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Analyzing the Influence of Parameters of Delay Time Analysis on Down Time using Taguchi Method

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Abstract

Objectives: This paper focuses on the influence of delay time parameterson the consequence parameter of downtime per unit time. **Methods/Analysis:** DTA data sets needed for various systems are synthesized in line with the Taguchi method of design of experiments. Main effects of plot for the parameters are arrived for individual parameters. Interaction effect among parameters also had been considered for analysis. **Findings:** Main effects of plot for means clearly reveals the parameters having most influence on the consequence variable of downtime per unit time. Also the inspection time is found not influence much. Attempt also has been made in this article to find out the interaction between certain key parameters. The interaction plot reveals the clear opposite interaction between some parameters and the maintenance inspection time. **Application/Improvements:** The information on the factors that affect the down time the most can best be utilized by maintenance managers and other stake holders to give focused attention to particular parameters associated in breakdown failure reduction techniques, during the post-DTA implementation period.

Keywords: Breakdown Management, Inspection Cost, Maintenance Inspection, Repair Time

1. Introduction

Research community had been contributing many research papers in the name of maintenance over the last thirty years[1,2]. These are review articles on the maintenance area covering areas like reliability, servicing, breakdown repair, inspection, repair, overhauling, replacement policies etc. The numbers of articles are more than hundred. Even the recent article[3] too attempted finding the prioritization of the maintenance acts to be done by determining the pavement condition index. Still, the industry could not get any concepts or procedures that could have a direct usability or impact[4].In the same article the author mentions that the industry made use of only the models related to replacement policies and cash flow strategies. The delay time analysis is a tool that provided a direct link between the optimum inspection interval and the consequence variable of down time per unit time, numerically.

In maintenance inspection, parts or systems are inspected periodically, the intention being to look for the presence of any fault. Detected faults will be rectified. Any fault that is not within the visible range of the inspection point of time shall end up as failures, leading to breakdown losses. The concept of Delay Time Analysis (DTA) is that when the system has a fault at some part of it, the faulty component gives an indication and then after a lapse of time the fault reaches the stage of a failure, leading to the functional stoppage at system level.

In simple terms, delay time is the duration of time from the start of fault to a point of time when the fault has reached the status of a failure of the part. The starting point of fault is refined as that point of time where a fault has matured enough to issue indications detectible by a maintenance inspection by the inspectors. As per article[5], the delay time concept defines a two stage stochastic process for a failure where the first stage is the initiating phase of a defect (or fault). Figure 1 where the initial point

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of fault is represented as point u, and the second is the stage where the defect leads to a breakdown (failure).

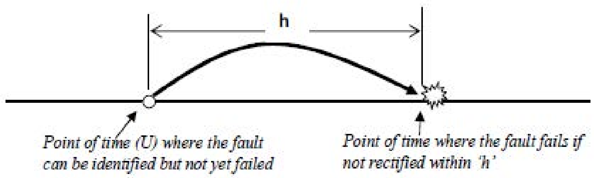

Figure 1. Delay time concept.

The cost of downtime is a real factor that must be targeted for reduction in the maintenance strategies of factories. Delay time analysis is not a defect prevention technique. Instead the technique tries to reduce the number of breakdowns by catching up the already started defect in the system by periodic maintenance inspection on the system.Research article[5] can be refered for further characteristics assumptions of the delay time based inspection of repairable systems. The same assumptions had been followed for all purposes in this article too.

The concept of delay time is originally introduced in the article[6]by Christer in the building maintenance and the concept is extended by the same author to industrial problems on maintenance. The concept has been used in inspection modelling over last twenty years by many authors[7–10].Fault detection probability improvement possibilities have been analyzed in article[11]. Problems associated with the estimation of the distribution for the delay time and the relevant parameters, in the subjective manner and in the objective manner have been discussed in articles[12–14].Downtime models for combining more than one system, at plant level, which is an implementation issue can be seen in article[15].Review paper on delay time analysis can be seen in a moderate manner in article[3]and in an exhaustive manner in the review article[16]. Sensitive analysis on delay time parameters had been done in articles[5,10].However the analysis to investigate the influence of DTA parameters through Taguchi method is yet to be done which is the objective of this article.

In this article the investigation of parameter that mostly influencesthe consequence variable of DT_uhas been done by making use of the Taguchi method of design of experiments. Attempt has been done to rank the DTA parameters of inspection time, breakdown repair time, the failure rate and the delay time distribution parameter. Main effects of plots for different parameters also had been arrived at for the purpose.

There are advantages of having knowledge about the most influencing parameter on the consequence parameter in DTA. Maintenance managers and other stake holders of DTA implementation, like the maintenance technicians and production operators can be watchful about the variation of values of these DTA parameters during the regular production run of the equipment. Objective of this article is to find out the most influencing parameter at macro level so that the information can best be utilized by maintenance managers to give focused attention to particular parameters associated in breakdown failure reduction techniques.

In DTA there are many parameters involved; however only four basic parameters have been considered in this parameter-influence analysis. Following notations shall be used for those four parameters and shall be followed throughout this analysis: -

- λ- rate parameter indicating the failure rate for the subsystem, number of times per unit time.
- t_i – maintenance inspection time, periodically done on the system, time units (minutes /hours /days..)
- t_b – Average time needed to bring the system back to operating condition in case a breakdown occurs at any of its subsystem, time units (minutes/hours/days..)
- H – Average delay time for the faults experienced in the system, time units (minutes/hours/days..), this is the delay time parameter.
- T – is the inspection interval to be optimized
- p_b - proportion of faults that end up as failures during the period T, given that faults will occur in T.
- DT_u – down time per unit time, which is taken as the consequence variable for optimization.

Other DTA parameters like cost per inspection, cost per breakdown repair too can be considered; however, for the purpose of analysis, the delay time down time model alone is tackled in this article.The key parameters that will be considered for analysis in this article will be λ, ti, tb&H. The influence of various parameters on the consequence variable, down time per unit time (DT_u) is analyzed by plotting the main effects plot from MINITAB.

2. Methodology for Analysis

For the purpose of analysis a number of datasets {λ, t_i, t_b&H} on many systems are needed. In order to decide the minimum number of runs required, the Taguchi method in design of experiments is sought. The Taguchi method demands the data for various levels of the parameters involved. For this purpose, possible range of data on failure rate, delay time, maintenance inspection time and average breakdown repair time are obtained on an objective manner from a steel casting factory in southern India. The factory can be considered as belonging to medium scale industry category, produces steel castings in batches utilizing the conveyor belt type of sand mold making in a semiautomatic manner. Relevant data on the ranges of failure rates, inspection time, average breakdown repair time and average delay time have been collected in relation to this semiautomatic mold-production line, in an objective manner in discussion with the maintenance manager and the maintenance technicians.

Once the required numbers of data sets on various data range levels of the key parameters are obtained, the value of the consequence variable will have to be computed. For this purpose, a computational set up is to be done to make use of the downtime model of article[5] which is given in our notation as,

$$DT_u = \frac{t_i + \lambda.T.p_b.t_b}{T + t_i} \quad (1)$$

where,

$$p_b = \int_0^T \frac{(T-h)}{T} f(h)dh \quad (2)$$

and*f(h)* representing the *pdf* of delay time, a data gathered from the past history or by subjective estimate. Here after the symbol, D(T), shall be represented in this paper as DT_u but with same meaning of down time per unit time.

Validation of the computational set up used for computation is done by making use of the down time model of article[5] which are shown in equations[1]& [2]; the input test values have been taken from numerical example given in article[17] and looking forward to obtain similar result.Values for various combinations of different parameter data ranges have been substituted in to the validated computational set up to obtain corresponding numerical values of consequence variable, DT_u. Exponential failure rate pattern and exponential delay time distribution have been assumed for the purpose of analysis. The delay time distribution is,

$$f(h) = \frac{1}{\mu} e^{-\frac{h}{\mu}} \quad (3)$$

whereμ is the delay time parameter for a system which is shown as H in this article. The values of parameters and the consequence variables are then fed into MATLAB to obtain the Main Effects of Plot to analyze the pattern of variation of the consequence variables for different DTA parameters.

3. Setting up of Datafor Analysis

The number of factors involved in the downtime model is 4 and three levels for each factor have been considered based on the general data range prevailing in the industry. L9 orthogonal array is sufficient for analyzing the effect of these four parameters on the consequence variable, DT_u. Table 1 gives the orthogonal array as suggested by the Taguchi method.

Table 1. Orthogonal array for the computational run

Run no.	λ	H	t_i	t_b
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2. Orthogonal array for the computational run

Run no	System ID	Lamda	H	t_i	t_b
1	s1	0.005556	7	0.25	0.5
2	s2	0.005556	28	0.5	1
3	s3	0.005556	112	1	2
4	s4	0.011111	7	0.5	2
5	s5	0.011111	28	1	0.5
6	s6	0.011111	112	0.25	1
7	s7	0.033333	7	1	1
8	s8	0.033333	28	0.25	2
9	s9	0.033333	112	0.5	0.5

The final information gathered, will look like, for example, some systems have one failure in 3 months, some once in two. To reflect worst case a failure case of one failure in one month too had been taken as one of the level. The numerical input data for different parameters, in three ranges are synthesized as λ{0.005556 - 0.011111

- 0.033333} failures per day, H{7 – 28 -112} days, t_i(0.25 – 0.5 – 1}days, t_b{0.5 – 1 – 2} days.

Table 2 gives the complete information on the input data set for an L9 array needed for Taguchi method of analysis. The interpretation for the data in Table-2 is that each data set has been deemed to belong to a system and the systems have been name as s1, s2….s8. This is for the purpose of identifying each system uniquely.

4. Establishing and Validating Computational Set Up

Computation is performed to get the values of consequence variable, DT_u in the bench mark example[17]where t_c0.3, t_b0.8 t_c0 hours and for an exponential average delay time parameter (H) of 20 hours for an exponential defect arrival rate of 0.2, using equations [1], [2] and [3]yield Table 3, based on which optimization graph shown in Figure 2 obtained.

Table 3. Sample data of DTuvs T by applying DTA model to reduced the down time per unit time

Sl no	inspectioninterval,T	b(T)	DT_U
1	1	0.0246	0.233796
2	2	0.0484	0.137165
3	3	0.0714	0.101293
4	4	0.0937	0.083707
5	5	0.1152	0.073993
6	6	0.1361	0.068352
7	7	0.1563	0.065069
8	8	0.1758	0.063256
9	9	0.1947	0.062410
10	10	0.2131	0.062223
11	11	0.2308	0.062499
12	12	0.2480	0.063105
13	13	0.2647	0.063951
14	14	0.2808	0.064970
15	15	0.2965	0.066116

This graph is the superimposition of the DTn (downtime per unit time value when no DTA based maintenance inspection is applied) and DTu (pattern of graph when breakdown management is applied through DTA for the same subsystem) showing the downtime per unit time for different PMI intervals of T.

Value for the decision variable of T=10 for a DTu*0.0622 which is the same case as in Christer's example. The optimum point is denoted by A in Figure 2. This optimization computations and curve generation can be done in EXCEL if the expression for the integral function is solved and available. The same work of computation and graph can be obtained straight away from MATLAB by giving the DTA models straight away and letting the MATLAB do the integration too.

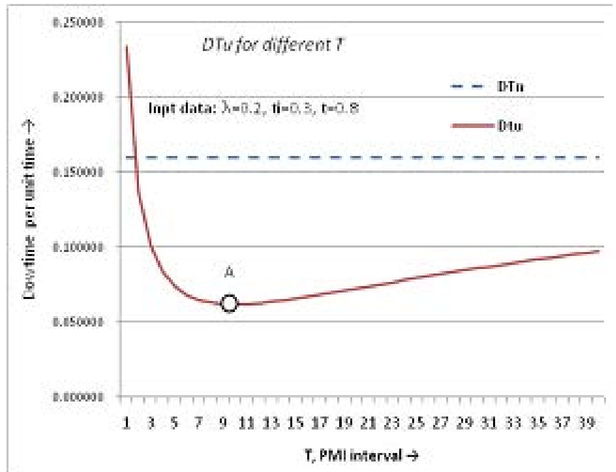

Figure 2. BDTn and DTu covering the computed values of for the benchmark example17.

5. Results and Discussions

Table 4 gives the computational results by showing T_i*, the optimum inspection interval computed for the data set pertaining to i^{th} system and DTu_i* which is the resultant downtime per unit time achievable if a systems are stopped for an intentional maintenance inspection to identify faults with the objective of repairing them before landing into the status of a breakdown.

Table 4. Computational results from MATLAB

Run No	System ID	DTu_i*	T_i*
1	s1	0.003007802	1000
2	s2	0.005897483	1000
3	s3	0.004137819	52
4	s4	0.022555168	1000
5	s5	0.006393552	1000
6	s6	0.006233982	92
7	s7	0.034065603	1000
8	s8	0.030946133	17
9	s9	0.010548457	112

On feeding the datasets of L9 orthogonal array and the numerical value of the consequence variable downtime per unit time (DTu) the main effects of plot for the data means are obtained which are shown in Figure 3. It can be noted that as the failure rate λ increases from minimum value to the maximum, the downtime per unit time increases. As the numerical value of delay time parameter H increases, the consequence variable shows a declining trend. This is obvious that the probability of detecting the fault at the fault-stage itself becomes more since more cushion time is available during the fault time, before reaching to the failure stage. Therefore, the probability of any fault landing up into failure stage is very small. As the value of breakdown repair time t_b increases the consequence variable DTu too increases but not as steep as influenced by the failure rate parameter λ.

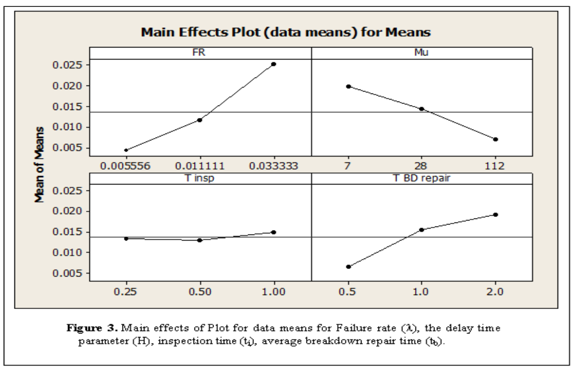

Figure 3. Main effects of Plot for data means for Failure rate (λ), the delay time parameter (H), inspection time (ti), average breakdown repair time (tb).

It is interesting to note that the maintenance inspection time t_i do not seem to influence much. It is obvious that as the value of t_i increases the model automatically suggest for a less-frequent inspection (i.e. longer inspection interval T). The response table generated from MINITAB is given in Figure 4 which shows that the failure rate (λ is labeled as 'FR') has the atmost influence (Rank = 1) on the consequence parameter, the downtime per unit time.

Response Table for Means

Level	FR	Mu	Tinsp	T BD repair
1	0.004348	0.019876	0.013396	0.006650
2	0.011728	0.014412	0.013000	0.015399
3	0.025187	0.006973	0.014866	0.019213
Delta	0.020839	0.012903	0.001865	0.012563
Rank	1	2	4	3

Figure 4. Response table for the different factors that influence the consequence variable, downtime per unit time.

Interaction plot for all four factors are obtained on feeding same data in MINITAB and the resultant plot is shown in Figure 5.

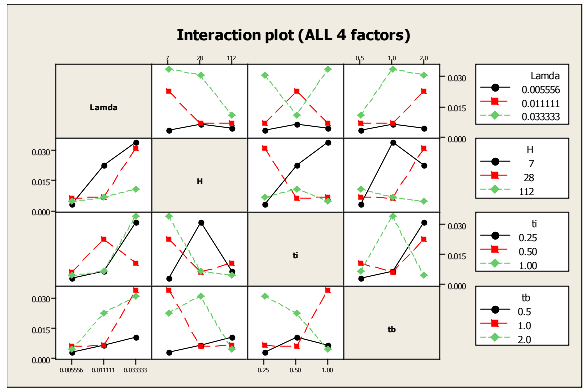

Figure 5. Interaction plot for all 4 factors together, Y-axis representing consequence variable DTu.

The left-bottom corner of the multiple graph figure shows the interaction (Lamda x t_b).

- For a fixed value of Lamda any increase in t_b pushes up DT_u, revealing a direct proportionality of DT_u with the product (λt_b).
- Going two graphs up from the left-bottom corner the interaction (Lamda x H) can be seen. For a fixed value of Lamda, any increase in H proportionately brings down DT_u. This is obvious that the product 'λH', infact, represents the expected number of breakdowns that can be reduced and hence the increase in the value of the product λH proportionately reduces DT_u.
- It is obvious to note that the inspection time has severe interactions with all other three factors {λ,H and t_b}. The reason is that because on the introduction of the DTA technique, additional time of t_i is consumed which is on the 'cost' side and the factors λ,H &t_b can be taken to be on the benefit side, when they work in a combined way.
- If they can be treated in a cost-benefit manner, where the product (λ.H. t_b) can be considered as a maximum expected breakdown time that can be saved on consuming an additional time of t_i.

6. Conclusion

In the down time model of delay time analysis, the four parameters of failure rate, delay time parameter, maintenance inspection time and average breakdown repair time have been analyzed against the consequence variable of down time per unit time. Taguchi method of design of experiments is used for the purpose. It is found that the failure rate has the maximum influence, followed by breakdown repair time and delay time parameter. The inspection time does not have much effect since the model makes the inspection interval longer when the inspection time becomes longer.

As far as the interactions between the parameters, the factors of failure rate, delay time, and the breakdown repair time have good interaction with a common parameter of inspection time. This means that the parameters failure rate, delay time parameter and the average breakdown repair times all take one side (the benefit side) and the inspection side is on the other side (cost side) of the objective of the delay time analysis; the objective being incurring additional idle time to save some potential breakdown time. Therefore, the maintenance manager can have a focused attention in the most influencing parameter during the regular maintenance program through the delay time methodology.

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