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Factors Influencing Capacity Utilization of Mechanical Resources in Construction Industries

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Abstract: ***Construction industries in present world do face several challenges from project feasibility status to handing over of the project. With the unbounded scope and inevitable need for automation and machine tools, the success of any project heavily relies on the effective and uninterrupted performance of mechanical resources used in the projects. Companies spend huge amounts to own, operate and maintain these resources. The optimum utilization and failure-free performance of these resources are expected from the stake holder's perspective. An experiment is carried out using the principles of Design of Experiments to decide as which are the most influential factors affecting the utilization of the mechanical resource with the help of Mini Tab software and the results are discussed.***

Key Words: Break-down, Mechanical resources, Resource utilization, Work availability.

I. INTRODUCTION

Construction industries across the globe use different machineries to carry out several activities related to the ongoing projects. These machinery are either owned by them or hired from some external agencies. Every construction project utilizes any or some of the machinery as required for completion of the scheduled activities. The total cost of the project includes the usage cost of the machinery. The usage cost or sometimes called hire charge of the machinery comprises of different elements such as Ownership charges, Operational (repair and maintenance) charges, running charges which include fuel or energy charge and lubrication charges along with the wages of operators, overheads etc. These charges may broadly be grouped in two heads as fixed and variable cost. The fixed cost of the machinery remains constant irrespective of the usage of the machinery whereas variable costs are linked to the performance. The performance of the machinery contributes to the utilization of the same and is always in focus by the resource managers. Plant capacity utilization according to Johansen (1962) (1) the maximum amount that can be produced per unit of time with the existing plant and equipment providedthat the availability of variable factors of production is not restricted. Capacity utilization refers to the ratio between the actual output produced and the potential output available.

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According to Marucheck and McClelland (1992) (2), capacity utilization plays a major role in improving profitability compared with other strategic variables, including market share, inventory, vertical integration and industry growth.

This inference was further supported by other research by Achi et al. (1996) (3) stating that excellent capacity management can boost average annual returns on invested capital by as much as 3–4%. Therefore, capacity determination and utilization are of prime importance for any organization.

The utilization of the machinery depends on various factors which are controllable and uncontrollable. Some of the controllable factors which affect the utilization do relate with trouble-free performance of the machinery and availability of the work to perform the job. From among many factors two of the most influential factors from the authors' point of view are considered in carrying out an experimental study to analyze the effect of them on machinery utilization. The principles of design of Experiments are used for carrying out the study with the help of Minitab-16 version.

II. CASE STUDY

This case study is based on the performance of the Road Rollers working under a civil construction division of Public Works Department of State of Uttar Pradesh in India. There are many divisions spread across all the districts of the state. These divisions are responsible for planning, execution and supervision of different civil construction jobs related to Roads, Buildings, Bridges, etc. Different mechanical resources are available in the division to support the construction work. Road Rollers are most utilized earth moving machines, especially for the construction of roads. Engineers responsible for operation and maintenance do face different challenges in meeting the optimum performance standards of mechanical resources and are always in search for factors which affect their performance and endeavoured to control them in a way to achieve the target utilization of the machinery. The standards and levels considered in the study are based on the past performance and experience. The responsibility of the Engineer in Charge is to fully utilize the road rollers for construction work thereby avoiding idleness of the rollers. Factors which affect the utilization of road rollers are-

1. Work availability
2. Rollers break down

The following table shows the design layout of the experiment with response values. Each experimental condition was replicated five times so that a reasonable estimate of error variance (or experimental error) can be obtained.

Table- I: Process parameters and their levels for the experiment

Process Parameter	Labels	Low Level	High Level
Work Availability	A	50%	150%
Roller Break-down	B	5%	10%

III. OBJECTIVE OF THE EXPERIMENT

Following are the objectives of the experiment-

1. Which main effect or interaction might affect the utilization of the road rollers?
2. Which main effect or interaction might influence variability in utilization of road rollers?
3. What are the best settings of factors to minimize variability in utilization?
4. How to achieve a target utilization of 100%?

Levels for the experiment - All the above parameters or factors are studied at two levels, low and high.
Response of the experiment - (Quality Characteristic of interest): Utilization of the Road Rollers.
Procedure for the experiment - 2 factors at 2 levels were studied using a 4 run 2^2 full factorial design.
Selection of factors and their levels - By brainstorming.

Table - II Design layout of the experiment with response values

Trial No.	A	B	Utilization				
1	50%	5%	46%	47%	48%	49%	50%
2	50%	10%	41%	43%	45%	47%	49%
3	150%	5%	96%	97%	98%	99%	100%
4	150%	10%	91%	93%	95%	97%	99%

A. OBJECTIVE – I

Determination of main/ interaction effects which influence the mean utilization of the road roller- To determine the effect of process parameters A and B and its interaction AB, we need to construct a coded design matrix with mean utilization values as shown in the table.

Table - III Coded design matrix with mean utilization index

A	B	AB	Mean Utilization
-1	-1	1	48%
-1	1	-1	45%
1	-1	-1	98%
1	1	1	95%

The column AB is obtained by simply multiplying the coded values in columns A and B. The interaction AB yields a combined effect of two factors, A and B. The result from Minitab software is shown in figure. It illustrates the normal plot of effects. The graph illustrates that process parameter 'A' i.e. Work availability is statistically significant at 5 percent significance level. In other words, this effect has a larger impact on the mean utilization of the road rollers, though roller breakdown has very little impact on the mean utilization of road rollers. This finding can be further supported by considering the main effect plot and interaction plot.

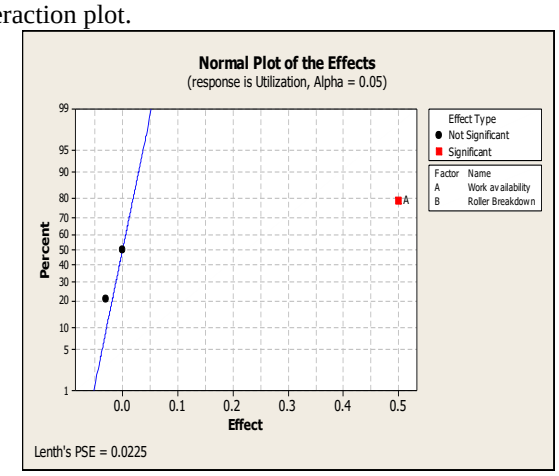

Figure – I Normal plot of the effects

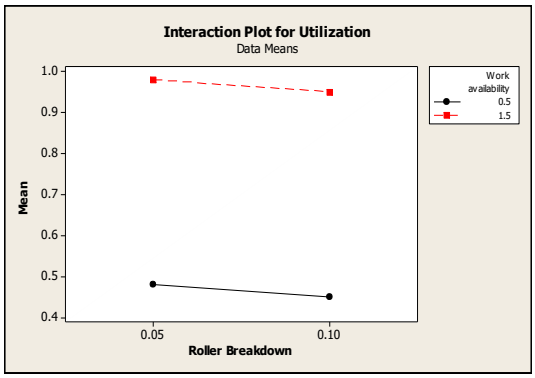

Figure - II Interaction plot for Utilization

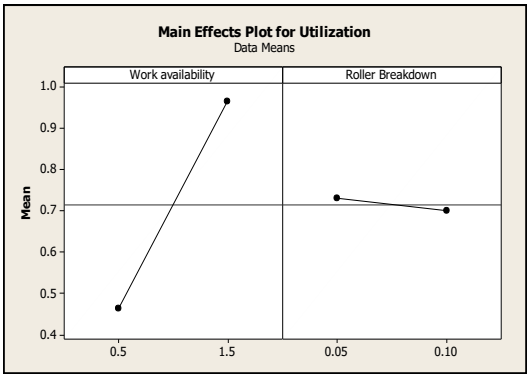

Figure - III Main effects plot for Utilization

It can be seen from the above figure that that work availability has a huge impact on mean utilization of road rollers whereas roller breakdown have very little impact on mean utilization of road rollers. However, it is interesting to note that roller break down have lower sensitivity to variability in mean utilization of road rollers when compared to work availability. The figure indicates that there is a strong interaction between work availability and mean utilization of road rollers. Mean utilization of road rollers is maximum (98%) when work availability is kept at high (150%) and roller breakdown is kept at low (5%) whereas mean utilization of road rollers is the minimum (45%) when work availability is kept at low (50%) and roller breakdown is kept at high (10%).

B. Objective – Ii

Determination of main/ interaction effects which influence variability in utilization of road rollers.

In order to determine the effect of A, B and interaction AB on process variability, we need to construct a coded design matrix with the response as variability in road roller utilization which is shown in the table.

Table - IV Coded design matrix with variability as the response

A	B	AB	Utilization Values					Variability in Roller Utilization (SD)	ln (SD)
-1	-1	1	0.46	0.47	0.48	0.49	0.50	0.016	-4.15
-1	1	-1	0.41	0.43	0.45	0.47	0.49	0.032	-3.45
1	-1	-1	0.96	0.97	0.98	0.99	1.00	0.016	-4.15
1	1	1	0.91	0.93	0.95	0.97	0.99	0.032	-3.45

Minitab software is used to identify effects which are most important to process variability. The figure shows a Pareto plot of the effects on variability [ln (SD)]. It is clear from the graph that the process parameter 'B' i.e. roller breakdown has a significant effect on roller utilization variability, whereas work availability 'A' and interaction 'AB' has no effect on impact on utilization variability.

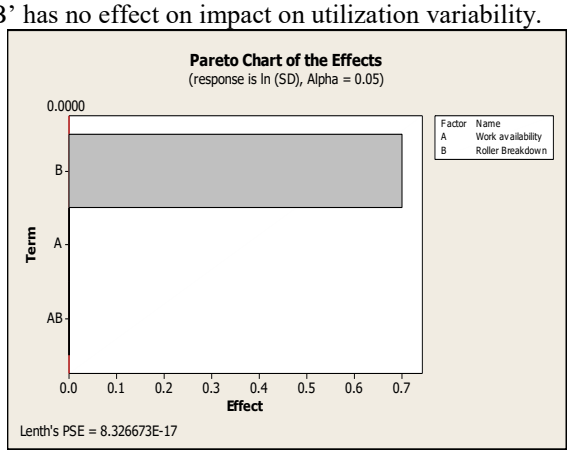

Figure - IV Pareto chart of the effects

C. Objective – Iii

What is the best setting of factors to minimize variability in utilization?-

Following figure shows that variability is minimum when roller's breakdown is kept at minimum.

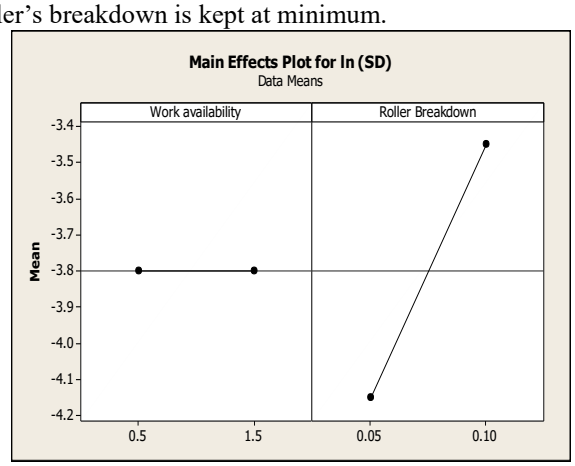

Figure - V Main effects plot for ln(SD)

D. OBJECTIVE – IV

How to achieve a target roller utilization of 100%? In order to achieve a target utilization of 100%, we need to initially develop a simple regression model which connects the response of interest (i.e. Utilization) and the significant process parameters. In order to develop a regression model, we need to construct a table of effects and regression coefficients. It may be noted that regression coefficients for factors at 2-levels are just half the estimate of effect.

IV. EFFECT OF WORK AVAILABILITY ON UTILIZATION

Mean utilization at high level of work availability = (98% + 95%)/2 = 96.5% = 0.965

Mean utilization at low level of work availability = (48% + 45%)/2 = 46.5% = 0.465

Effect of work availability on utilization = 96.5% - 46.5% = 50% (0.965 – 0.465 = 0.50)

Regression coefficient of work availability (A) = 0.50/2 = 0.25

Interaction effect between work availability and roller break down (AB):

Mean utilization at low level of AB = (45% + 98%)/2 = 71.5% = 0.715

Mean utilization at high level of AB = (48% + 95%)/2 = 71.5% = 0.715

Therefore

Interaction AB = 0.715 – 0.715 = 0.00

Regression coefficient of the interaction term AB = 0.00 /2 = 0.00

The regression model for the utilization can be therefore written as:

$$\hat{Y} = \beta_0 + \beta_1 (A) + \beta_{12} (AB)$$

Where

β_0 = overall mean utilization = (48%+45%+98%+95%)/4 = 71.5 = 0.715

β_1 = regression coefficient of factor A (work availability) = 0.25

β_{12} = regression coefficient of interaction AB (work availability x roller break down) = 0.00

The predicted model for utilization therefore given by:

$$\hat{Y} = 0.715 + 0.25 (A) + 0.00 (AB)$$

Using above predicted model we need to determine the settings of parameters which gives a target utilization of 100% (i.e. $\hat{Y}$ = 1.0). Moreover, we know that low level of roller breakdown (factor B) yields minimum variability, therefore we can set B at low level (i.e. 1).

Now we can write-

1.0 = 0.715 + 0.25 A +0

0.25 A = 1.0 – 0.715 = 0.285

A = 0.285/0.25 = 1.14 (in coded terms)

The following equation can be used to convert the coded values into actual parameter values (or vice versa)

$$\text{Actual} = \frac{High+Low}{2} + \frac{High-Low}{2} \text{ X Coded value}$$

For example, for factor A, high level setting = 1.5, Low level setting = 0.5, coded value = 1.14

$$\text{Actual} = \frac{1.5+0.5}{2} + \frac{1.5-0.5}{2} \text{ X Coded value}$$

= 1.0 + 0.5 x 1.14

= 1.0 + 0.57

Actual = 1.57

Therefore, to achieve a target utilization of 100% we need to set the work availability at 157 % at the roller breakdown of 5%. We need to perform confirmation experiments or runs to verify the result of our analysis. If the result of confirmation experiments or runs (i.e. Each observation from the trials) fall within the interval of $\hat{Y} \pm 3$ (S.E.), then the results are satisfactory. Here S.E. refers to standard error and is calculated as -

S.E. = SD/√n, where SD is the sample standard deviation and 'n' sample size.

V. CONCLUSION

This study considers two process parameters or factors which have maximum effect on the response value of the experiment i.e. utilization. The levels of these parameters are based on performance records of the machines and past experience Hand Book on Road Construction Machinery, Indian Road Congress Government of India, Ministry of Shipping and Transport (Roads Wing), June 1985 (4) illustrate the different performance parameters for the machines used. There may be even more parameters affecting the utilization of the machineries, some of them may be qualitative in nature also. All those parameters which in any means affect the performance may be included in the experiment to make the results more specific and comprehensive.

The size of the experiment being conducted depends on many factors such as-

1. No. of factors/ interactions to be studied.
2. No. of levels of each factor.
3. Budget and resources allocated for carrying out experiments.

This study may form a basis to further investigate and accurate the result to widen the experiment horizon. Authors may find even other suitable parameters affecting the process response of their choice. There is several statistical software other than Minitab available in the market to analyze these situations. The Author has chosen Design of Experiment principle to investigate the process because of its capability to analyze individual process parameters along with their interaction effect.

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Corresponding author Ajay Kumar Tripathi is a research scholar and is presently associated with Uttar Pradesh Public Works Department and shoulders the responsibility of Operation and maintenance of earth moving equipment, Hot mix plants/ C.C. plants, different Electrical/ Mechanical projects and have varied experience of teaching at graduate and post graduate level at Motilal Nehru Regional Engineering College, Allahabad (India), Research experience of design and development of air conditioning and refrigeration products at Carrier Aircon Ltd., L.G. Electronics and Fedders Lloyd Corp. Ltd (India) of about 20 years. Author is an active member of ISHRAE, UP chapter.

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