waste materials, dust particles and other particulates which need to be transported to safer destination for maintaining sustainable and quality developmentaround the area surrounding the site of the plant. Moreover, the nature and quantum of exercise to be taken by this handling process differs drastically from plant to plant depending on the capacity of power generation. The capacity of power generation of the plant decides the requirement of coal, quantum of emission to which the environment gets subjected and technology required to tone up the ambient ecological balance.

Though the requirement of a product may possibly appear to be individualistic one the task ofmeeting even that requirement i.e. manufacturing of the product and its supply to the end usercertainly not only becomes a collective one but also indispensably depends on accuracy, reliability, compatibility and consistency of different sections and individuals constituting the same. A product/task may be prepared by a group or committee but its quality and reliability depends on integration of the individuals/groups/sections/institutionsconstituting it, their comprehension of the social goal and courage to uphold, preserve and promote the same by being committed to. In a typical organization, several people with different actions and attitude take a product from the stage of concept to the phase of adaptation by the customers via market.

The selection of the of the product for business of the enterprise is made necessarily on the basis of information collected by the marketing division but the decision regarding ‘Which product’ is certainly taken by the upper echelon of the management and hence, that echelon may decree, “ We are in that particular product business”. Consequently, marketing division gets tasked with positioning the organisation to sell that product; engineering division finds commissioned to select the best site it can have and design the best product it can; sales persons are engaged in taking orders for the product and manufacturing division is expected to manufacture the products that bear the matching with the type that its marketing division has promised and presumably, engineering division designed. Moreover, manufacturing division must manufacture the proper number of them for less than the specified unit cost by the specified limit of time period to comply with the orders taken by the sales division. Each group does its best to the knowledge available and experience gained for achieving its well defined and clearly specified objectives. `

In an ideal world, in a business enterprise, all its divisions namely Management, Design, Manufacturing, Processing, Marketing and Sales work together to specify a product. They agree on features, cost and ranges of desired values for measurable qualities.The communication among these groups sorts out which factors are really important and what limit of tolerances are acceptable around targeted values quantifying the quality of the output. Any trade-offs among competing characteristics are made on the basis of their relative importance.

As the world is not ideal, there may develop individualistic ego of position and prominence.Consequently,clashes may occur wherefrom thought goes radiated but capturing those radiations of thought requires receptivity and absorptivity for analysis to arrive at a conclusion complying with the unfailing recorded faith of development that science develops with clashes of ideas. Thus, the scenario discussed in the preceding paragraph and required for achieving matchless quality in a product certainly seems to appear all uncommon. What shouldthe mechanical engineer do then? The word ‘mechanical’ may connote literally the quality of being unintelligent but this discipline of engineering is definitely destined to make use of even non-living material natural resources leave aside living or unintelligent animals as a living, responsive and intelligent one in giving a new dimension of development –as evident from invention of steam engine by James Watt paving way for bloodless revolution and providing wings to realizational approach of dreams to productivity, mobility and quality adding feathers

to prosperity and comforts even beyond imagination via stone age and industrial revolution. Not only the thermal power plantbut also its material (coal) handling section also requires attention of mechanical engineering so that the section may function in an unhindered manner and the plant may escape the state of starving for coal. The process of material handling needs to be optimized and for doing so, the process parameters needs to be identified and their values determined to achieve the best possible outcome which can be obtained by maximizing the possibility that the process generates an optimal combination of process outputs. Evidently, this becomes easier when the output parameter gets modeled and simulated as a function of independent variables.
This paper details the identification of various variables namely detention period of the wagon rake, interarrival of wagon rakes, number of wagons received per rake and availability of unloading system and subsequently describes modeling of detention period as a function of other independent variables.For doing so the response surface methodology has been applied.

The coal handling process takes into account the arrivals of loaded wagon rakes for maintaining regular supply of coal, their unloading and storage within the stipulated period of time to avoid/minimize any demurrage charges as well as the other related cost involved in production of useful form and easily transmissible nature of energy and its economical storage. In order to run the thermal power plants in a strategically effective manner with development boosting mission, quality matching attitude and demand meeting approach it is essential to know the next arrival of coal loaded wagon rake and its probable detention. The detention of coal loaded wagon rakes primarily appears to depend on the interarrival times and number of wagons but certainly would get affected by availability of the unloading system accounting the preparedness thereon. The knowledge of all these would help to take necessary and appropriate step that may be necessarily initiated/applied in time to have a check over the cropping of any intricacy/bottlenecks in the material handling system of the plant and its adverse impact on the system functioning, if any.

Response surface methodology has been successfully used in recent years for analyzing various problems in the field of engineering, which provide not only better understanding of problems being faced but also the possible meaningful solutions and remedial measures. In 1951 Box and Wilson (1)presented a detailed discussion on response surface methodology. Subsequently this methodology has found its application in different areas of engineering and technology from material selection to smart material preparation and befitting use in adding comforts to man in astonishing way. Montogomery and Bettencourt Jr (9)used this methodology in computer simulation. Giribone (7) made use of response surface methodology for analyzing non-equispaced configurations applied in a discrete and stochastic simulation of a manufacturing company. Rubinstein et al (10)applied this technique of using response surface in determining in-situ engineering properties of soil. Dorica and Giannacopoulos (4)used this process in space mapping for electromagnetic optimization. Fang and Perera (5) used response surface methodology as damage identification technique. Song et el (11) used this methodology for engineering design optimization. Kawaguti (8) made use of this technique in production of glucosyltransferase and conversion of sucrose into isomaltulose. Chang and Chen (2) used this in paper feeder design. Costa and Perera (3)finds multiple response optimization as a global criterion based method.Ginta et al (6) applied the response surface methodology to predict tool life in end milling titanium alloy Ti-6Al-4V using uncoated WC-Co inserts. The literature survey made reveals that so far, modeling and simulation of coal wagon rake parameters related to the receipt of bulk coal and its handling appear to be little discussed. Further, it has also been noticed that there has been little use of response surface methodology in analysis of the data related to such systems. This state of literature certainly appears to be a catalytic zeal for the moving impetus in making use of response surface methodology to analyse and evolve a model, carrying out simulation of coal rake parameters for thermal power plants. In this paper, an attempt has been made to correlate wagon rake detention period with arrival of coal rake number of wagons received per rake and the availability of the unloading system for such plantsusing response surface methodology.

2. Physical System

In this study, the bulk material handling system chosen for observation was from a coal based medium capacity (i.e. around 1000 MW)thermal power plant. A large number of such plants are operational in India. The data and information regarding the time of arrival of coal wagon rakes, duration of their detention at the plant for coal unloading, number of wagons per rakereceived and availability of the unloading system have been collected. The plant under study has to receive coal loaded wagon rakes from different resource stations located at distant and different geographical places. The process of unloading of the wagon rakes primarily depends on the time interval between the arrival time of the present wagon rake and that of the preceding wagon rake i.e. interarrival time between arrivals of two successive wagon rakes, number of wagons per rake received in the present arrival and availability of the unloading system of the plant.Generally, the transportation of coal gets affected due to changes in geographical conditions, weather, government policy, regulation management at the plant level, etc. Moreover, such handling processes and unloading system are also affected by some unforeseen factors over which the plant does not have control. This clearly indicates the complexities involved in the process of coal handling. The handling systems have to face various uncertainties that affect the system performance adversely. Consequently, a challenge is found by the practising engineers to evaluate such eventualities and evolve the most feasible strategy for unhindered and improved system operation.

3. Response Surface Methodology

Response surface methodology (RSM)was first applied to optimize the state and requirement of experimental conditions by Hotelling in 1941 and he was followed by Friedman and Savage in 1947.This methodology is a collection of mathematical and statistical techniques used for modeling and analysis of problems and establishing relationship between several explanatory variables and one or more response variables. Box and Wilson suggested second degree polynomial for knowing the effect of variables and their interactions. A response of interest may be influenced by a number of variables and very often it is desirable to get that response optimized. A mechanical engineer in manufacturing division of a product remains conscious of knowing the working life of the tool and hence may be tempted not only to assess the tool life but also to maximize it.The tool life may be function of cutting speed of the tool and depth of cutand mathematically, it may be represented as

$$Y=f(V, t) +\epsilon,$$

whereY representstool life, V is cutting speed; t is depth and ϵ is the noise or error observed in the response Y.

If we denote the expected response by $E(Y) = f(V,d) =\eta$, then the surface represented by $\eta= f(V, d)$is called a response surface.Usually the response surface is represented by plotting ŋ versus the levels of V and d. Often contours representing the lines of constant response is plotted in the appropriate planes tohelp visualize the shape of a response surface. Each contour corresponds to a particular height of the response surface. In RSM problem generally, the form of relationship between the response and the explanatory independent variables isnot known. The first step in this methodology is to find a suitable approximation for the true functional relationship between the response variable and the set of independent variables. A low order polynomial is first tried in some regions of the independent variables. If the response gets well modeled by a linear function of the independent variables, the approximating function is the first order model. If there is curvature in the system, a polynomial of higher degree such as second order model may be used. Almost all RSM problems make use of one or both of these models. Undoubtedly, it is unlikely that a polynomial model will be a reasonable approximation of the true functional relationship over the entire space of the independent variables, but for a relatively small region they usually work quite well.

The parameters in the approximating polynomials are estimated by making use of methods of least squares. The response surface is then analysed over the fitted surface. If the fitted surface is found to be an adequate approximation of the true response function, the analysis of the fitted surface will be approximately equivalent to analysis of the actual system. The use of proper experimental designs for collecting the data enables effective estimation of model parameters. The designs used for fitting response surfaces are known as response surface designs.

RSM is a sequential procedure. Generally a pointis selected on the response surface that may be placed remote from the optimum i.e. either maximum or minimum as desired. There may be a little curvature in the system and the first order model may be appropriate for initial approximation.Theexperimenter is led rapidly and efficiently along a path of improvement towards the general vicinity of the optimum. Once the region of the optimum gets identified a more elaborate model like second order model may also be tried and an analysis can be carried out to locate the optimum value of response variable and the corresponding values of independent explanatory variables. Moreover, the analysis of a response surface may be thought of as ‘climbing up a hill’, when the top of the hill represents the point of maximum response i.e. the problem related to the mission of maximization for useful character of a system and as descending into valley when the trough of the valley describes the point of minimum response i.e. the problem related to minimize the undesirable outcome involved in a system process.

4. Model Development, Analysis, Selection and Application

4.1 Data Collection

For study of the material handling system and subsequent modeling the data have been collected from a coal based medium capacity (i.e.1000MW) thermal power plant operational in India. The data related to the system variables namely wagon rake detention period, interarrival times for wagon rakes and number of wagons per rake and availability of the unloading system in the plant have been shown in Table- 1. The data have been analysed by making use of SYSTAT software version.

Table-1

Data Observed in the 1000 MW Thermal Power Plant

Serial No.	Detention of Wagon Rake(hrs.)	Interarrival of Wagon Rakes(hrs)	No. of Wagon Rakes	Availability of unloading system
1	7.92	17.50	55	0.85
2	8.92	6.08	58	0.85
3	5.33	11.92	56	0.85
4	13.33	10.83	57	0.75
5	10	10.50	58	0.80
6	11.58	0.75	58	0.75
7	10.83	16.58	57	0.80
8	17.33	4.67	57	0.70
9	8.83	21.83	58	0.85
10	13.33	23.67	58	0.85
11	16.33	3.5	58	0.80
12	6.83	17.5	58	0.85
13	8.25	4.33	57	0.85
14	12	1.67	58	0.80
15	10	8.17	58	0.80
16	12.17	2.00	58	0.75
17	10.67	8.50	58	0.80
18	9.17	23.50	57	0.85
19	11.83	2.83	58	0.80
20	13.5	6.75	58	0.80

21	15	6.17	57	0.80
22	19.5	1.33	57	0.75
23	10	13.5	57	0.85
24	15.58	5.92	58	0.80
25	20	0.75	58	0.75
26	21	3.5	58	0.75
27	12.5	11.17	57	0.8
28	18	1.50	58	0.70
29	9.17	14.00	56	0.85
30	8.67	9.33	56	0.85
31	17	1.92	55	0.70
32	15	1.58	58	0.70
33	15	3.67	58	0.75
34	18	0.67	58	0.70
35	21.83	0.83	58	0.70
36	15	10.33	58	0.80
37	16.75	1.75	58	0.75
38	23.25	2.92	58	0.7
39	24.75	2.25	58	0.7
40	31.17	3.58	58	0.7
41	11.5	6.50	56	0.8
42	19.75	9.00	58	0.75
43	21.67	5.33	58	0.7
44	21	5.83	56	0.7
45	21.5	3.83	57	0.7
46	16	10.67	58	0.8
47	6.42	19.67	56	0.85
48	9	5.5	58	0.85

The process of analyzing the data is carried out with a definition of the problem which affects the system performance of the plant in a planned way. The definition of the problem gets refined through examination of all available information/data collected and literature survey made. For selecting a variable as response in the system analysis it is necessary to have applied the primary criterion of being meaningful i.e. its significance in the context of the objective to be achieved. Obviously the response should relate to the quality or cost or characteristic that is targeted for improvement. Certainly it is required to have the response which is repeatable, quantifiable and measurable. Though it is tempting to select a response simply because it is easy to measure, the meaningfulness criterion should necessarily take precedence. Careful planning and reviewing at various check points improves the quality, compatibility and accuracy of the model and helps in drawing inferences which have higher degree of reliability and better acceptability and above all improved compliance with real life situations.

4.2 Model development

Among variables detention period of wagon rakes, interarrival of wagon rakes, number of wagons received per rake and the availability of unloading system the detention period of wagon rakes is selected as response because any change particularly detention period longer than that of allotted one directly causes financial loss to the plant in terms of increase in demurrage charges directly payable to the railway. The detention period not only fulfills the criteria of being meaningful but also possesses the quality of being measurable, quantifiable and repeatable. The other variables are considered as explanatory variables because their values potentially determine the value of response. The model presenting relationship of response, detention period of wagon rakes with explanatory variables identified in this study of the thermal power plant is proposed as below:

$$D = a_0+a_1X + a_2Y+a_3 Z+a_4 X^2+ a_5Y^2 +a_6Z^2 +a_7 XY+ a_8YZ + a_9XZ$$

where D is response variable, detention period of wagon rake; a_0 is unknown but deterministic constant in the expression; a_1, a_2, a_3 , a_4, a_5, a_6, a_7 , a_8 and $a_9$are unknown coefficients of the explanatory independent variables namely interarrival times (X), number of wagons received per rake(Y) and availability of the unloading system(Z), their quadratic form i.e. interaction with self (X^2 ,Y^2, Z^2) and above all their interactions,XY, YZ and XZ. Making use of SYSTAT software the values of the unknown constant and the coefficients of variables, their quadratic form and interactions have been determined. The proposed model has been completely known as follows:

$$D=13.960+1.489X+2.047Y-7.056Z+2.137X^2+0.701Y^2 +1.016Z^2 +2.878XY-2.293YZ-3.910 XZ$$

The variables of the known model have been defined and presented in Table -2

For this suggested model obtained by response surface analysis the coefficient of determination (R^2) has been calculated and found to be 0.735which is around 70% and hence acceptable one. The values of multiple R and adjusted squared multiple R and the F-ratio and p-value for analysis of variance and lack of fit test have been shown in Table-3. The regression coefficients for uncoded factors are also shown in Table -4.

Table-2

Definitions of Variables used

Variable Name	Symbol	Definition
Detention Period	D	The total time taken in hours for unloading the wagon rake.
Interarrival Time	X	The difference between the arrival of the wagon rake being unloaded and the preceding wagon rake unloaded.
Number of Wagons per Rake	Y	The total number of coal loaded wagons per rake received.
Availability of Unloading System	Z	The readiness of unloading system to receive the coal loaded wagon rake for getting unloaded.
Quadratic form of X	X^2	The product of interarrival period with itself.
Quadratic form of Y	Y^2	The product of number of wagons per rake received with itself.
Quadratic form of Z	Z^2	The product of availability of unloading system with itself.
Interaction of Interarrival Time with Number of Wagons per Rake	XY	The product of interarrival period with number of wagons per rake received.
Interaction of Number of Wagons per Rake with Availability of Unloading System	YZ	The product of number of wagons per rake received with availability of unloading system.
Interaction of Interarrival Time with Availability of Unloading System	XZ	The product of interarrival period with availability of unloading system.

Table-3

Parameter	Value
F-ratio of ANOVA	11.720
p-value of ANOVA	0.000
F-ratio of lack of fit test	0.264
p-value of lack of fit test	0.941
Multiple R	0.857
Squared Multiple R	0.735
Adjusted Squared Multiple R	0.672
Standard Error of Estimate	3.168

Table-4

Effect	Coefficient
Constant	720.384
X	-2.190
Y	-30.386
Z	443.690
X^2	0.004
Y^2	0.356
Z^2	131.851
XY	0.072
YZ	-12.523
XZ	-2.382

5.Results and Discussion

Among the four parameters of the operating system namely detention period of coal loaded wagon rakes, interarrival time of wagon rakes, number of wagons received per rake and availability of the unloading system for any thermal power plant the detention of wagon rake is the most critical one, because longer detention period beyond the allowable free time would invite direct financial loss in terms of the demurrage charges payable to the railways for no productive work; while the others would also affect the functioning of the coal unloading system. In medium capacity power plants, the requirement of coal for power generation boilers is relatively lesser as compared to high capacity thermal power plants and hence the number of rakes received per day would be about 2-4. However, it was noticed that the interarrival time of wagon rakes to the medium capacity power plants vary largely within a range of 3-20 hours. It is often found that the arrivals of wagon rakes take place in a relatively more regular manner as compared to low capacity power plants. Thus, the difference in time between the arrivals of the preceding rake and the succeeding rake shows a relatively more uniform nature. Whenever the interarrival times of wagon rakes were in the range of 2-6 hours, the unloading section of the plant had to face extra work load in clearing the preceding rake arrival apart from dealing with the succeeding rake arrival. This phenomenon led to the development of typically high rake detention times till the predecessor rake got cleared from the unloading section. However, the unloading section of medium capacity thermal plants would not face such operational situations regularly. In practice, the detention period of wagon rakes mostly appeared to be lying in the range of 8-15 hrs at such plants and this led to delayed unloading of wagons at the plant incurring relatively lesser demurrage charges. In this manner, the duration of wagon rake detention is relatively lesser for the medium capacity thermal power plants compared to the low capacity thermal power plants. On the other hand, the period of wagon rake detention at the high capacity power plants receiving more number of rakes in a day is relatively lesser and the system has to negotiate a reduced period of interarrival time.

The wagon rake handling data of the system was analysed by making use of response surface methodology of SYSTAT software for statistical analysis. The coefficient of determination (COD) for the suggested model is 0.735 which justifies the acceptability of the modeland its compatibility with the observed data. The F-ratio and p-value for analysis of variance and lack of fit test to the collected data has also been found and shown in Table-3. The regression coefficients for uncoded factors have been shown in Table-4. The surface plot of response variable, detention period vs. interarrival time and number of wagons per rake has been shown in Fig.1 whereas the contours of desirability have been shown in Figure -2.The optimization using desirability approach has also been carried out and the findings are shown in Table-5 and the desirability plot has been shown in Figures-3a-3c.

The surface plot of response variable, detention period of wagon rake versus explanatory variables, interarrival time of wagon rake and number of wagons per rake shown in Figure-1 gives a three dimensional view of variation in explanatory variables and resulting effect on the response variable. This plot provides an insight of proper combinations of the factors at suitable level to enable the response variable attain the desirable state.

Table-5

Desirability Analysis

Target value of D	7.000 hrs
Lower value of target	6.000 hrs
Upper value of target	8.000 hrs
X	22.679 hrs
Y	55.490
Z	0.842
Optimal response	7.000 hrs
Overall desirability	1.000

Table-5 clearly shows that target value of detention period is 7.000 hrs which is achieved corresponding to the values of explanatory variables, interarrival period =22.679 hrs i.e. one rake per day, number of wagons per rake =55.490 i.e. around 55 and availability of unloading system =0.842. Overall desirability has been found to be 1.000 which undoubtedly signifies it as the best solution under the given circumstances. The desirability plots as shown in Figure-3a-c support the feasibility of the values of response variable, detention period and explanatory variables, interarrival time, number of wagons per rake and availability of unloading system. The contour plot of the desirability as shown in Figure -2 provides options in selecting the values of explanatory variables, interarrival time of the wagon rake and the number of wagons received per rake for a particular value of the response variable, detention of wagon rake but certainly its utilization requires expertise and experience of the personnel employed to judge thefeasibility and suitability of these values to the variable under the situations. Consequently, this optimization process provides a rigorous means for incorporating the expert judgements into the process outputs and determining the best balance among factors affecting the response variable.

6. Conclusion

Based on the observed data related to coal handling system and collected from medium capacity thermal power plant operational in India and subsequent merit based analysis using the response surface methodology in systat software for statistical analysis the following conclusions/inferences may be drawn:-

(i) Better understanding of the coal handling process of any thermal power plants can be made with response surface analysis.

(ii) The degree of reliability of the equation giving forecast of the event, detention period of wagon rakes and making use of inter arrival time, number of wagons received per rake and availability of the unloading system is 0.735.

(iii) The equation for forecasting the value of detention period of wagon rakes proves to be a potential and meaningful tool in ascertaining better performance and higher degree of reliability for smooth operation of the plant.

(iv) The management and administration gets enabled to know the situation in advance and, subsequently, be prepared to avert the adverse impact of the possible event, if any, by applying the needful corrective measures.

(v) The desirability plot provides optimum value of the response variable and the corresponding values of explanatory variables.

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