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Analyzing the Effect of Grouping Subsystems for Periodic Maintenance Inspection of Equipment using Delay Time Methodology to Minimize the Downtime per Unit Time

Babu Chellappachetty[1*], R. Raju[2]

[1]School of Mechanical and Building Sciences, VIT University, Vellore - 632014, Tamil Nadu, India; chettybabu@yahoo.com

[2]Department of Industrial Engineering, College of Engineering Guindy, Anna University, Chennai - 600025, Tamil Nadu, India; rraju@annauniv.edu

Abstract

Objectives: To analyze the effect of conducting maintenance inspection on equipment at subsystem level and at group level on the downtime per unit time for the equipment. **Methods/Analysis**: Using Delay Time Analysis (DTA). Taguchi design of experiments is sought to synthesize the data sets to involve the realistic effect of four DTA parameters, defect arrival rate, inspection time, breakdown maintenance time and the delay time distribution parameter, whose levels have been adjusted to match normal situations prevail in industry with some rounding off. Numerical example is shown for the consequence variable of downtime per unit time, computed at subsystem level and at equipment level. **Findings**: Subsystems fit for maintenance inspection can be segregated from those which should be left out for breakdown maintenance strategy by simple method, which is discussed. To aid the group inspection strategy, mathematical models to arrive at the data aggregates are presented, the extension of which can lead to plant level data aggregation too; the way the inspection time can be applied in a parallel or series manner on all subsystems have been discussed. The indicator, the downtime per unit time which is computed based on aggregates can mislead the planner is pointed out for making out a better decision while deciding maintenance inspection intervals. The grouping analysis has finally led to three strategies for the practitioner to choose from while implementing DTA based maintenance inspection, the circumstances in which one can resort to any strategy is also indicated **Conclusion/Application**: Three strategies, Single inspection, Grouped inspection-series and Grouped inspection-parallel are available for the practitioner when planning PMI through DTA,. Certain parts can be left to breakdown maintenance strategy. Caution is given about possible creeping up of error due to data aggregation in grouped inspection.

Keywords: Delay Time Analysis, Grouped Inspection, Maintenance Inspection Interval

1. Introduction

In periodic maintenance inspection of a part or a system that is done periodically by adopting the Delay Time Methodology (DTM), the intention is to see if there is any fault. When a fault is detected, it is immediately rectified by corrective maintenance action. If the fault occurs after the maintenance inspection is over, then the fault could brew to a failure that will call for a breakdown maintenance leading to more losses either by way of time or money or both. In Delay Time Analysis (DTA), the basic concept is when a fault arises in a part or a system, it gives certain indication before it mature to reach the stage of a faiure (breakdown). DTA models recognises this and the models have parameters like maintenance inspection time (t_i), corrective maintenance time (t_c), breakdown maintenance time (t_b) and the delay time parameter α to optimize the downtime per unit time (DT_u) by introducing

**Author for correspondence*

Periodic Mainteanance Inspection (PMI) at interval T that consumes an inspection time of t_i. During such maintenance inspection, it is also recognised that the inspection need not be perfect, but with a probability of detecting the fault, if a fault is present, the β factor (0<β<1). As β increases, better is the chance of detecting a fault that is present, and hence expect to achieve a better value of DT_u.

This paper is organized as follows: First the concept of DTA is given in section 1.1, review of literature in section 1.2, basic mathematical models of DTA from existing literature is presented in section 1.3. Problem statement about Single inspection and group inspection strategy in section 2.1; the modes of inspection within the group inspection strategy in section 2.2; the methodology adopted to get the different strategies of grouping parts for inspection is discussed in 2.3; Numerical example, and the way the input data set is generated with the Taguchi method of design of expermiments and way data sets are applied in the proposed methodology is given in section 3. Results and discussions are given in section 4 before reaching the concluding part of the paper.

1.1 Concept of Delay Time Analysis (DTA)

In its simpler form, delay time is the duration of time from when a defect is first observable to a point of time when a repair would be essential if a corrective action is not performed within this period. As per Christer et al.[1] the delay time concept defines a two stage stochastic process where the first stage is the initiating phase of a defect (or fault), and the second is the stage where the defect leads to a breakdown (failure). Before a component breaks down, assuming that it is not going to be a sudden breakdown, there will be tell-tale signs of reduced performance or abnormalities. The time gap between the first indication of abnormality (initial point *u* in Figure 1.) and the actual failure time (failure point) is the delay time or the opportunity window to carry out the corrective maintenance and avoid a failure situation.

If an inspection is carried out during the delay time h, then the defect is likely to be identified and corrective maintenance action can be taken thereby saving the situation of entering in to a failure and facing the associated consequences.

If at all the failure distribution and the delay time distribution could be arrived at for a part or a system then it is possible to model the relationship between the PMI interval T and the expected down time per unit time.

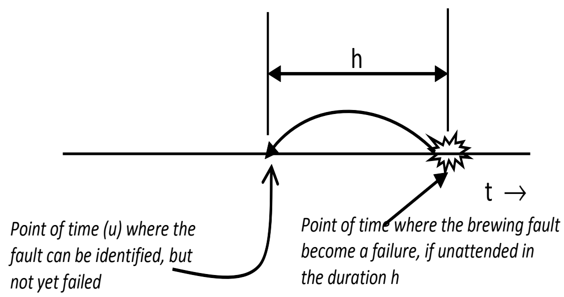

Figure 1. Concept of delay time.

1.2 Review of Literature

In the research paper[1] it is assumed that the time of origin of a fault is uniformly distributed over time since the last inspection and is independent of the delay time h. The length of delay time is assumed to follow the exponential distribution. The list of assumptions is shown in[1].

A modified delay time model allows non-perfect inspection and arbitrary distribution of the initial fault time and delay time distributions, which make delay time models more practical which is explored by[3], and later referred by[5]. The methodology of obtaining the subjective estimate on the delay time adopted by[1] which are also mentioned in[6], by querying the repair technician as follows:

- How long ago could the fault have first been noticed by an inspection or by an operator (=HLA)?
- If the repair was not carried out, how much long could this fault be delayed until it would have caused a failure (=HML)?

The subjective estimate of delay time was obtained as h = HLA + HML.

By analyzing sufficient number of faults or failures, a distribution for f(h) may be obtained. In[2], the author has presented a case study where delay time analysis has been applied at Pedigree Petfoods Limited to derive an optimum-cost maintenance policy for the canning line. The technique was later adopted by management. It was observed that the distribution of *h* was observed to be approximately exponential with a longer tail. In[3] another case study had been presented where the DTM and failure analysis were applied to model the preventive maintenance of a vehicle fleet of tractor units operated by Hiram Walker Limited. The owners of the factory were benefited by increasing the duration between two maintenance intervals. Case study related to environment cost model is in[4].

In[7] Wang et al investigated the series of problems faced by researchers in the methods of obtaining subjective estimate on the delay time distribution and also has proposed a revised method of obtaining the same, by explaining how to combine the opinions of more than one experts on delay time. Baker *et al.*, in[8] and[9] proposed a method of using objective data collected from records kept by engineers maintaining several items of medical equipment. Considering the difficulties in obtaining the estimates on parameters, In[10], Wang has suggested to proceed initially with subjective data and then improve the same when objective data starts pouring in due course of time. Exhaustive details on the recent advances in delay time based maintenance modeling by Wenbin Wang in[11].

1.3 The Delay Time, the Basic Mathematical Model

As per[1], the down time per unit time, D(T), is,

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

where λ is the parameter for the exponential distribution for the failure process indicating the rate of occurrence of defects built from past data t_i is the average down time due to maintenance inspection and the t_b being the mean downtime due to breakdown repairs and *b(T)* is the proportion of faults that will end up as failures during the period T, given that faults will occur in T, where,

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

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. Expression for the DTA incorporating the imperfect inspection too is given in by Chirster et al in[1].

However in this paper the Christer's basic model given in equation (1) taken into consideration for arriving at the values of DT_u.

2. The Proposed Methodology to Take a Decision on the Effective DT_u for Grouping

2.1 Problem Background-Introduction to the Proposed Study

A plant contains many equipment; each equipment their own subsystems; subsystems have their own parts; It is possible to implement the DTA methodology by plant or equipment or subsystem or by part. Theoretically it is possible to obtain the DTA data up to the depth of fault mode, the lowest level. Key DTA related data are obtained by subjective means, delay time values for a fault for example.

If a factory decides to implement the DTA based Periodic Maintenance Inspection (PMI) on their equipment with the objective of reducing downtime per unit time of available time, then another decision has to be taken whether to subject the subsystems to inspection on single subsystem basis or as a group. A subsystem is deemed to belong to equipment provided its failure shall render the equipment dysfunctional in this analysis. Characteristics of the single inspection and group inspection are as follows: -

- Single inspection: Do the inspection on all subsystems at their optimized interval Ti* for an indicated value of DTu* based on their DTA data set. During which time the equipment will be ordered to stop for carrying out the inspection. 6 different periodic intervals if 6 subsystems are involved in the PMI arena, for example.
- Group inspection: Bunching up all subsystems and subject them to maintenance inspection, in a single common interval, Te* computed for a DTue* based on the DTA data applicable for the group; however dealing with the inspection on subsystems can be either doing inspection on all of them in parallel or in sequence. Grouping may be at equipment level or even at higher level.

Here after for the rest of this paper, the terms single inspection and group inspection shall mean the above statements.

Generally the tendency is to combine many subsystems and perform group inspection following a check list covering many subsystems/parts involved. Downtime per unit time (DT_u) or Cost per unit time (C_u) can be the objective variable for minimization. This paper proceeds to discuss by keeping the DT_u as the objective variable. When it comes to arriving at the DT_{ue} for equipment or at higher level, all the input parameters of individual subsystems (say parts) are subjected massive averaging. There can be certain subsystems or parts which may have the breakdown maintenance itself as optimal maintenance strategy. In this paper subsystems (parts) are segregated into PMI worthy and breakdown-worthy (BD worthy) parts.

If DT_n is the downtime per unit time contribution of a part if left to breakdown maintenance strategy and no PMI shall be planned for the same then

$DT_u < DT_n$ is the basis for categorizing parts into PMI-worthy parts.

$DT_u \geq DT_n$ is the basis for categorizing parts into BD-worthy parts.

Objective variable of downtime per unit time (DT_u) is optimized for two subsequent levels, one at the equipment level and another at the subsystem level. Net effect on the DT_u is computed for both cases to see if decision will be better.

2.2 Mode of Inspection within the Group Inspection Strategy

In order to perform the group inspection, say at an equipment level, the DTA parameters of its subsystems are to be aggregated. There could be two cases while aggregating the subsystem data to obtain an equipment DTA data (higher level).

1. First case is to assume that, during inspection time, all subsystems are inspected (and corrective repairs done if needed) one by one in serial manner (Series inspection). This is done where there are limited inspection resources available. This type of group inspection is addressed as group inspection-series type in this paper.
2. Second case is to assume that, all subsystems can be inspected at the same time (parallel inspection). This is done where there are enough human and testing resources available to perform the inspection of all subsystems at a time and that this is technically feasible too. This type of group inspection will be addressed as group inspection-parallel type.

Parallel inspection assumption is in consistent with the assumption of Christer *et al* in[1], where all the inspection and the corrective repair actions are completed within the allotted inspection time of t_i.

Basis for data aggregation at equipment level, in case of series inspection is taken as,

$$\lambda e = \sum_{k=1}^{m} \lambda_k, k = 1, 2, .. m \tag{3}$$

$$tie = \sum_{k=1}^{m} ti_k, k = 1, 2, .. m \tag{4}$$

$$tbe = \frac{1}{m}\sum_{k=1}^{m} tb_k, k = 1, 2, .. m \tag{5}$$

$$He = \frac{1}{m}\sum_{k=1}^{m} h_{i=k}, k = 1, 2, .. m \tag{6}$$

Where m is the number of parts screened for being PMI-worthy. For the case of equipment level parameters the additional letter of '*e*' is used in the equations; *tie* representing the inspection time required performing on all parts in a single interval at equipment level, for example. It is assumed that all subsystem-parts have same number of data points in order to arrive at their own DTA input parameter average values of λ, t_i, t_b and H in order to force aggregation on them at equipment level, like the average *tbe* for example. This may not be the case in reality when dealing with DTA related data for parts and the practitioner is cautioned about this aspect; some compromise may have to be done on this.

Basis for data aggregation at equipment level, in case of inspection done on all subsystem parts simultaneously (in parallel), is given by changing the aggregate for *tie* only as,

$$tie = max\{ti_k\}, k = 1, 2, .. m \tag{7}$$

2.3 Methodology Adopted to Arrive at the Downtime Per Unit Time Indicator for the Strategies of Inspecting at Subsystems Level and at Equipment Level Grouping

1. Prepare the data set comprising all DTA parameters applicable at subsystem level. Data at this level is the first level to get from factory, when the subsystem happens to be at part level.

2. Compute DTu_i*, T_i* at subsystem level for all subsystems that belong to one equipment based on the subsystem's independent DTA parameter values.
3. Compute the Net DTus, downtime per unit time for the equipment (basis: subsystem, part, inspection at their own unique intervals). For this purpose,
   a. Sort out those subsystems for which are not PMI worthy, called as BD worthy;. BD worthy subsystems will have their contribution of downtime per unit time, as DTn_j, j = 1,2..n. DTn is the down time per unit time contributed by a part that is not subjected to DTA related Periodic Maintenance Inspection (PMI). These parts will show no further reduction in DT per unit time even if it is subjected to PMI.
   b. Certain parts, depending on their DTA parameters shall indicate that a reduction in downtime per unit time due to this part is possible when subjected to DTA related PMI. Such parts are called as PMI-worthy parts. Each of these parts will have their own optimum inspection interval, T_i, contributing a DTu_i, i = 1,2...m.
   c. Net DTu for the single equipment, when inspection is performed at subsystem level, Net DTus $= \sum DTu_i + \sum DT_j$, for single inspection basis.
4. Now arrive at the input DTA parameters at equipment level (higher level) aggregating those data of all the lower level PMI worthy subsystems for the serial inspection case, using equations (3)–(6).
5. Compute the DTue* at higher level, based on the equipment DTA data, which shall result in a single inspection interval Te* for all subsystems for which PMI is worthwhile. Net DTue = DTue+$\sum DTn_j$. Since this value is computed for the Equipment level grouping with series type inspection, let this be called it as Net DTue-s.
6. Compute DTUe-p, the Net DTue for the parallel inspection case, for the same equipment, with the only change for aggregating *tei*, using equation (7).
7. Now three net DTu values are available {Net DTus, Net DTue-s, Net DTue-p}, from which a convenient strategy can be chosen depending on the environment prevailing at the factory.
8. The final decision may prompt the practitioner
   a. to leave certain subsystems of the equipment to BD maintenance strategy; Never take them for maintenance inspection.
   b. Other subsystems may be decided
      i. To undergo single inspection with matching inspection intervals, T_i, i = 1,2..m, which are unique for individual subsystem (part) or,
      ii. To undergo group inspection with a common single inspection interval, T. Within this equipment level inspection grouping strategy, the inspections could be done on subsystems, either all at a time (parallel) or in series, depending on resource constraints.
9. Do similar computations for all the equipment and arrive at the decisions.

3. Numerical Example to Study the Effect of Grouping

Exponential distribution with parameter λ is assumed for the defect arrival rate, and the average delay time H is represented as α where 1/H = α, is used as the parameter to describe the delay time pdf as,

$$f(h) = \propto e^{-\propto h} \tag{8}$$

In order to investigate the effect of grouping of parts, it is necessary to arrive at the input data set for all subsystems on DTA parameters. For this purpose sample data for equipment is obtained from the industry for the values of λ, defects arrival rate (objective data) and the values of t_i, t_b and H are obtained in a subjective manner, since current maintenance practices do not provide room for collecting such data. In order to arrive at a more general unbiased data, Taguchi data set to investigate the effect of 4 factors (λ, t_i, t_b, H each set at four practical levels) yielded L16 design. Table 1 shows the L16 design. Following the same symbols of Christer's equation (1), data levels of λ {0.005556-0.033333-0 .142857-0.285714}, ti {0.0625-0.1250-0.5000-1.000}, tb {0.125-0.500-1.000-2.000} and average H {1-4-7-14} have been chosen. The values of data are nearly practical when we consider the time unit 'day'. The same 16 sets of data are appended second time to get a set of 32 data rows. All data combination as per Taguchi design must be present and the order the data rows are not important for this experiment. The 32 rows are then shuffled randomly. Now each row of 32 is represents the DTA data set of subsystems. These subsystems are assigned to four equipments *e1-e4* each having 8 lower level subsystems, represented as *p1 to p8*.

Table 1. Input data for Taguchi 4F x 4L design

run no	λ	ti	tb	H
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

Table 2 shows the final version of the 32 sets of synthesized input data needed for a DTA wherein the lower level of subsystem considered is individual parts. It can be noted that each row can be identified by the combination {equipment name-part name} which is unique, by combination name but may represent in reality, similar part at times; same clutch type is available for maintenance in two different equipment, for example.

For the sake of checking correctness of the formula expressions used to compute delay time per unit time, DTu, as per equation (1), for the defects arrival rate (exponential distribution is assumed), the delay time distribution (exponential distribution, with arrival rate α is assumed), the numerical example of Christer et al in[12] for the basic model is solved and the graph obtained is shown in Figure 2 for the DT_u with same data of λ0.2, t_i0.3, t_b0.8 and H20 (i.e. α = 0.05) yielding the solution as T10, DT_u of 0.0622 for the basic model. Point B in Figure 2 is explained in the results and discussion.

Table 3 shows the data for the equipment level aggregation, the first four rows showing data set for the inspection done in series for the parts concerned (represented as e1 s, e2 s …) and the rows 5-8 showing those for the inspection done on all subsystem parts in parallel (simultaneously and represented as e1 p, e2 p, …).

Same equation (1) is employed for all computations to get the optimum periodic maintenance inspection interval T* to achieve optimum downtime per unit time, DTu*, at equipment level too.

Table 4 shows the consolidated results showing different values for *Net DTu* for 4 equipments for three cases; single part inspection basis as Net (DTus), group inspection (series) as DTue-s and group inspection (parallel) as DTue-p.

The Net DTu= (DTu contribution by PMI worthy parts + DTn contribution by BD worthy parts)

For single inspection,

$$DTus = \sum_{i=1}^{m} DTu_i \tag{9}$$

For group inspection, for example, cell values in,

Table 4\DTue-s\e1 = (Table-3\DTu\e1 s) + (Table-2\DTnj, j=1,3,4,7,8 as in table-3 for e1)

4. Results and Discussion

From Table 2, it can be noticed that the subsystem e1-p1 is not PMI worthy since its DT_u > DT_n; and subsystem e1-p2 is PMI worthy since its DT_u < DT_n showing a savings potential of (DT_n-DT_u). It can be seen that, the aggregated data of all equipments (e1, e2, e3 and e4) indicate the scope for having reduced downtime per unit time value when a PMI strategy is planned, at equipment level group inspection since their respective DTu* values are lower than their DTn.

In Table 4 it is obvious that all DTue-p (the DTue values for *parallel* inspection cases) are invariably found smaller than DTue-s, those for the series inspection cases; the reason is that the total inspection time consumed for inspection of all subsystem is lesser (all inspections are performed within the inspection time of the part demanding longest inspection time). This strategy is possible only if all inspection related material resources and enough number of inspectors is available to work parallel on the equipment inspecting all parts and that all parts are technically accessible at the same time.

In Table 4, in the case of equipment e1, DTus0.3222, single inspection at subsystem level one by one at their own T_i*, indicates favorable compared to DTue-s 0.3265 for group inspection of all parts at equipment level (series). Equipment e2,e3 and e4 supports group inspection-series since all of their DTue-s values are lesser than the DTus

Table 2. Data set, with two sets of L16 datasets, shuffled at random. (Parts to be left out for breakdown maintenance strategy are shown shaded). Computed results T_i*,DTu_i* are given

Slno	Eqpt name	Part name	λ	ti	tc	tb	H	DTn	T_i	DTu_i	Effective Dtu
1	e1	p1	0.142857	0.5	0	0.125	4	0.01786	10000	0.01790	0.01786
2	e1	p2	0.285714	0.5	0	0.5	14	0.14286	12.5	0.08500	0.08500
3	e1	p3	0.033333	0.5	0	2	1	0.06667	10000	0.06666	0.06667
4	e1	p4	0.005555	1	0	2	14	0.01111	10000	0.01120	0.01111
5	e1	p5	0.033333	0.0625	0	0.5	7	0.01667	12.5	0.01380	0.01380
6	e1	p6	0.142857	0.25	0	2	7	0.28571	4	0.12290	0.12290
7	e1	p7	0.005555	0.0625	0	0.125	1	0.00069	10000	0.00070	0.00069
8	e1	p8	0.033333	0.25	0	0.125	14	0.00417	10000	0.00420	0.00417
9	e2	p1	0.005555	0.25	0	0.5	4	0.00278	10000	0.00280	0.00278
10	e2	p2	0.033333	0.5	0	2	1	0.06667	10000	0.06667	0.06667
11	e2	p3	0.033333	1	0	1	4	0.03333	10000	0.03340	0.03333
12	e2	p4	0.033333	1	0	1	4	0.03333	10000	0.03340	0.03333
13	e2	p5	0.142857	0.0625	0	1	14	0.14286	4	0.03370	0.03370
14	e2	p6	0.033333	0.25	0	0.125	14	0.00417	10000	0.00420	0.00417
15	e2	p7	0.142857	0.0625	0	1	14	0.14286	4	0.03370	0.03370
16	e2	p8	0.285714	0.0625	0	2	4	0.57143	1	0.12080	0.12080
17	e3	p1	0.005555	0.25	0	0.5	4	0.00278	10000	0.00280	0.00278
18	e3	p2	0.285714	1	0	0.125	7	0.03571	10000	0.03580	0.03571
19	e3	p3	0.285714	1	0	0.125	7	0.03571	10000	0.03580	0.03571
20	e3	p4	0.005555	0.5	0	1	7	0.00556	10000	0.00560	0.00556
21	e3	p5	0.285714	0.25	0	1	1	0.28571	2	0.25530	0.25530
22	e3	p6	0.285714	0.0625	0	2	4	0.57143	1	0.12080	0.12080
23	e3	p7	0.005555	0.5	0	1	7	0.00556	10000	0.00560	0.00556
24	e3	p8	0.142857	0.25	0	2	7	0.28571	4	0.12290	0.12290
25	e4	p1	0.285714	0.5	0	0.5	14	0.14286	12.5	0.08500	0.08500
26	e4	p2	0.033333	0.0625	0	0.5	7	0.01667	12.5	0.01380	0.01380
27	e4	p3	0.142857	0.5	0	0.125	4	0.01786	10000	0.01790	0.01786
28	e4	p4	0.142857	1	0	0.5	1	0.07143	10000	0.07150	0.07143
29	e4	p5	0.142857	1	0	0.5	1	0.07143	10000	0.07150	0.07143
30	e4	p6	0.005555	1	0	2	14	0.01111	10000	0.01120	0.01111
31	e4	p7	0.285714	0.25	0	1	1	0.28571	2	0.25530	0.25530
32	e4	p8	0.005555	0.0625	0	0.125	1	0.00069	10000	0.00070	0.00069

for the subsystem level single inspection, DTue 0.2870 is < DTus 0.3285 in case of e2 for example.

Logically DTus is supposed to offer the least DTu than the DTue-s all times. This is because DTus is the sum of all DTu* which were the result of performing the inspection at T_i* which is unique and least for the individual case. Imposing a common Te in the name of grouping is likely to destroy the optimal points on all parts, either way, and

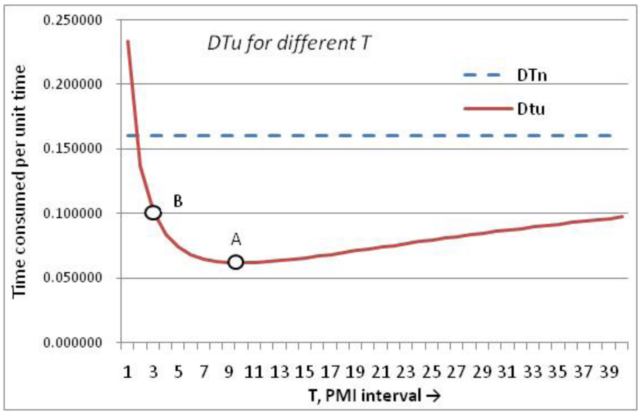

Figure 2. Variation of downtime per unit time as per input parameter values for the example in[12] for the basic model. Optimal DTu for periodic maintenance inspection is at point A and the line DTn indicates downtime per unit time for the same part when left to the strategy of breakdown maintenance.

hence the final sum DTu-s is supposed to be higher in case of DTue than DTus. In Figure 2, for example, if a group inspection imposes a common maintenance interval of Te = 3 on the part {Christer's example in[12]} then this part shall be forced to contribute a DTu of 0.1013, shown as point B, to the group inspection strategy which will be always > DTu achieved by the same individual part which is having its own unique T* = 10 with a DTu0.0622 at single inspection strategy, which is shown as point A, the optimal point in Figure 2.

Still it is observed in Table-4 that the DTue-s of e1 alone is found to fit in to this logic and e2 s, e3 s, and e4 s are found to violate. This is due to the error that occurred during the aggregation of individual subsystem's parameters like the t_b, H which may not contribute to DTu in proportion to their values of t_b or H since the final contribution for DTu is dependent on other parameters too.

Table 3. Aggregated data set at equipment level (row1-4 for serial inspection case, row 5-8 for parallel inspection case)

Sl No.	Eqpt name	Parts left out for BD maintenance	λ	ti	tc	tb	H	DTn	Te	DTu	Effective DTu
1	e1 s	1,3,4,7,8	0.461904	0.8125	0	1.00	9.33	0.461904	6.5	0.2260	0.2260
2	e2 s	1,2,3,4,6	0.571428	0.1875	0	1.33	10.67	0.761904	2.5	0.1467	0.1467
3	e3 s	1,2,3,4,7	0.714285	0.5625	0	1.67	4.00	1.190475	1.5	0.4165	0.4165
4	e4 s	3,4,5,6,8	0.604761	0.8125	0	0.67	7.33	0.403174	6.5	0.2318	0.2318
5	e1 p	1,3,4,7,8	0.461904	0.5	0	1.00	9.33	0.461904	5	0.1857	0.1857
6	e2 p	1,2,3,4,6	0.571428	0.0625	0	1.33	10.67	0.761904	1.5	0.0891	0.0891
7	e3 p	1,2,3,4,7	0.714285	0.25	0	1.67	4.00	1.190475	1	0.3097	0.3097
8	e4 p	3,4,5,6,8	0.604761	0.5	0	0.67	7.33	0.403174	4.5	0.1917	0.1917

Table 4. Indicated Net DTu for 4 equipments for different strategies of Periodic Maintenance inspection in DTA (sum of DTu, DTn)

Equipment Number	Individual Inspection Basis at Unique T for Individual Parts (DTus)	Eqpt Level Inspection with Single T (Serial), (DTue-s)	Eqpt Level Inspection with Single T (Parallel), (DTue-p)
e1	0.3222	0.3265	0.2262
e2	0.3285	0.2870	0.1694
e3	0.5843	0.5018	0.3950
e4	0.5266	0.4043	0.3642

Therefore the resultant values of higher level aggregation may not reveal the reality numerically.

5. Conclusion

By synthesizing a generalized data set for many subsystems through the Taguchi design of experiments technique, possible effects of all factors (defects arrival rate, inspection time, breakdown repair time, delay time parameter) and the subsequent computation of DTu at a higher level reveal that the higher level data aggregation can indicate both ways, to favor or disfavor the grouping strategy, depending on the basic DTA set of lower level data. The methodology of arriving at the parameter aggregation is done a lower level to a higher level grouping for inspection is shown; a numerical example is presented for this purpose.

Averaging out the parameters like the inspection time, breakdown repair time or the average delay time over many part data is diluting the effect of final indicator, the down time per unit time. The main difference in data aggregation between series type of group-inspection and parallel type lies in the way the inspection time (t_i) is aggregated. In the first case the inspection times are summed up and in the second the part or subsystems that consumes longest (maximum) inspection time is taken as the aggregate for higher level grouping.

The downtime per unit time for group inspection (series) on parts at equipment level following a common single interval should always be greater than that for the sum of downtime per unit time for same number of parts subjected to single inspection strategy, following their own individual optimal intervals. This is the reality. However, analysis revealed that the massive aggregation of data on inspection times, breakdown times and the average delay times, leads to misleading indications, while moving from a lower level to a higher level DTA related data, calling for further research on data aggregation while grouping.

Even if we go for a higher level grouping for inspection, say at equipment level, still there is the question of choosing between doing the inspection activities on all subsystems in series or in parallel (simultaneous inspection). Factories having sparable inspectors do not mind in carrying out inspection in parallel; but in case of most Small and Medium Enterprises (SME), committing more man power at a time for a service type of activity is not encouraged. Group inspection, where all subsystems are scheduled to be inspected in a single interval, has the advantage of being viewed as facing lesser number of pestering in the eyes of production personnel.

However, if the number of random type of failure cases is more, then the plant managers do not mind in committing more manpower for maintenance inspection to bring down the net down time. The strategy of parallel inspection can be adopted provided enough inspection equipment and human resources can be mobilized in parallel and of course, access to all parts and usage of inspecting instruments are technically feasible.

It is to be noticed that the delay time basic model has been used in this paper for demonstration of the data analysis. This model considers that the total available time for an equipment is the same as the operating time since the breakdown repair time and inspection times are considered negligible compared to the periodic maintenance interval, T. Therefore the resultant DTu*, the downtime per unit time can taken only for comparing between strategies and shall not be used for an absolute planned value to be compared with the actual situation later during reality

This strategy is acceptable only if the objective is about reduction in downtime per unit time. Practitioners who implement delay time methodology must be cautious about this statistical indicator error while going for higher level aggregation of DTA data sets. It is also cautioned that the same interval T may not be optimal if the basis is cost of inspection, and/or cost of downtime.

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