USE OF AVAILABILITY SIMULATION TO FIND OPTIMUM PERIOD OF TIME BETWEEN SCHEDULE MAINTENANCE

Dr. Z. I. AL-DAOUD
Assistant Professor
Collage of Engineering
University of Baghdad

HUSSAIN A. M. AL-BAWI
M.SC.Student
Collage of Engineering
University of Baghdad

ABSTRACT

This paper is concerned with the investigation of the optimum period of time between maintenance by the aid of Monte Carlo simulation technique of an old water tube boiler, double identical drums; its capacity is 70 ton/ hour of super heated steam. There are a multitude of failures that are caused by boiler operator's errors, boiler inspector, boiler maintainer and faults of boiler auxiliary equipments which lead to operation parameter deviations and boiler shut down. Changing maintenance plan to be based on optimum period of time between scheduled maintenance and inspection will achieve maximum boiler availability.

الخلاصة

يتعلق هذا البحث في دراسة وايجاد افضل فترة زمنية بين الصيانات المبرمجة بأستخدام اسلوب المحاكاة لمرجل بخاري قديم ذو وعائيين متناظرين علوي وسفلي طاقته الانتاجية 70 طن لكل ساعة من البخار المحمص. يتعرض هذا المرجل لحالات فشل عديدة نتيجة لاخطاء الكادر التشغيلي وكادر الصيانة والفحص لهذا المرجل اضافة الى فشل بعض المعدات الملحقة بالمرجل والتي تؤدي الى حدوث انحرافات في المتغيرات التشغيلية وبالتالي توقف المرجل. ان تغيير خطة الصيانة والفحص بحيث انها تعتمد على افضل زمن بين الصيانات والفحص المبرمجة سيؤدي الى تحقيق افضل توفرية ممكنة للمرجل البخاري.

KEYWORDS: Availability, Simulation, Reliability, Optimum period between maintenance.

INTRODUCTION

Availability gives the probability of a unit being available - not broken and not undergoing repair when called upon for use, it combines the concepts of reliability and maintainability. Many studies are submitted to increase boiler reliability by describe the process design and control of boiler leak detection system **[marques j.2002]**, and improving boiler combustion efficiency **[david C. 2000]**. This paper is an attempt to increase boiler availability by changing the period of time between scheduled maintenance and inspection. System availability simulation process is based on Monte Carlo simulation method **[Kelton N. 2000]**, **[Sanders R. 2002],** 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 **[reliability hotwire. 2006]**.

SIMULATION METHODOLOGY

The simulation method to estimate system's availability is employed. It 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. A simulation model of the system could be developed that simulates 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**

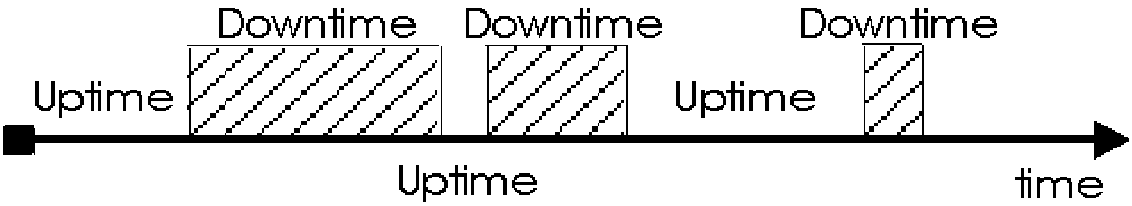


Fig.1: Uptime and downtime of system

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 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 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 the end of each loop by the number of loops.

MONTE CARLO SIMULATION MODELS

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

1-First Model: generation of time to failure that based on boiler reliability model which consist of three subsystems in series connection, first and second subsystems consist of two components with parallel connection. The reliability model is calculated to be:

$$R_{system} = [1-(1-e^{-0.00035t})(1-e^{-0.000256t})]\times[1-(1-e^{-0.00037t})(1-e^{-0.0002t})]\times e^{-0.000189t} \quad (1)$$

Simulation 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 **eq. 1**, then evaluate boiler failure rate from the equation:

$$\lambda_{system} = -\frac{t_o}{\ln R_{system}} \quad (2)$$

Where:

λ_{system} = failure rate

t_a = mission time

R_{system} = boiler reliability

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

$$t_{simulation} = -\lambda_{system} \times \ln(U) \quad (3)$$

Where:

U = *Rnd*

$t_{simulation}$ = *Simulated* mission time

λ_{system} = failure rate

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

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

$$Average\ t_{simulation} = \frac{\sum_{i=1}^{100} t_{simulation}}{100} \quad (4)$$

-*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 $t_{simulation} \geq t_o$ = no failure

Average $t_{simulation} < t_o$ = failure

SECOND MODEL: generation of emergency repairing time, it is depends on the field data repairing times distribution, researcher considers the boiler as a one component, that because of, 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 **[Murphy E. 2002]**, but according to the natural of the collected field data of repairing times they are modeled by uniformly rectangular distributions, because of, the collected repairing times are not exact values, but they are in form of one day, two day,…….ect., 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 is represents the probability of occurrence, and it is divided by the number of the collected data, y-axis is 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, the distribution models are illustrated in **Fig. 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:

$$New\ mission\ time = t_o - (t_{simulated} + t_{repair}) \qquad (5)$$

THIRD MODEL: generation of the second time to failure depends on the calculation of boiler reliability from **eq.1** too, but at new mission time of **eq. 5**. 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 is pass a partial maintenance.

Researcher models this fact by the equation below:

$$\lambda_{system} = -\frac{t_o}{\ln(R_{system} - (d \times s))} \qquad (6)$$

Where: d = the subtracted value to evaluate the real reliability when the boiler passes partial emergency maintenance,

S = number of the failures which were occurred, that (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.

Researcher determines the value of (d) to be (0.025), this value is evaluated by validation of the historical field data base, and the validation is depends on the boiler data of the last three years as mentioned below:

- 1^{st} year: the boiler was suffered of (9) times of emergency shutdown, that take (49) days as a repairing time.
- 2^{nd} year: the boiler was suffered of (12) times of emergency shutdown, that take (58) days as a repairing time.
- 3^{rd} year: the boiler was suffered of (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 **[Charles E. 1997]**:

$$\text{Availability} = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} \qquad (7)$$

Availability of 1st year = $\frac{8640-(49\times 24)}{8640+(35\times 24)} = 0.787\%$

Availability of 2nd year= $\frac{8640-(54\times 24)}{(8640+(35\times 24))} = 0.774\%$

Availability of 3rd year= $\frac{8640-(51\times 24)}{8640+(35\times 24)} = 0.7822\%$

Average availability= $\frac{0.787+0.774+0.7822}{3} = 0.78\%$

Researcher validate the outputs of the program with the average availability by making many try 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 **eq. 5** 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 pass 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.

FOURTH MODEL: is the evaluation of schedule repairing time, investigations show that the schedule maintenance time is 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 planed to be (35) days, the primary time is about (15) day, and it is necessary for each scheduled shutdown, whatever the mission time, secondary time is then (20) day, it is depends on the planed 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) month the schedule repairing time will be equal to $t_{schedule} = (\frac{11}{12}) \times 20$
- For mission time of (10) month the schedule repairing time will be equal to $t_{schedule} = (\frac{10}{12}) \times 20$
- For mission time of (9) month the schedule repairing time will be equal to $t_{schedule} = (\frac{9}{12}) \times 20$
- For mission time of (8) month the schedule repairing time will be equal to $t_{schedule} = (\frac{8}{12}) \times 20$

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

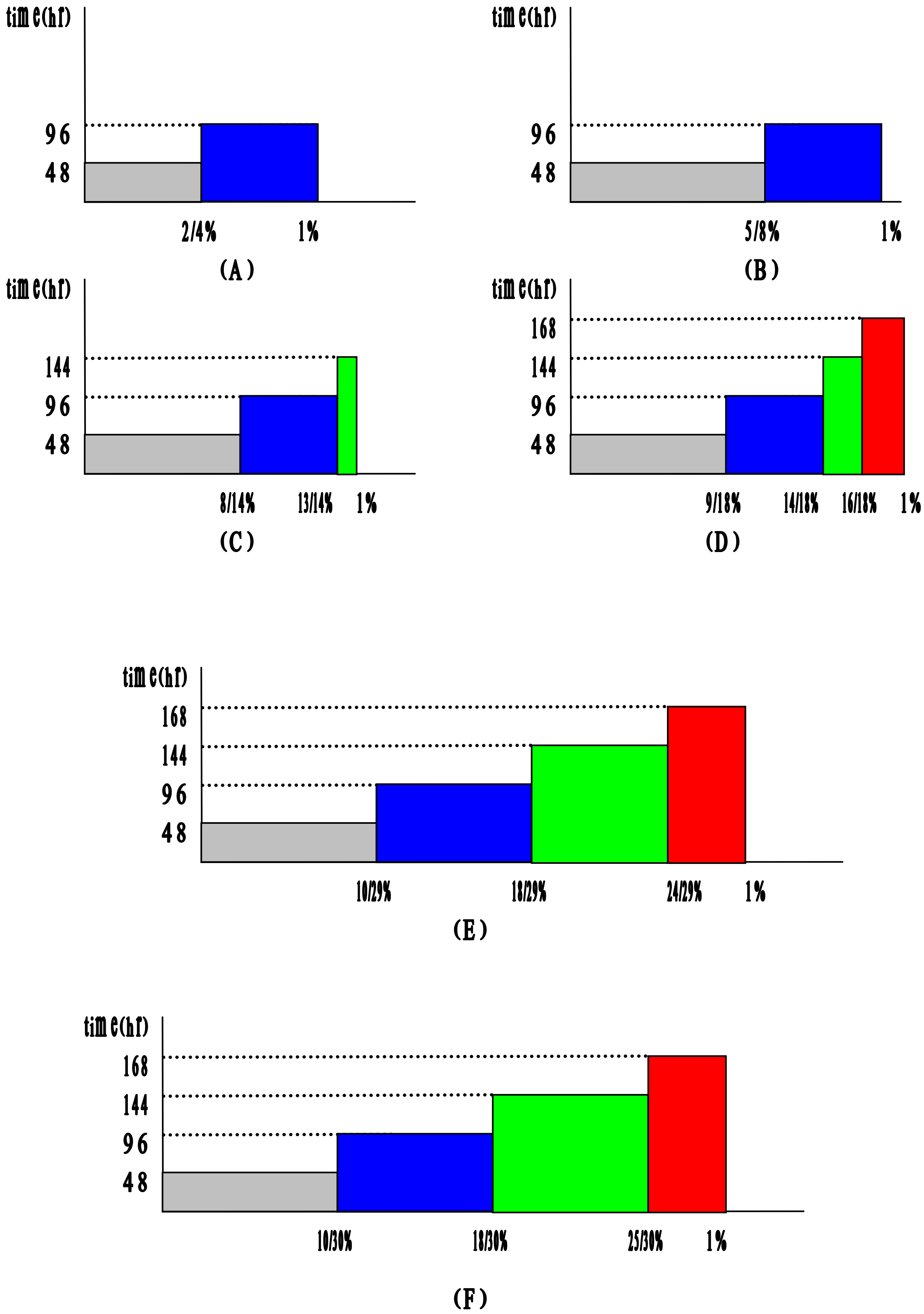
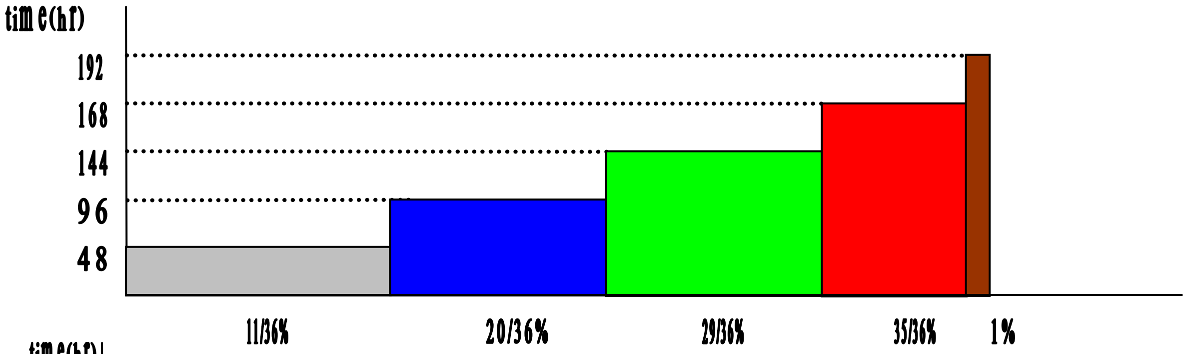
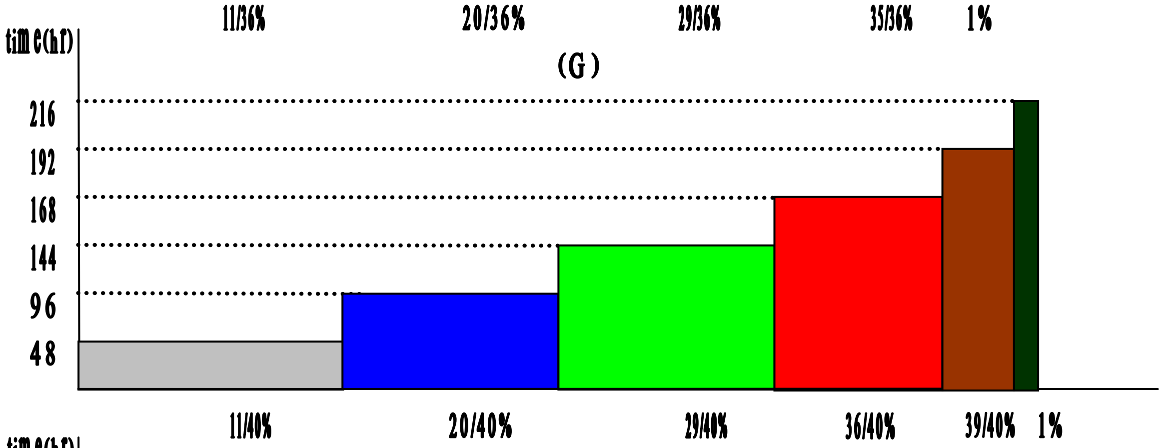


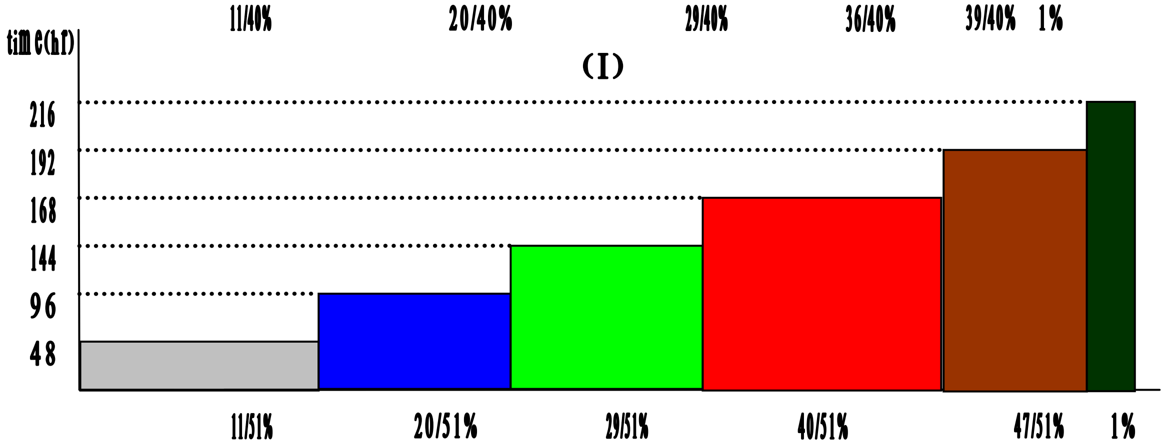
Fig. 2: Boiler repairing time distribution for mission time as, (A) first month, (B) second month, (C) third month, (D) fourth month, (E) fifth month, (F) sixth month, (G) seventh month, (I) eighth month, (J) ninth month, (K) tenth month, (L) eleventh month, (M) twelfth month



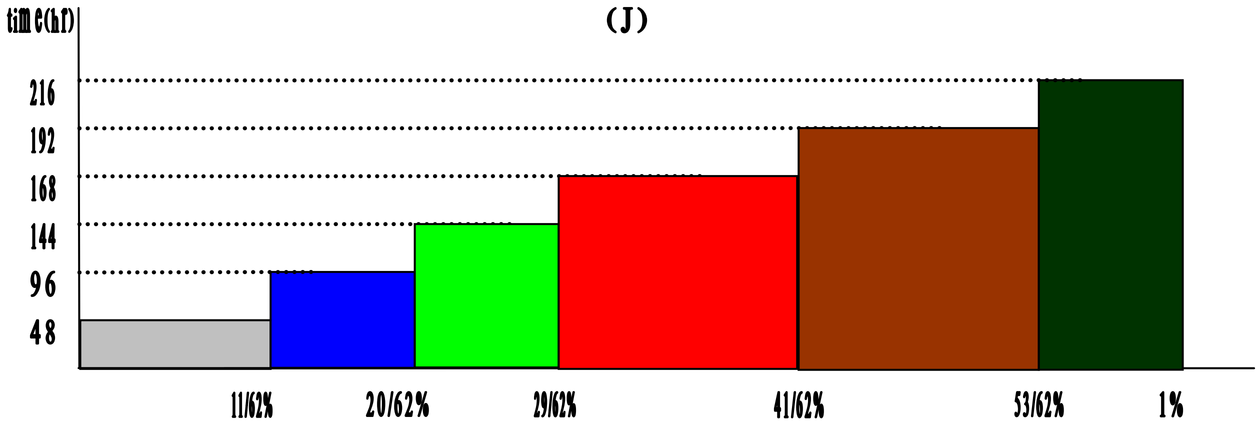
(G)



(I)



(J)



(K)

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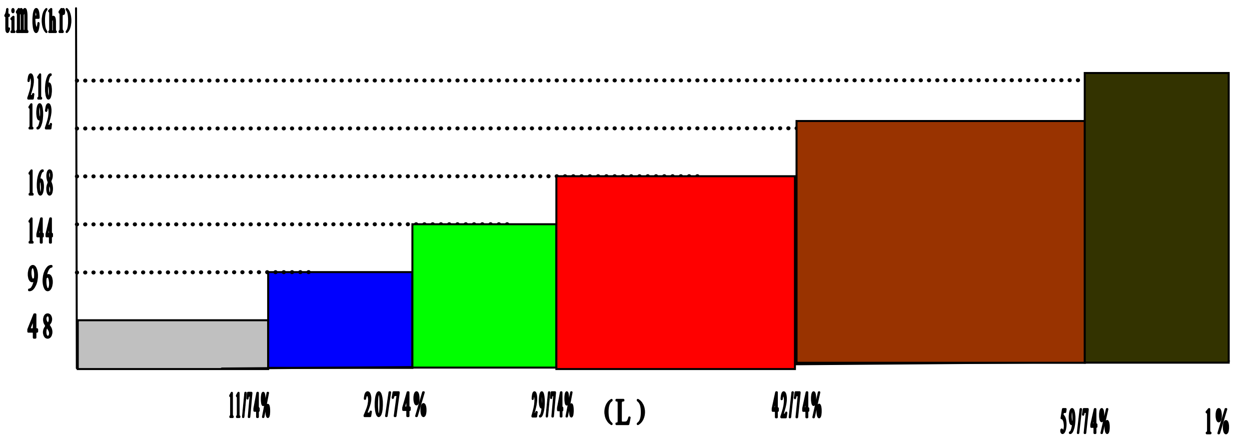
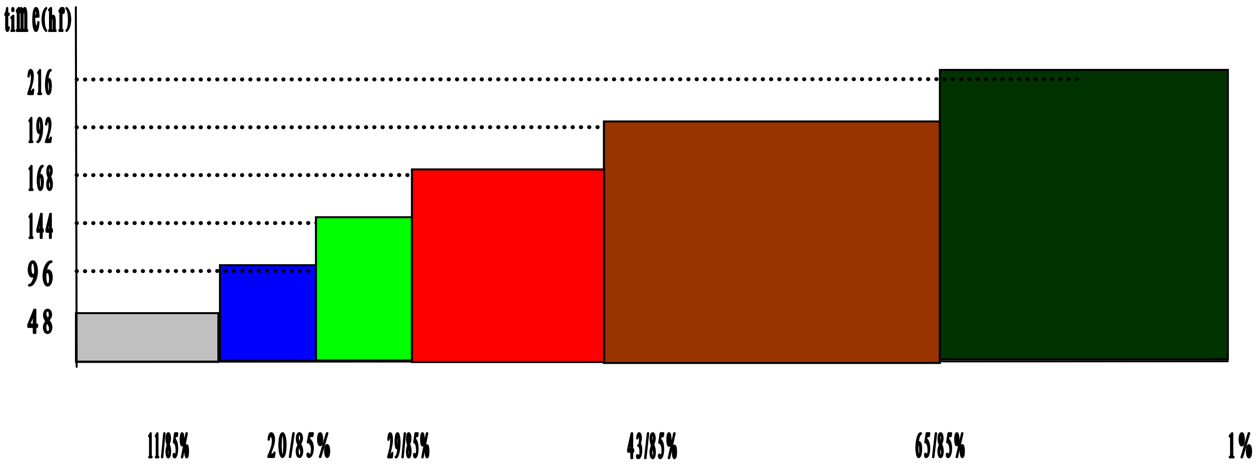


(L)



(M) Continued

Results

Fig. 3 represents the output (bar chart) of the computer program that used to perform the availability simulation after formulating all the simulation models based on visual basic language, each bar in the figure represents the availability of the boiler at its related mission time, first availability is simulated at mission time equal to one month, the others are simulated with increasing mission time by one month one each stage till the mission time reach its maximum value (twelve months).

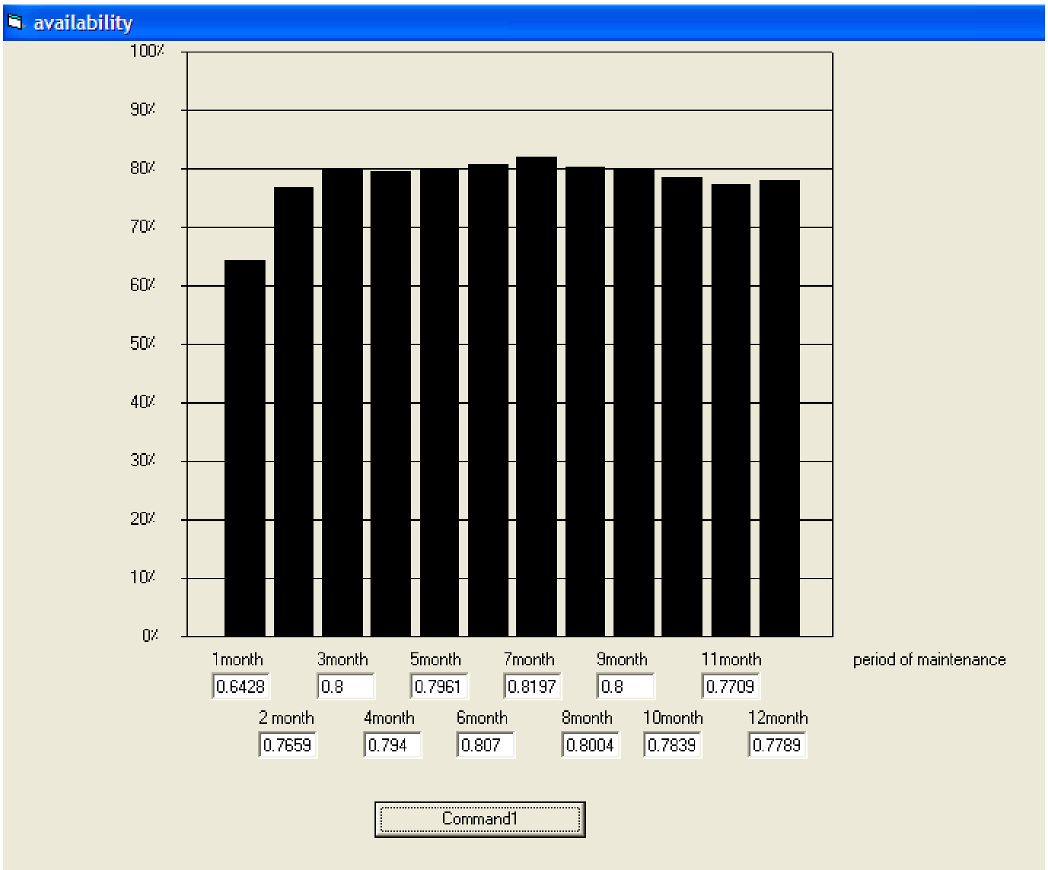


Fig. 3: Simulated availability bar chart

CONCLUSION

In this work the boiler availability is investigated by changing boiler mission time, from one month to twelve month, in order to determine optimum period of time between scheduled maintenance that achieves as possible as maximum availability, from **Fig. 3** it is clear that maximum availability is achieved by use of seven month as a period of time between scheduled maintenance, so that, this period is represents the optimum period of time between maintenance.

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