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RESEARCH ARTICLE

A STUDY ABOUT AVERAGE CYCLE TIME IN MAINTENANCE OF EQUIPMENT.

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Abstract

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Maintenance of equipment nowadays has a larger role in the firms as a result of huge development of equipment, and the production shifted from workers to machines, the control chart is a main tool in the statistical process control, it is used to promote quality level of maintenance of equipment, and control chart can assure lower average cycle time of maintenance procedure under using of Taguchi method of quality control, and several mathematical equations in the procedure will be used to find value of average cycle time in maintenance of equipment in the firm, because the role of maintenance increased, and it will force to reduce failure rates and defects amount which are proportional to higher quality level of applied maintenance.

As a new subject, the research will study to combine four factors of maintenance, average cycle time, x-bar control chart, and quality level.

As a new methodology, Taguchi method of quality control was used to obtain the result of aims of the research which are to achieve small average cycle time in the maintenance procedure.

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Nomenclature:-

The following abbreviations and symbols are the list of Nomenclature used in the research:-

y_0: Failure rate parameter of exponential distribution of the average time for occurrence of assignable cause. It is the average time for occurrence of the assignable cause exponentially distributed with mean $1/y_0$).

y: Failure rate parameter of exponential distribution of average interval for occurrence of the assignable cause. It is the average interval for occurrence of the assignable cause exponentially distributed with new mean ($1/y$) and $y = Ar * y_0$).

Ar: Extension rate in the age of the equipment. It is proportional ($1/r$) to the original one.

δ: Value for the shift of "in-control" process

μ: Process mean.

μ0: Process mean to out-of-control condition

μ1: Process mean in the control chart

w: Warning coefficient. It is maintenance threshold or it is warning width, and in this research, we assign *w* as two third of the magnitude of control width *k*.

ß: Standard deviation of the process.

s: Sample size

k: Control limit coefficient of control chart or control width.

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P_w: *The probability when the process is under control state, and there is no any extra action required.*
P_r: *The probability when the process is under control state but the process mean falls in the warning zone.*
Ω *(•): A cumulative density function of normal distribution.*
h: Sampling interval.
T_{cm}*: Average maintenance time.* It is required elapsed time for each action of maintenance procedure.
h_0*: Expected sampling interval*
ψ*: Average time of occurrence of the assignable cause within an interval.*
T_0*: Mean time duration in which the procedure is in the beginning to the first sampling after the process shifts.*
M_P*: Magnitude of process mean shift if an assignable cause occurs.*
$\overline{P_w}$*: Probability that the mean falls inside warning control limit.*
$\overline{P_r}$*: Probability that the mean falls between the warning and control limit.*
h_1*: Expected sampling interval when the process is out-of-control state.*
θ*: Error probabilities.*
ARL: Average-run length when the process shifts to the out of control state.
T_1*: Expected time interval within the faulty process.*
$Ttap$: *A constant average time to testing the sample, analyzing the results, and plotting which is considered as a consistent time.*
$Tart$*: A constant average time for repairing but after the assignable cause has been identified, and to bring a process back to an in-control state after assignable cause has been identified.*
T_{com}*: Complete average cycle time length.*

Introduction and literature Review:-

The control charts are the important tools of statistical process control SPC, they can be used in order to detect process shifts in both line of mean and variance, the tool of x control chart can monitor and indicate average cycle time, and to show if the procedure of maintenance of equipment is not under statistical control, the corrective action will be done in order to prevent further nonconforming products and to be manufactured by defected equipment and to stop losses [1], it means that the maintenance will return production to the corrected condition, the maintenance with SPC is used to achieve an optimal product quality, the x control chart is used for this purpose, therefore it is regarded as a main tool in maintenance procedure in the manufacturing firms, and it can give greater chance to designate a model to value statistical criteria in this procedure, the first model of economic design of x control chart was applied by the researcher, and later he extended his research from single to multiple assignable causes in which the failure mechanism was assumed to be an exponential distribution [2], by its equations, it can really give lower time and minimum cost when compared with other models such as Shewhart's model, because the researcher added an optimum methodology in his research in order to get three design parameters: subgroup size (n), sampling interval (*h*) and control-limit width (+ k & - k standard deviation), and this initial model was made for minimizing cycle time [3].

Literature review:-

Several previous studies have been completed in order to improve control charts and determine average cycle time. After Duncan's study, there were many papers proposed an economic design of control charts, therefore an optimization procedure was developed for determining parameters of cycle time for the x-bar control chart [4]. Then a literature review achieved about average cycle time in economic design of control charts between years 1981-1991 [5], they concluded improvements on the models and cycle time. Thus, several other recent studies achieved and made other developments and variable results so as to achieve theoretical development of average cycle time of economic design for control chart subjects. According to the Duncan cost model, the researcher "Engin - 2004" developed an application for the use of economic statistical x chart design in the textile yarn industry as experimental study and searching for the optimum n, h and k the author considered the power of the control chart to be at least 0.95 and the penalty-cost as minimal as possible [6]. An integrated model of control chart and maintenance management was developed, in which the control chart was used in order to monitor the equipment and to provide signals which indicate equipment deterioration, while planned maintenance is scheduled at regular intervals to obstruct equipment failures [1]. In more developed subject, other studies focused on software to detect algorithm for economic design of x-bar charts parameters, and majority applications were carried out by using MATLAB, C, and SAS, it proposed a genetic algorithm for economic design of x-bar charts by using these programs [7&8].

Taguchi method of quality control:-

The Japanese engineer-statistician Dr. Genichi Taguchi developed Taguchi method which is defined as a quality control methodology because it can combine control charts with process design to achieve a robust total design, this method aims at reducing product variability within a production system to develop design and specifications into the products in firms [9], thus the maintenance of equipment can have their control enforced, Taguchi method of quality control was expanded by many studies so as to be used in various fields of engineering and involve identification of proper control factors to obtain optimum results of the production process [10], therefore the aims of the maintenance of equipment as an engineering service are to gain best results, and it can be applied in manufacturing process. The Taguchi method of quality control recognizes the roles of researches through research development programs, and in reducing the occurrence of defects and failures in maintenance by firms. Figure 1 shows the losses, target value, both lower and upper limits of specifications, and rework and waste areas resulted by any maintenance procedure or manufactured products, they happened when it is out of control, thus, the main contribution of Taguchi method lies in several mathematical formulas with quality improvement technique to gain suitable average cycle time of maintenance of equipment in the firms, a study affirmed consideration of this method that the task of economic design of control charts is important in manufacturing process and quality control, therefore it tries always to eliminate variances in the process before they can occur [11].

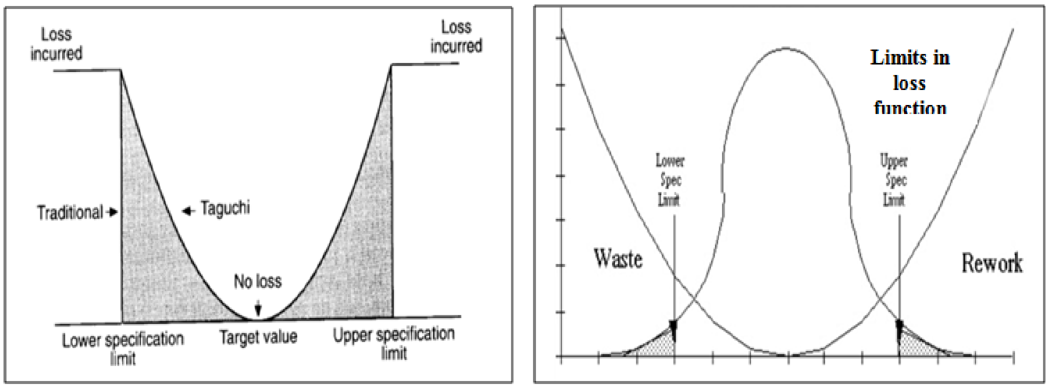

Figure 1: Taguchi methods of quality control and loss function of limits, waste, and rework

Several researches indicated the importance of Taguchi method of quality control, they proved that they can overcome bad design of products and bad plans of maintenance, in addition, it can increase design and inspection features, and focus on robust design during manufacturing process, it uses way of statistical procedures and relies on developed model rather than statistical techniques during manufactured phases [12], in addition, Taguchi presented his views about design of products by a program with three phases such as: system design, parameter design, and tolerance design [13] which can enhance maintenance of equipment during manufacturing process by reducing variations in the process and minimizing average cycle time through robust design of experiments which is a new concept and related to the maintenance procedures, and the method tends not to defect and high quality level of the procedures, Taguchi method of quality control takes place in four steps of defining all factors specific for the optimization problem, selecting suitable control factors, analysis of results, and conducting of the verifiable experiments [14].

Options of new Developments:-

After great development of technology and production methods and as a result of increased uses of automated machines and robots in the firms, the manufacturing process were shifted from workers to equipment or machines, therefore the number and quantity of maintenance of equipment became bigger and took more importance by the firms.

This new state took an evident role to continual production by equipment and decreasing stoppage, therefore, it takes now a vital role to control main options of quantity, quality, time, and cost of maintenance of equipment, the effects of these options became larger more than ever because the relation among these options and maintenance became more stronger, nowadays most academicians and technicians recognize that there is a strong relationship between product quality and equipment maintenance [15], therefore the interrelation among several options, product's quality, control chart, and maintenance procedure is the working axel by the firms, but there is another interrelation between control chart and maintenance procedure which was enlarged and still continue, many results of studies affirmed the actual integration between control chart and maintenance procedure, even they approved more benefits to the firms, and they determined jointly optimal design parameters on an x control chart and time of maintenance [16]. Others prepared economic design model of control charts as essential basic to maintenance of equipment in the firms, because of the maintenance frequency that may take a long time in the firm, therefore to reduce unnecessary extra time, they developed an integrated model of control chart and maintenance management [17], the equipment will be accepted by firms when their measurements meet required specifications of maintenance procedures time and there will be no loss of cycle time and there will be no loss of quality according to associated standards, and this is the main objective of all firms. Therefore all aforementioned losses should be minimized until measurements of equipment will accept limits of cycle time in control and take free state of defects, deficiencies, and significant variations, and the average cycle time will be at right value when the results are same target in the maintenance procedure, this concept is used in most models of economic design of control charts, therefore Taguchi suggested that any deviation from value results of target is a loss of cycle time [18].

Cycle parameters and variables:-

There are several parameters and variables related to cycle time in control chart, they are considered in the economic design of control charts [19], there are 29 of parameters that will be inserted into control chart in order to find average cycle time, they are expressed by symbols as Nomenclature, in addition, there are some decision variables and other parameters noted in other references [16].

There are three variables that should be selected and assumed as decision variables in control chart in order to find average cycle time when designing control chart and to monitor the maintenance of equipment, the variables are: sample size (n), interval between successive subgroups (h), control limits (k), and warning coefficient [20]. Also, it is necessary to mention essential assumptions about maintenance procedure which begins in-control state, and a study [16] suggested as follows:

- The maintenance procedure is either in-control or out-of-control condition, and it will be in-control at beginning of the operation, but later it is shifted and it cannot be back to the start of in-control automatically.
- There is one assignable cause in the maintenance procedure, but there is shifts (MP ß) if an assignable cause occurs, also, during repair the procedure will be in continuity as the x are in normal distribution.
- The maintenance procedure will be conductive when the statistic character is located over two third magnitudes of the control width.

Aims of the Research:-

This research has following aims:

- It tries to find average cycle time of maintenance of equipment in the control chart
- It uses Taguchi method of quality control and several mathematical equations to find value of average cycle time.
- It tries to minimize loss of average cycle time, and to minimize loss of quality according to associated standards.

Methodology of the Research:-

The methodology consists of several steps, the research will:

- Take parameters and decision variables from analyzing previous and recent studies, then using them in the research after some changes.
- Collect options of quantity, quality, cost, and time of maintenance of equipment, and illustrate strong interrelation among options, maintenance, control chart, and cycle time of control chart.
- Affirm that the actual integration between control chart and maintenance become more beneficial to firms, and to confirm that theses interrelation is maximized and developed.
- Use Taguchi method of quality control and mathematical equations to find average cycle time of maintenance of equipment through control chart.

Average cycle Time:-

The cycle time represents the time of the cycle work of maintenance procedures of equipment, its value determined in control chart by solving several mathematical equations in which they can be inserted within production process in the firm, the cycle time is regarded as expected average cycle time because it will be defined as the total time length required for maintenance of equipment [19], it will start in-control condition, but if an assignable cause occurs on this stable condition, the cycle will begins to be detected in the procedure in order to be brought back to an in-control state, the cycle time has 4 time intervals [16] such as:

(1) The interval in which the production process is in-control
(2) The interval in which the production process is out-of control but still undetected
(3) The interval between the time at which the assignable cause is detected and identified
(4) The interval between the time at which the assignable cause is identified and repaired

In many maintenance procedures, the average time for occurrence of assignable cause is exponentially distributed with mean ($1/ y_0$), and value of the cycle time can be referred as a good kind after achieving each one of correction actions, but the cycle time cannot be specified as a realistic value state when the failure rate of the maintenance is increased after each action of the maintenance, hence the extension in the age of the equipment inside production process is proportional (1/Ar) to the original, therefore the average interval for occurrence of assignable cause is exponentially distributed with new mean (1/y) and $y = Ar * y_0$).

The operating of equipment and average cycle time are important factors that should be precisely measured and necessary to produce high quality maintenance of equipment in the firms, they are required to perform inspection about in-operation equipment, but the inspection process has limited time to perform on-control state of related equipment activities, and this will lead to fix each of:

- Value for the shift of "in-control" process δ
- Process mean to out-of-control condition μ0
- Process mean in the control chart μ1

Therefore, the selection of corrected value for shift size can be assumed as a difficult decision tackled by the quality practitioner due to the lack of former process knowledge [20], in such case we should have a state in which if the quality characteristic is located between the zone called "warning zone" of (μ + w $ß/\sqrt{s}$) and (μ + k $ß/\sqrt{s}$) or between the zone of (μ - w $ß/\sqrt{s}$) and (μ - k $ß/\sqrt{s}$), then an action of maintenance of equipment should be taken and to be done, as affirmed by the study [21], the process will start "in-control" at a random time, then a step shifts during research for the assignable cause, but it is allowed to continue in operation, it is considered cycle time as depicted in Figure 2. [6], and it should be mentioned that the major function of control charting is to detect the occurrence of assignable causes so that the necessary corrective action may be taken before a large quantity of nonconforming product is manufactured [22], because the production process by equipment in the firms is assumed as a series of independent cycles over time, and each cycle begins with the production process in the "in-control" state and it will continue until the process changes and its change is detected and identified [23].

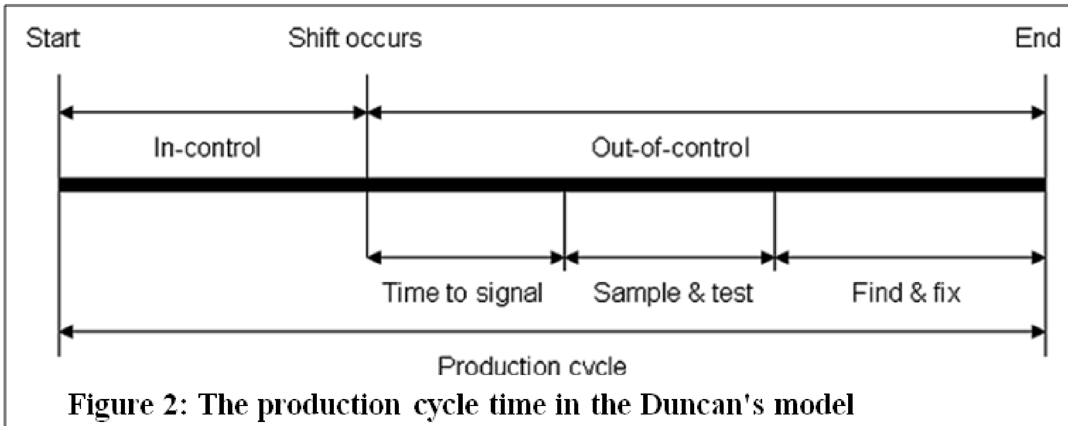

Figure 2: The production cycle time in the Duncan's model

To find expected sampling interval h_0 when the maintenance procedure is in-control state, it is supposed that both probabilities *Pw* and *Pr* as mentioned in above Nomenclature, and to find average cycle time, several equations will be used and some of them are presented by a study and as follows [16]:

At first, both probabilities are expressed by:

$P_w = \Omega(w) - \Omega(-w) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$

$P_r = 2[(\Omega(k) - \Omega(w)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$

Later, let h be the sampling interval and the T_{cm} is the required in elapsed time for each action of maintenance procedure, then the h_0 will expressed as:
$h_0 = h * Pw + (h + Tcm) * Pr \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$

In order to find the time value of occurrence of assignable cause within an interval ψ, it can be shown as following equation as came by Duncan-1956 [2]:

$$\psi = \frac{e^{y\text{h}_0} - (1 + y\text{h}_0)}{y\,(e^{y\text{h}_0} - 1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

But in order to find a complete average cycle time length $T_{com,}$ at first it is necessary to find T_0 and $T1$, and to get their values, the next steps should be followed:

- Equation 5 is ready to find Mean time duration in which the procedure is in the beginning to the first sampling after the process shifts T_0 which expressed as:

$$T_0 = (h_0 * e^{-yh0} + h_0 * e^{-y2h0} + h_0 * e^{-y3h0} + h_0 * e^{-y4h0} + \ldots) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

- The mean process μ will shifts to ($\mu + M_P$ ß) when the process fails, $\overline{P_w}$ and $\overline{P_r}$ can be shown and expressed as equation 6 and 7:

$$\overline{P_w} = \Omega\left(w - M_p ß\right) - \Omega\left(-w - M_p ß\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$
$$\overline{P_r} = \Omega(-w - Mpß) - \Omega(-k - Mpß) + \Omega(k - Mpß) - \Omega(w - Mpß) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

- The expected sampling interval when the process is out-of-control state h_1 can be shown and expressed as equation 8:

$$h1 = h * \overline{P_w} + (h + Tcm) * \overline{P_r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

- To find Average-run length when the process shifts to the out of control state *ARL* we need to find error probabilities θ, it will be as equation 9 and 10:

$$\theta = \overline{P_w} + \overline{P_r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$
$$ARL = \frac{1}{(1 - \theta)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

- To find Expected time interval within the faulty process T_1, equation 11 assures it:

$$T1 = h * \overline{P_w} * ARL + (h + Tcm) * \overline{P_r} * ARL \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

- It is essential to mention other two times in the maintenance procedure, such as: a constant average time to testing the sample, analyzing the results, and plotting which is considered as a consistent time $Ttap$ and a constant average time for repairing but after the assignable cause has been identified, and to bring a process back to an in-control state after assignable cause has been identified $Tart$, it is necessary to add them into the $Tcom$, then it can be shown by:

$$Tcom = T0 + T1 + Ttap * s + Tart \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Results and Discussion:-

Results:-

Large development of machinery and technology of production occurred, the process of manufacturing is shifted from workers to equipment, as a result, the maintenance becomes more important to continual production and decreasing stoppage in operated equipment, and the number of maintenance of equipment becomes higher after manufacturing process shifted from workers to equipment. It is resulted that many studies recognized that there is a strong relationship between equipment maintenance and product quality produced by the equipment, as results indicated interrelation among several options of quantity, quality, time, and cost of maintenance of equipment, and the effects of these options become larger more than ever because the relation among these options and maintenance become more stronger. There are 12 mathematical equations used to find value of average cycle time, the cycle time has 4 time intervals in production process, the cycle time is defined as total time length required for maintenance of equipment and it will start in-control condition, there are 29 parameters that will be used and inserted into control chart, they are mentioned in Nomenclature in this research. The maintenance procedure has two stats, it is either in-control or out-of-control condition in the firms and the in-control at the beginning.

Discussion:-

The maintenance becomes more important procedure in the firms because large numbers of maintenance are necessary after increasing role of equipment because the manufacturing process is shifted from workers to equipment. The in-operation equipment needs for larger amount of maintenance in order to continue production and generating new condition of higher quality maintenance and an interrelation crucial role to control main options of quantity, quality, time, and cost of manufactured equipment in the firm. If an assignable cause occurs on in-control condition, the cycle time begins to be detected and identified by a model in order to be brought back to an in-control state. The equipment will be accepted by firms when their measurements meet the required specifications of maintenance procedures time and there will be no loss of cycle time and there will be no loss of quality according to associated standards, the average cycle time of maintenance can be found but after using of 12 mathematical equations because it contains 29 parameters.

Conclusions and Recommendations:-

Conclusions:-

The control charts are the important tools of statistical process control, they use to detect process shifts in line of mean and variance, the tool of x control chart can monitor and indicate average cycle time, and to show if the maintenance is under control or not, the correction action will be done in case of no control to prevent further nonconforming products.

The cycle time represents time work of maintenance of equipment, its value determine in control chart by mathematical equations, the cycle time is regarded as expected average cycle time as total time length required for maintenance of equipment, to enhance maintenance of equipment during manufacturing process by reducing variations in the process and minimizing average cycle time through robust design of experiments, the equipment will be accepted by firms when their measurements meet required specifications of maintenance procedures, Taguchi method is defined as a quality control methodology because it can combine control charts with process design, Taguchi method lies in several mathematical formulas with quality improvement technique to gain suitable average cycle time of maintenance of equipment in the firms. When designing a control chart and monitor the maintenance of equipment, the variables are: sample size (n), interval between successive subgroups (h), control limits (k), and warning coefficient (w). Taguchi method of quality control used in various fields of engineering and involve proper control factors to obtain optimum results of production process, and used in order to continual production by equipment and decreasing stoppage, and to enforce equipment maintenance, this new condition has an evident role and plays vital role to control main options of quantity, quality, time, and cost of maintenance of equipment. After great development of technology of production and the increased uses of automated machines and robots in the firms, the manufacturing process are shifted from workers to equipment or machines, therefore the number of maintenance of equipment became higher, also it took bigger importance for the firm's level.

The maintenance procedure is either in-control or out-of-control condition, it assist to find average cycle time, the effects of options became larger more than ever because the relation among these options and maintenance became stronger, there are strong relationship between product quality and equipment maintenance, and there are many parameters and mathematical equations to find time cycle. The new studies use software programs in order to detect arithmetic state for economic design of x-bar chart parameters, and majority applications are carried out by using MATLAB, C, and SAS.

Recommendations:-

The research recommends to use control chart according to Taguchi method of quality control, and to use software programs to find value of average cycle time of maintenance of equipment in the firms.

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