Estimating Optimum Period of Time Between Maintenances by Using Monte Carlo Simulation Method

Faek Lateef Saleh
Foundation of Technical Education
Received on: 27/9/2011 Accepted on: 23 /10 /2012

ABSTRACT.
This work aims to increase the availability of steam generation plant through modifying boiler maintenance plan by determining the optimum period of time between maintenances to achieve maximum availability via simulation approach.
Applying simulation approach is an attempt to determine the optimum period of time between schedule maintenances to achieve maximum boiler availability. Therefore, PC program in visual basic language is designed as a tool to the implementation of availability simulation approach.
It notes that the boiler availability is increased by (6.9%) in changing the optimum time between scheduled maintenances and inspection to be seven months rather than one year.

Keywords: Maintenance, Simulation ,Availability, Monte Carlo Method, Optimum period.

1. INTRODUCTION.

Boilers are important equipments in chemical and refinery industries. They are normally operated for an extended period of time that leading to boiler components damage because of aging, corrosion, and abnormal operation condition.

Boiler is divided into three main components, furnace tubes, super heater tubes, and bank tubes. The stability of boiler operation is affected by the stability of its operational systems (combustion system, air combustion system, feed water system, blow down system, and soot blowing system).The maintenance and inspection activities are considered as an additional boiler system due to its great effect on boiler reliability and availability.

Steam availability is very important in chemical and petroleum industries, the down time of boiler leads to shutoff steam delivering that leads to shut down of the production processing units. It will certainly cause economical losses; furthermore, it may lead to the damage of boiler components and processing unit facilities.

Determination of optimum period of time between maintenance by changing maintenance plan, which is estimated through the application of simulation approach is an effective way to increase boiler availability.

Simulation is the most powerful modeling technique that can fulfill construction site requirements of dynamic and probabilistic modeling. Simulation is the next best thing to observe a real system. Therefore, it is the technique of solving problems by following the changes over time of a dynamic model of system with the passage of time. Simulation is not an optimization technique. Rather it is used to estimate the measures of performance of a modeled system. [1]

All the evaluated values of reliability and availability are depending on the collected field data. Necessary data base are collected from the operation, maintenance, and inspection department documents of "*Mid Land Refineries Company*" for the last ten years. There is some studies related to this study are illustrated below:

Mitchell J. Mondro [2] describes a simple technique for estimating the MTBF of a system that has periodic maintenance at regular intervals. This type of maintenance is typically found in high reliability, mission-oriented applications where it is convenient to perform maintenance after the completion of the mission. This approximation technique can greatly simplify the MTBF analysis for large systems. The motivation for this analysis was to understand the nature of the error in the approximation and to develop a means for quantifying that error. Derivation of the equations that bound the error that can result when using this approximation method is provided. It shows that, for most applications, the MTBF calculations can be greatly simplified with only a very small sacrifice in accuracy.

Bhatt [3] showed that two approximations for evaluating the reliability of redundant systems have been compared when the systems are subject to periodic maintenance (PM). These approximations are compared through the computing of MTBF of such systems by two mathematical methods. The MTBF is considered as one of the important parameters, that are used to measure the maintainability, therefore this parameter has been calculated in this during the maintainability assessment of the power plant.

2. AVAILABILITY SIMULATION.

Availability is a metric that combines the concepts of reliability and maintainability. Availability gives the probability of a unit being available - not broken and not undergoing repair (when called upon for use). The system availability simulation process is based on Monte Carlo simulation method [4], in this research; availability simulation is performed based on analytical system reliability model to be as a simulation mathematical model. This would not be confused with the methodology of uses Monte Carlo simulation of individual components to estimate the overall system reliability. [5] [6]

2.1. Monte Carlo Simulation.

One of the most common types of simulation is Monte Carlo simulation which randomly generates values for uncertain variables over and over to simulate a model. [4]

Simulation in system reliability and availability is based on the Monte Carlo simulation method that, logical model of the system being analyzed is repeatedly evaluated, each run generates random number to represent distributed parameter's value of each component (but with probabilities governed by the relevant distribution functions). [7], [8], [9]

The random behavior of Monte Carlo simulation in selecting variable values is the same with the variable that have a known range of values but uncertain value for any particular time or event [4].

Also, since the simulation of probabilistic events generates uncertain variable results, it is usually necessary to perform a number of runs in order to obtain an estimation of means of the output parameters of interest, such as reliability and availability. [7],[10]

Since Monte Carlo simulation involves no complex mathematical analysis, it is an attractive alternative approach, it is an easy way for modeling complex system, and the input algorithms are easy to understand, there are no constraints regarding the nature of input assumptions on parameter such as failure and repair rates, so no constant value can be used.[7], [11]

2.2. Simulation Methodology.

This work employs the simulation method to estimate a system's availability. This includes the number of expected failures, number of expected maintenance actions and then expected mean time to repair. The estimation process involves synthesizing system performance over a given number of simulation runs or loops. Each loop simulates how the system might perform in real life based on the specified failure and downtime properties of the system. These properties consist of the interrelationships among the components, and the corresponding quantitative failure and repair for each component. The reliability block diagram determines how component failures can interact to cause system failures. The failure and repair determine how often components are likely to fail, how quickly they will be restored to service. By performing many simulation loops and recording a success or failure for each loop, a statistical picture of the system performance can be obtained. Simulation model of the system could be developed to simulate the random failures and repair times of the system, thus creating an overall picture of the up and down states for the system, as illustrated in **Fig. (1)**. [12],[13]

3. AVAILABILITY CONCEPT AND DEFINITION.

For a system having a repair capability that will restore it to an operative state, another measure of such system performance is the availability. To predict system availability, both the failure and repair probability distributions must be considered. The general observation of availability is that: [14]

$$Availibility = \frac{uptime}{uptime + downtime} \quad (1)$$

Equation (1) corresponds only to historical data, in which, over an elapsed time period, total uptime and total downtime will provide the percentage of time the system is available. However, the primary interest is in predicting availability that is firstly required to understand its concept and the methods of system availability evaluation. Since the researcher focused on the historical data, so that equation (1) will be employed to evaluate boiler availability.

Since the term *availability* is related with a *repairable* or *maintained* system, it would be defined as the probability that a component or system is performing its required function at a given point of time or a stated period of time when operated and maintained in a prescribed manner. It is defined as the probability that an item will be available when required, or as the proportion of total time that the item is available for use. Therefore the availability of a repairable item is a function of its failure rate, λ and of its repair or replacement rate. The proportion of total time that the item is available is the *steady-state availability*, which is equal to. [7]

$$A = \frac{\mu}{\mu + \lambda} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \quad (2)$$

The instantaneous availability is defined as the probability of a system performing a specified function or mission under given conditions at a prescribed time. The instantaneous availability or probability that the item will be available at time *t* is equal to: [7], [14]

$$A = \frac{\mu}{\mu + \lambda} + \frac{\lambda}{\lambda + \mu} \exp[-(\lambda + \mu)t] \quad (3)$$

The determination of reliability and availability for a system with repairable subsystems is more complicated than that for a system without repair, because it is necessary to distinguish which subsystem is under repair while the other is operating [15]. The availability of maintained system is defined as the probability that the system is able to perform its intended function at a given time during its life. Where both, failures and repairs, are probabilistic events, being the time to that event a random variable. [16],[17]

Like reliability, availability is a probability therefore the rules of probability theory can be applied to availability when it is being quantified. Availability may be interpreted as the probability that a system is operational at a given point in time or as the percentage of time, over some interval, in which the system is operational. [10],[14]

3.1. Availability Simulation Steps.

Evaluation of system availability for a given operation time is performed by the following steps:

Random times-to-failure and times-to-repair are generated.
If the component or components that fail in that time period are vital to the operation of the system, the system is said to have failed.
This process is repeated for a specified number of iterations and the results are averaged to develop an overall model of system availability.

- The simulation program generates a random failure time for each component using Monte
- all of the simulation loops, the downtime is averaged and divided by the mission end time to determine the average availability.
- The point availability is determined by dividing the total number of times the system was operational at Carlo simulation, based on the analytical reliability model.
- This failure time is compared to the mission end time. If the failure time is greater than the mission end time, the loop is considered to be over and no downtime is logged for that loop.
- If the random failure time is less than the mission end time, a failure is logged against the system.
- At this point, a repair time is generated based on the system's repair distribution. This is logged as system downtime.
- The failed system has now accumulated life equivalent to the sum of the failure time and the repair time.
- If this sum, or elapsed time, is less than the mission end time, another random failure time is generated.
- If this new failure time is less than the remaining time (mission end time less elapsed time), another repair time is logged, and so on.
- This process repeats until enough failure and repair times have elapsed to meet or exceed the system mission end time, and the total downtime and number of failures for the loop are logged.
- This process is repeated for each loop, and the uptime for each loop (mission end time minus downtime) is calculated.

At the end of the end of each loop by the number of loops.

4. MONTE CARLO SIMULATION MODEL.

To illustrate how simulation data points are generated, it is important to demonstrate the availability simulation models by use of Monte carol simulation method:[4],[12]

1-First model: generation of time to failure that based on boiler reliability model which are given by equation (4):

$$R_A(t) = \exp(-\lambda_A \times t) \tag{4}$$

It is performed by generating a uniformly distributed random number *(Rnd)*, since $0 < R_{system}(t) < 1$, then let U random number in the same interval $0 < U < 1$. Substituting U for $R_{system}(t)$ and solving for (t) as the following steps:

-At a selected desired mission time (t_o), calculate boiler reliability $R_{system}(t_o)$ from equation (4), then evaluate boiler failure rate from the equation (5):

$$\lambda_{system} = -\frac{t_o}{\ln R_{system}} \tag{5}$$

-Generating random number Rnd in the interval $0<Rnd<1$.

U=Rnd

$$t_{simulation} = -\lambda_{system} \times \ln(U) \tag{6}$$

-Above step is repeated for 100 times, at each time the $t_{simulation}$ is recalculated.

-Average $t_{simulation}$ is calculated as below:

$$Average\ t_{simulation} = \frac{\sum_{i=1}^{100} t_{simulation}}{100} \tag{7}$$

-*Average* $t_{simulation}$ is compared with the mission time (t_o), if it is greater than (t_o), that's mean, the boiler is pass the mission time successfully and there is no failure, but if, it is less than (t_o), in this case, the boiler is failed and *Average* $t_{simulation}$ is represents the first time to failure.

Average $t_{simulation} > t_o$ = no failure

Average $t_{simulation} < t_o$ = failure

2- Second model: generation of emergency repairing time, it depends on the field data repairing times distribution, researcher considers the boiler as a one component, that because , there is no recorded repairing time of boiler systems failures available to be collected in the boiler operation documents, just there are periods of boiler downtimes beyond consideration of which systems are failed and lead to boiler downtime.

Although most of repairing times are conforming to the lognormal distribution [10],[18], but according to the natural of the collected data of repairing times which are tabulated in **table (2)**, they are modeled by uniformly rectangular distributions, because , the collected repairing times are not exact values, but they are in form of one day, two days,…….etc., in addition to there is no enough data base to be modeled, so that, their distribution are modeled by uniformly rectangular distributions, whereas, the x-axis represents the probability of occurrence, and it is divided by the number of the collected data, y-axis represents the number of day taken into repair (period of time).

To introduce emergency repair time, program generates random number uniformly in the range {0-1}, and apply this random number on the x-axis of the distribution to find the corresponding emergency repairing time (t_{repair}) on y-axis, by return to **table (2)** {which represents ,for example for (1) month mission time after (48) hours there are (2) times of maintenance and after (96) hours there are (4) times of maintenance} ,the distribution models are illustrated in figure (**2**: A, B, C, D, E, F, G, I, J, K, L, and M).

After generating time to failure and repairing time, the both values are subtracted from the mission time and the rest of the current mission time represents new mission time:

$$New\ mission\ time = t_o - (t_{simulated} + t_{repair}) \tag{8}$$

3- Third model: generation of the second time to failure depends on the calculation of boiler reliability from equation (4) too, but at new mission time of equation (8). Before the calculation of new boiler failure rate, there is a fact has to be considered, since the emergency maintenance is a partial maintenance, which is performed just to repair the failed parts, the boiler restarts with reliability not equal to 100% at time equal to zero, that because it passes a partial maintenance. This fact is modeled by the equation below:

$$\lambda_{system} = -\frac{t_o}{\ln(R_{system} - (d \times s))} \tag{9}$$

Where (d) represents the subtracted value to evaluate the real reliability when the boiler passes partial emergency maintenance, (s) is the number of the failures which were occurred, where (s) = 2 during calculation of the second time to failure, (s) = 3 during calculation of the third time to failure, the same order is applied for the other times to failure.

The value of (d) is determined to be (0.025), this value is evaluated by verifying of the historical field data base, the verification depends on boiler data of the last three years as mentioned below:

- 1st year: the boiler suffered from (9) times of emergency shutdown, that take (49) days as a repairing time.
- 2nd year: the boiler suffered f rom(12) times of emergency shutdown, that take (58) days as a repairing time.
- 3rd year: the boiler suffered from (10) times of emergency shutdown, that take (46) days as a repairing time.

The scheduled annual maintenance is approximately constant and equal to (35) days, the availabilities of the three years are determined according to equation (2), for example for first year:

Uptime + Downtime = Total time = 8640 + (35x24) = 9480 hr

Uptime = 8640 +(35x24) ─ (49+35) x 24= 8640 ─(49x24) = 7464 hr

Downtime = (49+35)x24 = 2016 hr

Availability of 1st year = $\dfrac{8640-(49\times24)}{8640+(35\times24)} = 0.787\%$

Availability of 2nd year= $\dfrac{8640-(58\times24)}{8640+(35\times24)} = 0.774\%$

Availability of 3rd year= $\dfrac{8640-(46\times24)}{8640+(35\times24)} = 0.78\%$

Average availability = $\dfrac{0.787+0.774+0.78}{3} = 0.78$

The availability outputs of the program is validated with the average availability by making many tries and error iterations to find the suitable value of (d).

The evaluation of the average second time to failure is evaluated randomly by the same procedure of evaluation of first time to failure, this average time to failure has to be compared with the new mission time in equation (8) as below:

-*Average second* $t_{simulation} > [\, t_o - (t_{simulated} + t_{repair})\,]$ = there is no second failure and simulation loop has to be stopped and the boiler passes the mission time *(t_o)* with one failure.

-*Average second* $t_{simulation} < [\, t_o - (t_{simulated} + t_{repair})\,]$ = there is a second failure and simulation loop has to be continued checking for third time to failure.

4- Fourth model: is the evaluation of schedule repairing time. Investigations show that the schedule maintenance time consists of two parts:

- Primary time, it is the time takes into performing the preparation and fundamental jobs.
- Secondary time, it is the time takes into replacing the plugged and corroded boiler tubes.

Researcher studies the schedule repairing times of this boiler, it is planned to be (35) days, the primary time is about (15) days, and it is necessary for each scheduled shutdown, whatever the mission time, secondary time is then (20) days, it depends on the planned boiler mission time.

Tube boiler corrosion rates are constant, and since (20) days are taking into repairing and replacing boiler failed tubes when the mission time is (12) months, so that researcher assumes that if boiler mission time is (11) month, the:

- For mission time of (11) months the schedule repairing time will be equal to $t_{schedule} = (\frac{11}{12}) \times 20$
- For mission time of (10) months the schedule repairing time will be equal to $t_{schedule} = (\frac{10}{12}) \times 20$
- For mission time of (9) months the schedule repairing time will be equal to $t_{schedule} = (\frac{9}{12}) \times 20$
- For mission time of (8) months the schedule repairing time will be equal to $t_{schedule} = (\frac{8}{12}) \times 20$
- For mission time of (7) months the schedule repairing time will be equal to $t_{schedule} = (\frac{7}{12}) \times 20$
- For mission time of (6) months the schedule repairing time will be equal to $t_{schedule} = (\frac{6}{12}) \times 20$
- For mission time of (5) months the schedule repairing time will be equal to $t_{schedule} = (\frac{5}{12}) \times 20$
- For mission time of (4) months the schedule repairing time will be equal to $t_{schedule} = (\frac{4}{12}) \times 20$
- For mission time of (3) months the schedule repairing time will be equal to $t_{schedule} = (\frac{3}{12}) \times 20$
- For mission time of (2) months the schedule repairing time will be equal to $t_{schedule} = (\frac{2}{12}) \times 20$
- For mission time of (1) month the schedule repairing time will be equal to $t_{schedule} = (\frac{1}{12}) \times 20$

5. SIMULATION OUTPUT.

The start of availability simulation is performed from the main window of the program by click "simulation" bottom as shown in **Fig. (3)**; the results of simulation will appear as a bar chart, as illustrated in **Fig. (4)**. In this work the boiler availability is investigated by changing boiler mission time, from one month to twelve months, in order to determine optimum period of time between maintenances that achieves as possible as maximum availability.

Reliability and availability equations are formulated into a program with visual basic language to be used as a tool to perform the cyclic procedure of calculations after entering all the required data base, as illustrated in **Fig. (3-1)**. The main window of the program is illustrated in **Fig.(3)**. The constructed program is designed to calculate boiler and its systems reliability and availability at any desired time.

6. RESULTS.

The output of the availability simulation which is illustrated in **Fig.(4)** shows that changing the maintenance plan to be seven months as a period of time between scheduled maintenance rather than twelve months will produce (6.9%) as an increasing in boiler availability.
From **Fig.(4)**, it can be recognized that the optimum period of time between maintenance which produces maximum availability is seven months, and since the boiler failure rate reaches its maximum value when the mission time exceeds seven months, so that, the maximum availability is achieved when the boiler failure rate reaches its maximum value.

7. CONCLUSION.

Depending on the results of availability simulation, the period of time between maintenances (maintenance plan) has to be changed from the present plan (twelve month period of time between maintenances) to seven months in order to achieve maximum boiler availability. Also, the maximum availability is achieved when the boiler failure rate reaches its maximum value.

8. REFERENCES.

[1] R. Dan Red, Nada R. sanders, "operation management", John Wiley & sons, Inc. 2004.

[2] Mitchell J. Mondro, "Approximation MTBF when a system has periodic maintenance", IEEE, 2002.

[3] A. K. Bhatt, & T. O. Haifley, “Evaluating MTBF Approximations for Simple Maintained Systems”, IEEE Transactions on Reliability, Vol. R-35, No. 2, June 1986.

[4] Janas L. Riggs, "production system", fourth edition, John Wiley & sons, Inc. 1995

[5] Reliability hotwire "Estimating Availability through Simulation ", http://www.weibull.com, the Magazine of reliability professional, issue 8, October, 2006.

[6] Robert B. Werden, "A practical method of optimizing system life cycle cost vs. availability", Microelectronics and reliability, Vol. 17, pp. 1-7, pergamon press, New York, 1986

[7] Patrick D.T. OCNNER "practical reliability engineering", fourth edition, JOHN WILEY & SONS, LTD, 2005.

[8] Reliability hotwire "Determining reliability of complex system / part2 simulation", http://www.weibull.com, of the Magazine of reliability professional, issue 3, may, 2002.

[9] L. Averill, N. Kelton, W. David, "simulation modeling and analysis", New York, McGraw-Hill, 2003. 10]- R. Billinton, “Reliability Evaluation in Distribution and Transmission Systems”, PROC. IEEE, Vol. 122, No. 5, May 2003.

[10] R. Billinton, “Reliability Evaluation in Distribution and Transmission Systems”, PROC. IEEE, Vol. 122, No. 5, May 2003.
[11] G.W.E. Neiuwhof, "the time dependent failure rate of a system consisting of three 50%-units in active parallel", Microelectronics and reliability, Vol. 17, pp. 41-46, pergamon press, New York, 2000.
[12] Virgil R. Rehg, "A system reliability and maintainability simulation", Microelectronics and reliability, Vol. 17, pp. 41-46, pergamon press, New York, 1988.
[13] Nathan Johnson, "optimizing maintainability", Microelectronics and reliability, Vol. 17, pp. 41-46, pergamon press, New York, 1975.
[14] Ebeling, Charles E., ″An Introduction to Reliability and Maintainability Engineering", McGraw-Hill Companies, Inc., 2001.
[15] McCormick N. J., “Reliability and Risk Analysis-Methods and Nuclear Power Applications”, Academic Press, Inc., 1981.
[16] Amendola A., & de Bustamante A. S., “Reliability Engineering”, ISPRA Courses on Reliability and Risk Analysis, ECSC, EEC, EAEC, Brussels & Luxembourg, 2000.

[17] B. Samer & Z. raidis, "Method of reliability analysis of control systems for nuclear power plants", Microelectronics and reliability, Vol. 17, pp. 105-116, pergamon press, New York, 1978.
[18] Kenneth E. Murphy," The Exponential Distribution: the Good, the Bad and the Ugly. A Practical Guide to its Implementation", IEEE RAMS Conference, 2002.

Table (1): Symbols and its descriptions.

Symbol	Description
d	Subtracted value
MTBF	Mean time between failure
MTTR	Mean time to repair
PC	Personal computer
PM	Periodic maintenance
R	Reliability
s	Numbers of failures
t	Desired period of time
t_o	Mission of time
U	Random Numbers
λ	Failure rate
μ	Repairing rate

Table (2): Boiler times to repair with variable mission time that collected from old boiler documents.

	Time to repair(hour)					
	48	96	144	168	192	216
Mission time (month)						
1	2	2				
2	5	3				
3	8	5	1			
4	9	5	2	2		
5	10	8	6	5		
6	10	8	7	5		
7	11	9	9	6	1	
8	11	9	9	7	3	1
9	11	9	9	11	7	4
10	11	9	9	12	12	9
11	11	9	9	13	17	15
12	11	9	9	14	22	20

Figure (1): Uptime and downtime of system.

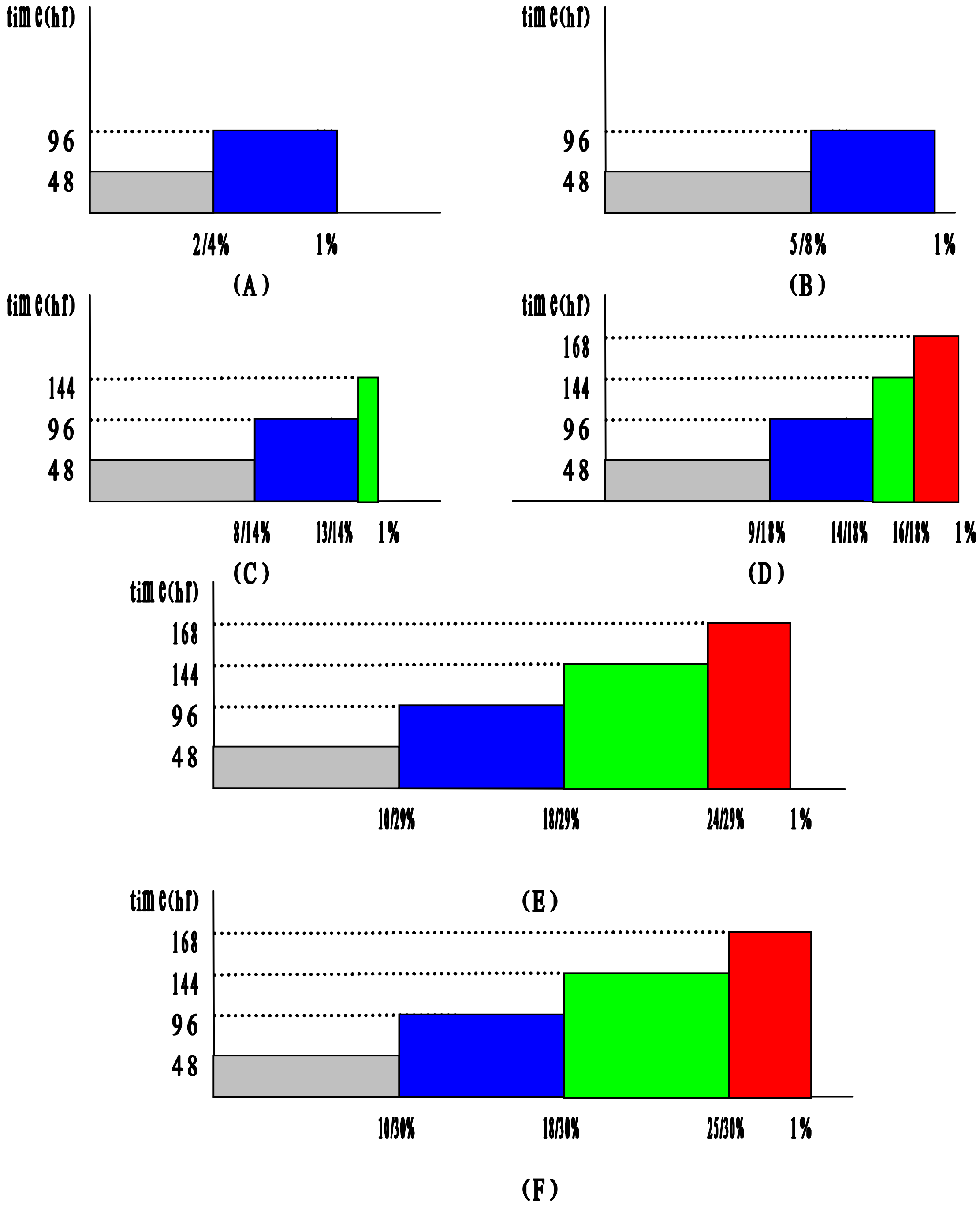
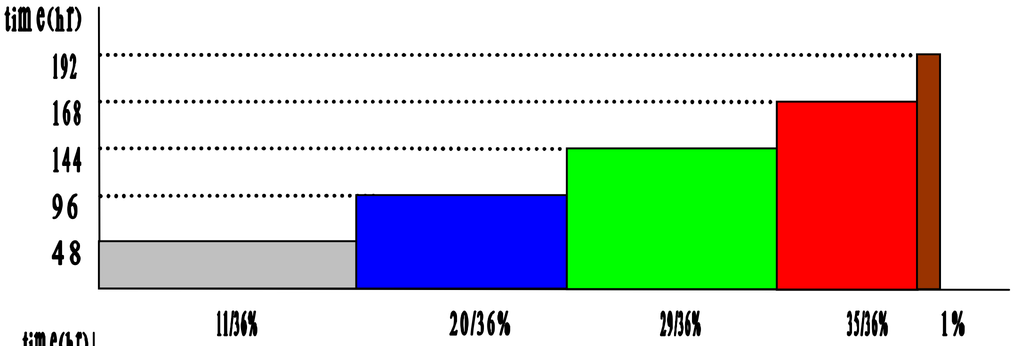
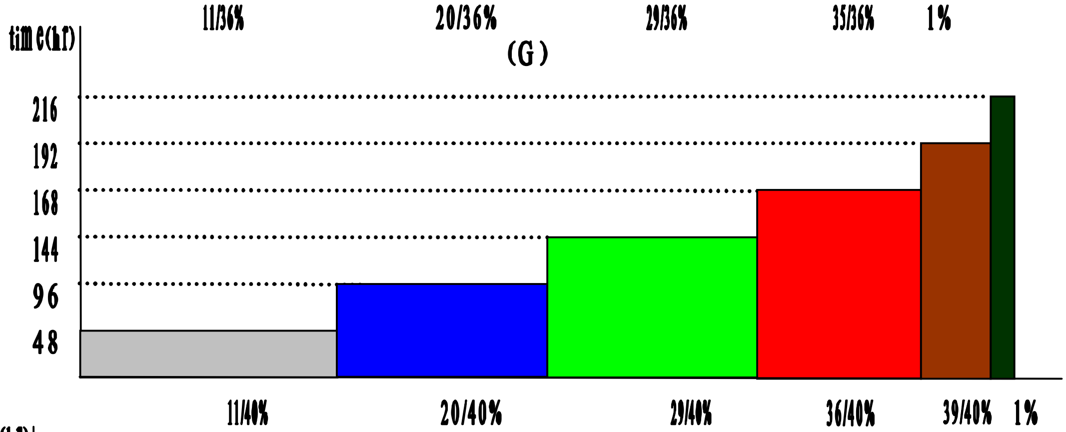


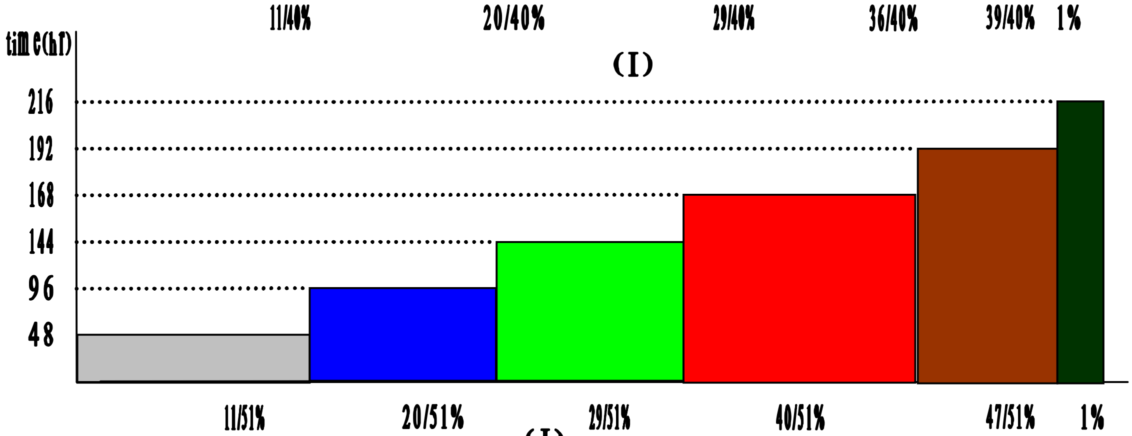
Figure (2), Boiler repairing time distribution for mission time as, (A) first month, (B) second month, (C) third month, (D) fourth month, (E) fifth month, (F) sixth month, (G) seventh month, (I) eighth month, (J) ninth month, (K) tenth month, (L) eleventh month, (M) twelfth month



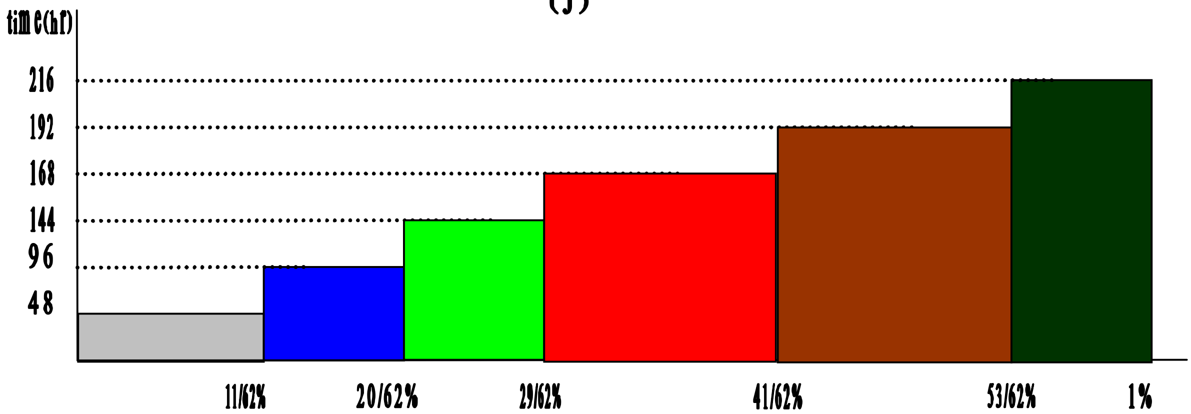
(G)



(I)

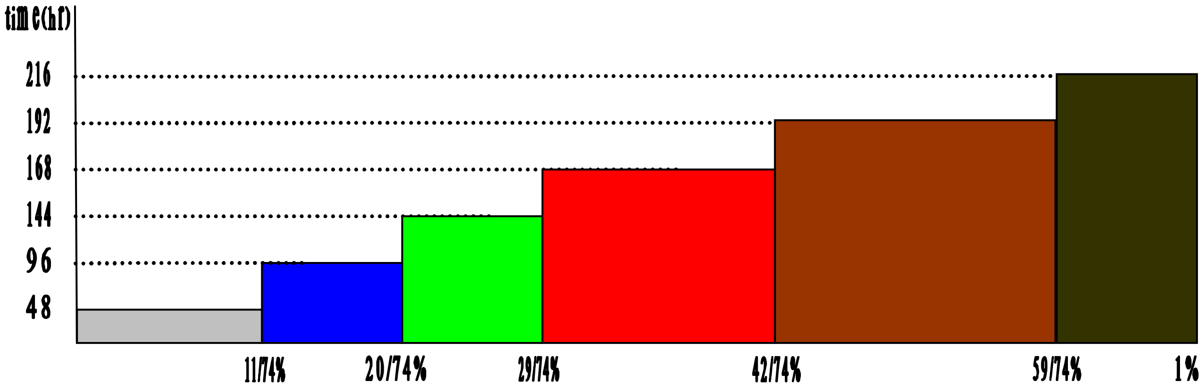


(J)

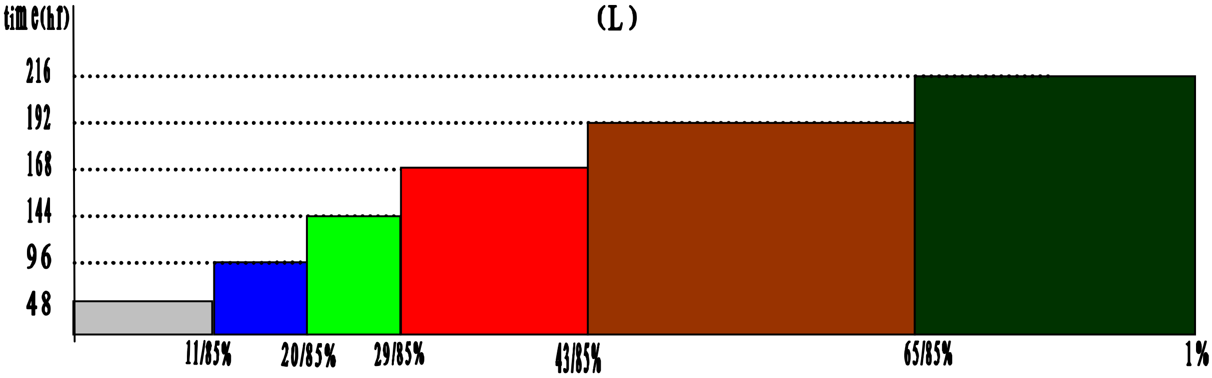


(K)

continuous



(L)



(M)

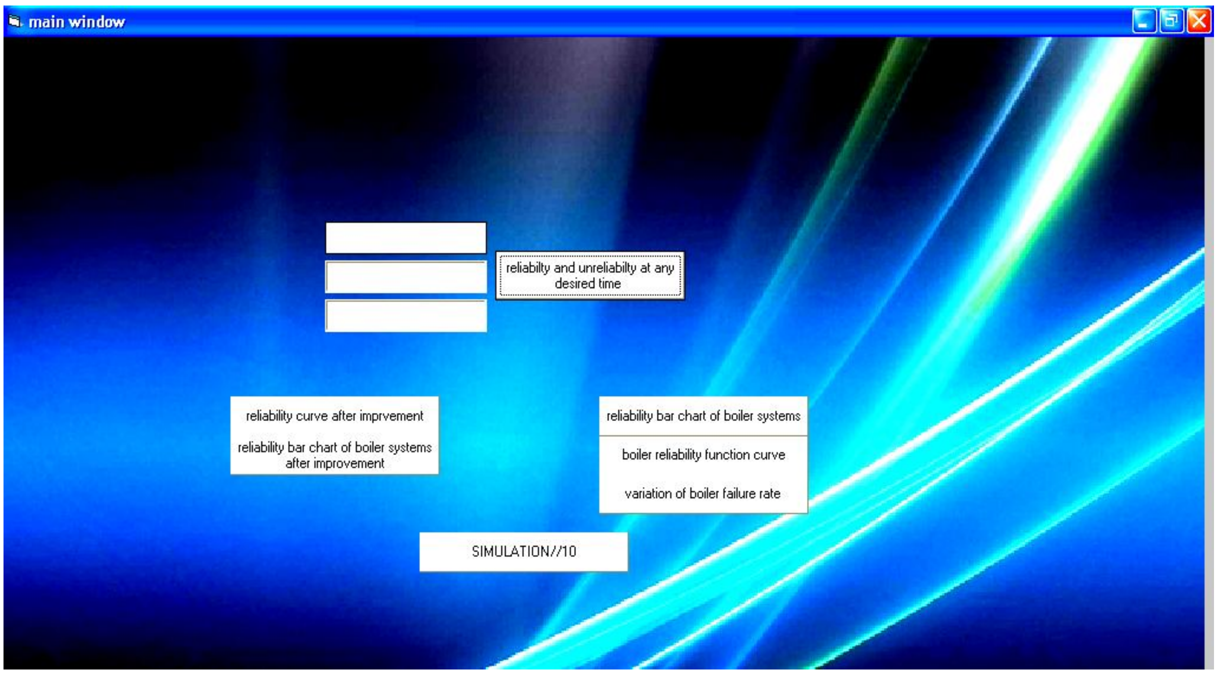


Figure (3): The program main window.

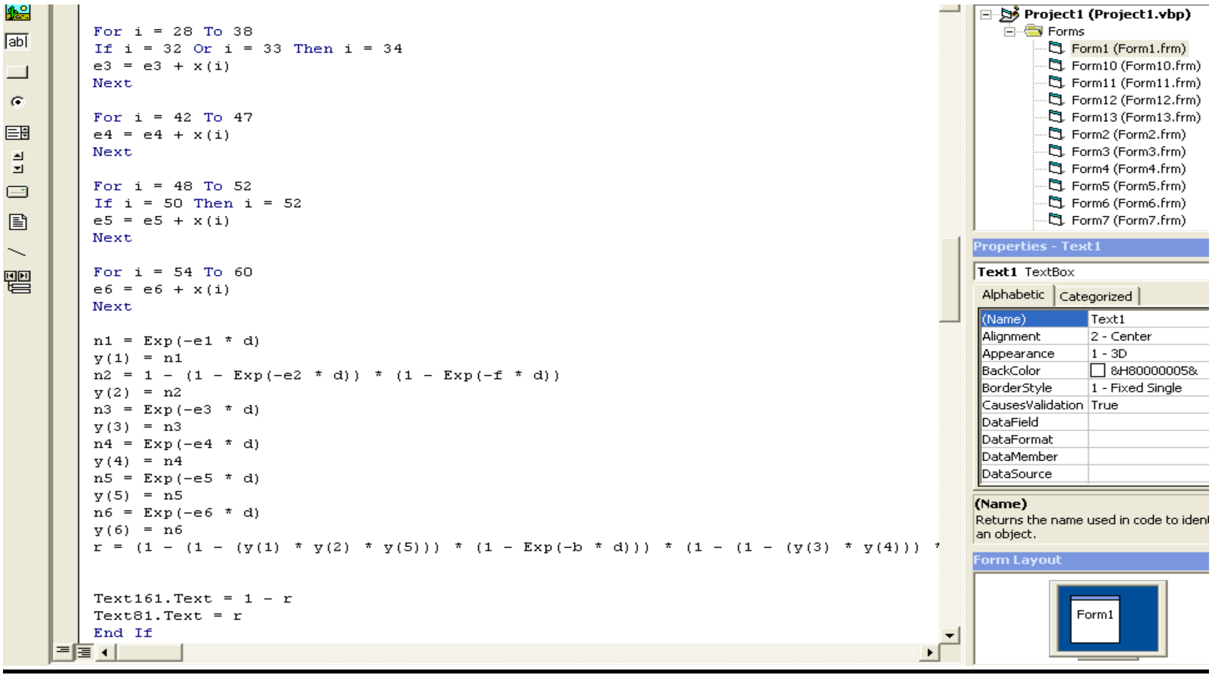


Figure (3-1): Formulation of boiler reliability and availability model in visual basic.

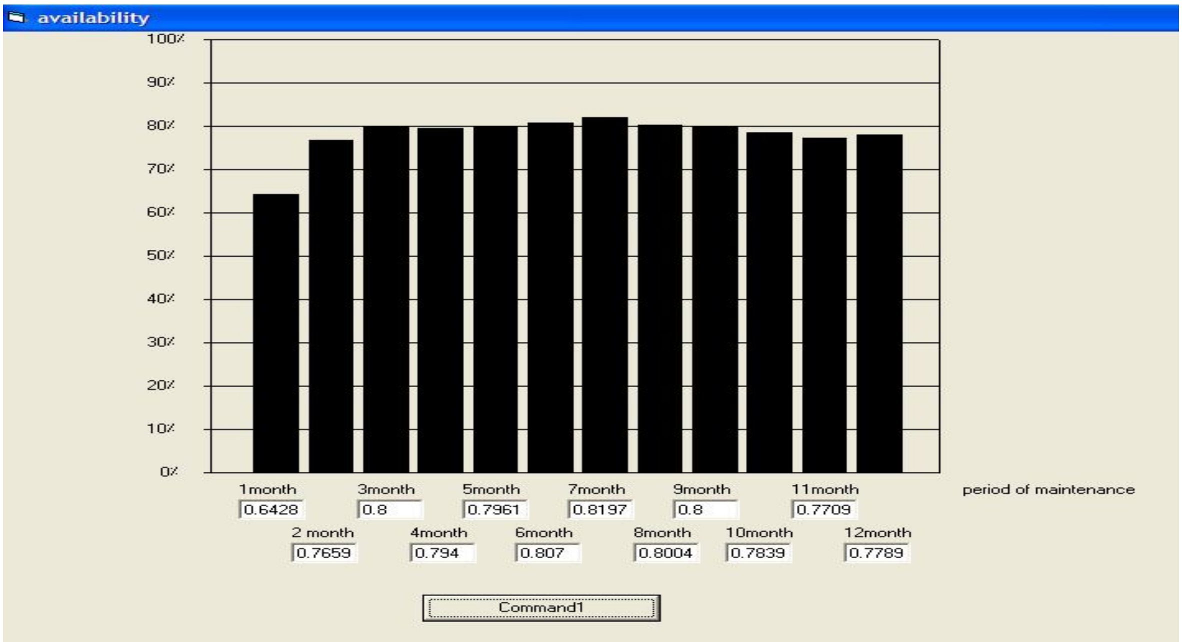


Figure (4): The simulation output window.

تحديد الفترة الزمنية الأمثل بين صيانة وصيانة أخرى عن طريق أسلوب مونت كارلو للمحاكاة

م.م.فائق لطيف صالح
المعهد التقني– الانبار

الخلاصة.

يهدف هذا البحث إلى زيادة توافرية محطة توليد البخار من خلال تعديل خطة صيانة المرجل من خلال تحديد الفترة الزمنية الأمثل بين صيانة وصيانة لتحقيق أكبر توافرية ممكنة عن طريق أسلوب المحاكاة.

أن تطبيق أسلوب المحاكاة هو محاولة لتحديد الفترة الزمنية الأمثل بين الصيانات ضمن الجدول الزمني لها لتحقيق أقصى قدر من توافرية للمرجل. لذلك، تم تصميم برنامج كمبيوتر في اللغة البصرية الأساسية (الفيجوال بيسك) كأداة لتنفيذ أسلوب محاكاة التوافرية للمرجل.

لقد تم ملاحظة زيادة توافرية المرجل بنسبة (6.9 ٪) عند تغيير الوقت الأمثل بين الصيانات والتفتيش وليصبح سبعة أشهر بدلاً من سنة واحدة.

الكلمات الرئيسية:الصيانة،المحاكاة،الوفرة،طريقة مونت كارلو،الفترة المثالية.