

Estimation of Optimum Period of Time between Scheduled Maintenance in Iraqi Oil Refineries by using Operation Research Techniques

Ali Moosa Taqi¹, Sedqi Esmaeel Rezouki²

^{1,2}Baghdad University, Collage of Engineering, Al- Jadriya Compound, Road, Baghdad, Iraq

Abstract: Operations research is a powerful mathematical method available to managers to solve their administrative problems. Some methods of operational research can be applied in field of maintenance management, in other words, applying scientific methods to finding solutions to industrial problems, including maintenance work. The objective of this study to use the probability model to estimate the optimum period of scheduled preventive maintenance to give the manager the opportunity to choose the best maintenance time with the lowest cost. Microsoft Excel was used to build a special probability model to solve this problem and perform calculations. The probabilistic model to solve this problem was carried out in Najaf Oil Refinery (NOR) as a case study instead of other Iraqi oil refineries. The three production units were used in NOR for this purpose.

Keywords: Preventive maintenance, Corrective maintenance, Scheduled maintenance, Lost Production Cost

1. Introduction

Industry began to develop largely and fast, and mechanization began to apply all fields. Complicated and high-cost machinery and equipment appeared, particularly in the field of oil facilities. Therefore, the need urged to develop maintenance systems to maintain the machines and equipment for as long as possible. Also, maintenance is no longer limited to a group of engineering and technical events carried out by specialists in these fields, but also became an administrative and accounting effort to plan, organize, direct and control. However, despite the importance of the maintenance management of oil refineries and the economic and social importance they represent to people's lives, studies and research in the maintenance of refineries are still limited, at least in Iraq.

This study will discuss a detailed explanation of the systems developed by the Researchers for the purpose of use in the maintenance of Iraq's oil refineries management such as cost and time for maintenance work by estimating the optimum time for scheduled preventive maintenance in Iraqi oil refineries by Najaf Oil Refinery as a case study through the equipment of the three production units in the refinery case study.

2. Maintenance definition and types

Maintenance is usually defined as its combination of all technical and administrative actions, including supervisory actions, intended to retain an item in, or restore it to, a state in which it can perform a required function [1].

There are many classifications for maintenance in books, papers and various studies. One of these ranking which is classified maintenance into two main types which one of these types is named preventive and two is named corrective as shown below in Fig. 1

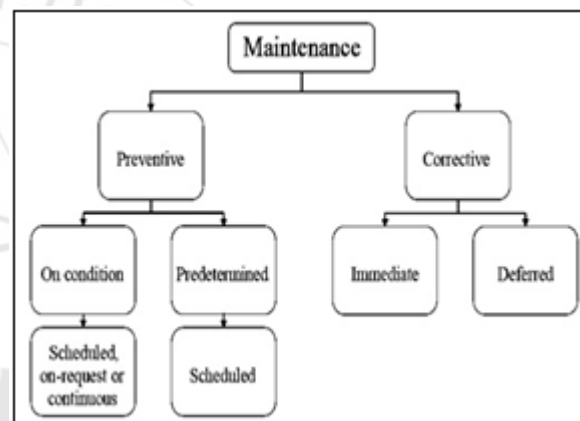


Figure 1: Types of maintenance [2]

2.1 Preventive Maintenance

Preventive maintenance is defined as maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of the equipment. Preventive maintenance can be predetermined or condition based:

2.1.1 Predetermined maintenance: Preventive maintenance carried out in accordance with established intervals of time or number of units of use (i.e. scheduled maintenance) but without previous item condition investigation;

2.1.2 Condition based maintenance:

Preventive maintenance based on performance and/or parameter monitoring and the subsequent actions [2].

2.2 Corrective Maintenance

Corrective maintenance also called breakdown maintenance, is the oldest strategy in the industry [3] is maintenance carried out after fault recognition and intended to put the equipment into a state in which it can perform a required function. Corrective maintenance can be immediate or

deferred:

2.2.1 Immediate maintenance: Maintenance which is carried out without delay after a fault has been detected to avoid unacceptable consequences;

2.2.2 Deferred maintenance: Corrective maintenance which is not immediately carried out after fault detection but is delayed according to given maintenance rules[2].

3. Importance of maintenance management

- 1) To ensure continuity in production.
- 2) To ensure efficiency in production.
- 3) To ensure productivity.
- 4) To deliver goods on the right time.
- 5) To ensure good housekeeping [4].

4. Introduction to Iraqi Oil Refineries

The refining industry in Iraq began very early, when Haditha Oil refinery was established in 1949 followed by Dora refinery in 1953. The process continued to grow and flourish in certain eras and decline in others, depending on political and economic factors such as wars, embargoes and so on.

The nineteen state petrol refineries are distributed in all governorates of Iraq and are administratively administered by three public companies affiliated to the Federal Oil Ministry, these are [Researchers]:

- a) **North Refineries Company:** The largest oil company affiliated to the Ministry of Oil. It is capable of refining (410000) barrels per day and is associated with the refineries (North, Saladin, Kirkuk, al-Kisk, Saynia, and Qayara.
- b) **Midland Refineries Company:** one of the most important oil companies affiliated to the Federal Oil Ministry. It is capable of refining (220000) barrels per day. It is associated with Dora, Najaf, Samawah, Diwaniyah and Karbala refineries.
- c) **South Refineries Company:** one of the largest oil companies affiliated to the Federal Oil Ministry, established in 1969. It is capable of refining (270000) barrels per day. The company consists of three refineries, Basra; Dhiqar and Maysan.

The following table (Table 1) lists the names of the government refineries in Iraq, their affiliation, their establishment dates, their production capacities, and their status of work after the invasion of ISIL (Islamic State of Iraq and the Levant) to several provinces on 10/6/2014 and the destruction, burning, and sabotaging of vital facilities, most importantly oil refineries [Researchers].

Table 1: Iraqi Oil Refineries [Researchers]

No	Location	Dependency	Comm. Date	Capacity	production stance
1	North Oil Refinery	North Refineries Company	1983	170000 BPD	Stopped
2	Salahuldin 1 Oil Refinery	North Refineries Company	1982	70000 BPD	Stopped
3	Salahuldin 2 Oil Refinery	North Refineries Company	1984	70000 BPD	Stopped
4	Lube Oil Refinery	North Refineries Company	-	250000 TPY	Stopped

5	Kirkuk Oil Refinery	North Refineries Company	1973	30000 BPD	Unstopped
6	Kasek Oil Refinery	North Refineries Company	1982	10000 BPD	Stopped
7	Seneyah Oil Refinery	North Refineries Company	1978	30000 BPD	Stopped
8	Qayyarah Oil Refinery	North Refineries Company	1956	14000 BPD	Stopped
9	Hadetha Oil Refinery	North Refineries Company	1949	16000 BPD	Unstopped
10	Durra Oil Refinery	Midland Refineries Company	1955	140000 BPD	Unstopped
11	Lube Oil Refinery	Midland Refineries Company	-	120000 TPY	Unstopped
12	Najaf Oil Refinery	Midland Refineries Company	2006	30000 BPD	Unstopped
13	Samawah Oil Refinery	Midland Refineries Company	1978	30000 BPD	Unstopped
14	Diwaniya Oil Refinery	Midland Refineries Company	2008	20000 BPD	Unstopped
15	Karbala Oil Refinery	Midland Refineries Company	Under construction	140000 BPD	-
16	Basra Oil Refinery	South Refineries Company	1974	210000 BPD	Unstopped
17	Lube Oil Refinery	South Refineries Company	1996	100000 TPY	Unstopped
18	Thiqar Oil Refinery	South Refineries Company	1981	30000 BPD	Unstopped
19	Missan Oil Refinery	South Refineries Company	2000	30000 BPD	Unstopped

5. Introduction to the Case Study

Najaf oil refinery (NOR), affiliated to the external refineries commission of the Central Refineries Company, is a medium capacity refinery with a production capacity of 30,000 barrels per day in three units in a capacity of (10000) barrels per day for each unit. Each single unit produces a range of (20-22%) of naphtha, (14%) of kerosene, (22%) of gasoil, and (51%) of diesel.

The foundation stone of NOR was laid on 3/10/2003 after identifying the suitable land with an area of (326) acres. The actual operation of NOR started by installing the first productive unit of the refinery on 10/2/2006 to witness on 7/10, the opening of NOR with a production capacity of (10000) barrels per day. After about (17) months, exactly on 15/3/2008, the second unit was opened with the same specifications of the first refining unit in terms of production capacity as (20000) barrels per day. The Central Refineries Company continued working hard to have the refinery reach in its designing capacity to (30000) barrels per day by setting up the third refinery unit, opened on 15/8/2009. In addition to the construction of refining units, a large number of tanks with fixed and mobile ceilings and different sizes and capacities have been constructed to increase the capacity of the reservoir. This will give it greater flexibility in the production process and emergency situations. Twenty two reservoirs and a storage card of 87 million liters were implemented as well as the new reservoir of Najaf of 125 million liters, bringing the total capacity of the reservoir up to (212) million liters, and this capacity of the reservoir provides the capability to increase the capacity of the refinery. NOR employs a very large number of engineers, technicians, administrators and others. The number of permanent staff is (798), 400 of whom are Najaf residents, 198 are Babylonians, 200 are Karbala residents, (221)

engineers, (414) technicians, and (163) administrators & guards in addition to (24) other workers are temporary employees [Researchers].

6. Statistical Method Assessing Scheduled Preventive Maintenance Cycle

The use of operational research methods to estimate the appropriate standard times for carrying out preventive maintenance at the lowest possible cost requires some information on the three production units, the time of preventive maintenance, the lost production cost, and the equipment maintenance cost.

The Researchers will estimate the best time for preventive maintenance on the three production units at Najaf oil refinery through knowledge of preventive maintenance costs and the cost of stopping production due to maintenance work in the refinery case study.

6.1 Scheduled Preventive Maintenance Cost

There are two basic types of main resources required to carry out maintenance work in general they are [8]:-

- a) Human Resources (Manpower)
- a) Materials and spare parts

The cost of preventive maintenance in the refinery case study is often composed of the cost of materials and spare parts used in preventive maintenance in addition to the cost of the manpower in the maintenance of engineers and technicians because all the equipment used in the refinery under study belong to the maintenance department in the refinery.

The Researchers prepared a rate of scheduled preventive maintenance costs by visiting the maintenance department's sections in the refinery and surveying the cost of the scheduled maintenance of each section and the costs of human resources (manpower) as well as the cost of materials and spare parts used in the process of scheduled preventive maintenance (SPM).

Prior to this, it was necessary for the Researchers to calculate the mean time to repair production units in Najaf Oil Refinery for the cost of staff working in scheduled maintenance. The duration of the scheduled maintenance of the equipment and machines of the entire production unit ranged from (20-30) days. The Researchers calculated the mean time to repair of preventive maintenance based on the preventive maintenance period in the refinery under study during the years (2012-2016) for the three production units which turned to be (26.344) days as follows:-

$$\begin{aligned} &\text{Mean of PM time of each production unit} \\ &= \frac{28.5 + 26.375 + 27.562 + 22.7 + 26.583}{5} \\ &= 26.344 \dots \dots \dots (1) \end{aligned}$$

The Researchers also considered this period for the purpose of calculating the cost of staffs working in the maintenance during the scheduled preventive maintenance in the refinery, considering that the average amount paid to the engineer in the refinery annually is 17400000 Iraqi Dinars and the average of what the technician receives in the refinery annually is 15202800 Iraqi Dinars as follows:-

$$\begin{aligned} &\text{Cost of maintenance engineers during PM} \\ &= \frac{\text{cost of engineers staff}}{26.344} \\ &= \frac{17400000}{365} \dots \dots \dots (2) \end{aligned}$$

$$\begin{aligned} &\text{Cost of maintenance technicians during PM} \\ &= \frac{\text{cost of technical staff}}{26.344} \\ &= \frac{15202800}{365} \dots \dots \dots (3) \end{aligned}$$

Therefore, it is possible now to calculate the cost of scheduled preventive maintenance in Najaf Oil Refinery clearly through the table (2) which is equal to 183,845,550.28 ID as shown below:

Table 2: Preventive maintenance cost in Najaf Oil Refinery [Researchers]

Cost of S.P.M. Departments of maintenance	Average cost of materials (ID)	Average cost of laborers		Total Preventive maintenance cost of department (ID)
		cost of engineers staff (ID) (N*average cost of every engineer)	cost of technical staff (ID) (N*average cost of every technical laborer)	
Heavy equipment	4100000	6*1,255,580.96=7533485.76	19*1,097,267.3=20848078.7	32,481,564.46
Valves	4235000	7*1,255,580.96=8789066.72	4*1,097,267.3= 4389069.2	17,413,135.92
Pipes and welding	8875750	13*1,255,580.96=16322552.48	35*1,097,267.3=38404355.5	63,602,657.9
Electricity	1290000	4*1,255,580.96=5022323.84	8*1,097,267.3= 8778138.4	15,090,462
Pumps	2603500	7*1,255,580.96=8789066.72	10*1,097,267.3= 10972673	22,365,240
Small machines	100000	20*1,255,580.96=25111619.2	7*1,097,267.3= 7680871.1	32,892,490
Total Scheduled Preventive maintenance cost for maintenance departments in Najaf Oil Refinery (ID)				183,845,550.28

6.2 lost production cost because of P.M. stopping

The cost of maintenance stoppage can be calculated by the following equation:

$$\begin{aligned} &\text{Lost production cost} \\ &= \text{Production capacity} \\ &* \text{Downtime period} \\ &* \text{Average price} \dots \dots \dots (4)[5] \end{aligned}$$

To solve this equation, its variables must be calculated:

6.2.1 Production capacity

The Researchers visited the production department in the refinery to calculate the production capacity for each type of

oil derivatives (naphtha, kerosene, gasoil and diesel) as well as the quantity of crude oil received during the five years of study (2012-2016). As shown in the following table.

Table 3: Production capacity in NOR for (2012-2016)[Researchers]

Year Productions (M ³)	2012	2013	2014	2015	2016
Naphtha	182376	220370	216334.696	214462.17	248025.736
Kerosene	100767.5	102768.9044	92707.446	100453.884	103928.336
Gasoil	173308.949	220414.8	218506.312	199250.763	198540.497
Diesel	618204	754288	724478	686419.54	864016.748
Crude oil	1111169.449	1328765.204	1282908.954	1228266.357	1449569.317

6.2.2 Downtime Period

To calculate the number of stoppage hours in the three production units for the five years of study (2012-2016) in Najaf Refinery, the Researchers visited the Production Department in the refinery to calculate the number of annual downtime due to scheduled preventive maintenance work as shown in the following table.

Table 4: Downtime period neither in NOR for (2012-2016)[Researchers]

S.P.M. Year	Preventive Maintenance			Total (Hr.)
	Unit One	Unit Two	Unit Three	
2012	0	684	633	1317
2013	661.5	0	0	661.5
2014	0	0	260.5	260.5
2015	1057	544.83	0	1601.83
2016	0	0	0	0
Total stoppage hours in the three production units				3840.83

least 2,400 cubic meters per day as well as the oil pipeline company - the Oil Terminal of Najaf to Distribution of petroleum products in addition to the price of purchase of crude oil as shown in the following table.

Table 5: Average Price of NOR's Production for (2012-2016)[Researchers]

Petroleum products	Price (ID)
Naphtha (ID/M ³)	42000
Kerosene (ID/M ³)	125000
Gasoil (ID/M ³)	125000
Diesel (ID/M ³)	60000
Crude oil (ID/Br)	5850

Now that all equation (4) variables have been found, the cost of stoppage due to preventive maintenance can be found by table (6) which equals (2104800677 ID/year) as shown below.

6.2.3 Average Price

To complete the variables of equation (4) the prices of oil derivatives produced in Najaf refinery must be calculated and at the selling price of diesel to the Ministry of Electricity - the Al-Haidariyah power station, which is provided with at

Table 6: Lost production cost of NOR for (2012-2016)[Researchers]

Years Petroleum products	2012				2013				2014				2015				2016			
	Production capacity (M ³ /Hr.)	Downtime Period (Hr.)	Average price (ID/M ³)	Lost production cost (ID)	Production capacity (M ³ /Hr.)	Downtime Period (Hr.)	Average price (ID/M ³)	Lost production cost (ID)	Production capacity (M ³ /Hr.)	Downtime Period (Hr.)	Average price (ID/M ³)	Lost production cost (ID)	Production capacity (M ³ /Hr.)	Downtime Period (Hr.)	Average price (ID/M ³)	Lost production cost (ID)	Production capacity (M ³ /Hr.)	Downtime Period (Hr.)	Average price (ID/M ³)	Lost production cost (ID)
Naphtha	20.7623	1317	42000	1148445862	25.08766	661.5	42000	697010457.8	24.62827	260.5	42000	269457902.1	24.41509	1601.83	42000	1642570592	28.23608	0	42000	0
Kerosene	11.47171	1317	125000	1888530259	25.15639	661.5	125000	2080118998	24.69574	260.5	125000	804155033.8	24.48198	1601.83	125000	4901996253	28.31344	0	125000	0

Gasoil	19.73007	1317	125000	3248062774	11.73161	661.5	125000	970057501.9	10.58304	260.5	125000	344610240	11.4776	1601.83	125000	2298145501	11.86396	0	125000	0
Diesel	70.37842	1317	60000	5561302748	25.16151	661.5	60000	998660331.9	24.94364	260.5	60000	389869093.2	22.74551	1601.83	60000	2186066417	22.66443	0	60000	0
Crude oil	126.4992	1317	-35757.94	-5957253008	151.2711	661.5	-35757.94	-3578148040	146.0506	260.5	-35757.94	-1360453068	139.83	1601.83	-35757.94	-8009202460	165.0238	0	-957.06	0
L.P.C (ID)	5889088635			1167699250			447639200.9			3019576302			0							
Total lost production cost (ID)														10,524,003,388						

Statistically, the best scheduled preventive maintenance cycle can be estimated based on the previous information and the following tables and equation.

$$S_n = N \sum_{1}^n P_n + S_{n-1} * P_1 + S_{n-2} * P_2 + \dots S_1 * P_{n-1} \dots \dots (6) [7]$$

Before that, the percentage of breakdowns for the five years of study (2012-2016) in Najaf Oil Refinery should be calculated as shown in the following tables (7)(8) :-

Table 7: Percentage of breakdowns in NOR for (2012-2016)[Researchers]

No.	Year	No. of Preventive Shutdowns
1	2012	2
2	2013	1
3	2014	1
4	2015	2
5	2016	0
Total		6

Table 8: Probability of failure in NOR [Researchers]

Years	Probability of failure
1	0.34
2	0.16
3	0.16
4	0.34
5	0

For calculating breakdowns rate:

Breakdowns rate=1*0.34+2*0.16+3*0.16+4*0.34+5*0=2.5

Now to calculate the breakdowns cost for the three production units in Najaf Oil Refinery:-

Total lost Prouduction cost /breakdowns rate (5) [6]
 = 10,524,003,388/2.5 = 4209601355.2 ID

Now to calculate the best scheduled preventive maintenance cycle based on statistical probability theory; it shows the expected number of stoppages if preventive maintenance was scheduled once a year, once in two years, once in three years and so on, as follows:

Where:-

S = number of cumulative expected failures during the period

n = expected number of stoppages

N= Number of production units

P = probability of stoppages

$S_1 = N * P_1 = 3 * 0.34 = 1.02$

$S_2 = N(P_1 + P_2) + S_1P_1 = 3(0.34 + 0.16) + 1.02 * 0.34 = 1.8468$

$S_3 = N(P_1 + P_2 + P_3) + S_2P_1 + S_1P_2 = 3(0.34 + 0.16 + 0.16) + 1.8468 * 0.34 + 1.02 * 0.16 = 2.771112$

$S_4 = N(P_1 + P_2 + P_3 + P_4) + S_3P_1 + S_2P_2 + S_1P_3 = 3(0.34 + 0.16 + 0.16 + 0.34) + 2.771112 * 0.34 + 1.8468 * 0.16 + 1.02 * 0.16 = 4.40086608$

$S_5 = N(P_1 + P_2 + P_3 + P_4 + P_5) + S_4P_1 + S_3P_2 + S_2P_3 + S_1P_4 = 3(0.34 + 0.16 + 0.16 + 0.34 + 0) + 4.40086608 * 0.34 + 2.771112 * 0.16 + 1.8468 * 0.16 + 1.02 * 0.34 = 5.5819603872$

It is possible now to calculate the best scheduled preventive maintenance period depending on the statistical probability theory as shown in the following table (9)

Table 9: Optimum scheduled preventive maintenance period in NOR for years (2012-2016)[Researchers]

Year	Probability of failure	Cumulative Probability of failure	Expected No. of shutdowns	Cost of L.P.C	Cost of preventive maintenance	Total cost	Total cost per year
1	0.34	0.34	1.02	2146896691	183,845,550.28	2,330,742,241.43	2,330,742,241
2	0.16	0.5	1.8468	3887145891	183,845,550.28	4,070,991,441.67	2,035,495,721
3	0.16	0.66	2.771112	5832638415	183,845,550.28	6,016,483,965.59	2,005,494,655
4	0.34	1	4.40086608	9262945907	183,845,550.28	9,446,791,457.49	2,361,697,864
5	0	1	5.5819603872	11748914005	183,845,550.28	11,932,759,555.59	2,386,551,911

According to the above table, it is noted that the cost of Scheduled Preventive Maintenance Cost (SPMC) is down continuously to rise again after this decline. It is clear that the standard time for scheduled preventive maintenance (SPM) is located every (three years) which costing (2,005,494,655) Iraqi Dinars, and will increase thereafter as noted in table (9).

So far, it is clear that preventive maintenance policy in the refinery per unit of production must be carried out once every (three years), ie, within the period in which maintenance costs are reduced minimally, in order to significantly minimize costs compared to previous costs when preventive maintenance operations were scheduled every five years, for example, as in the third production unit or once every two years as in the first production unit.

Finally, the Researchers asked the experts who working in the field of maintenance of Iraqi oil refineries on whether the results reached by the Researchers are logical and simulated reality, they accepted the results and they are representation of the reality of maintenance in Iraqi oil refineries.

References

- [1] American Petroleum Institute (API) "Recommended Practice for Procedures for Inspections, Maintenance, Repair and Remanufacture of Hoisting Equipment" Seventh Edition, March 2002 (Reaffirmed: August 2012).
- [2] EN 13306:2001, Maintenance Terminology. European Standard. CEN (European Committee for Standardization), Brussels, 2001.
- [3] Wang, L., Chu, J. and Wu, J., "Selection of optimum maintenance strategies based on a fuzzy analytical hierarchy process", International Journal of Production Economics, Vol. 107, pp. 151-63, 2007.
- [4] Gupta Dr. Tapen "Production and Operations Management", Blogger, Mar., Haryana, India, 2009.
- [5] AMCP 706-132, "Engineering Design Handbook: Maintenance Engineering Techniques", Department of Defense, Washington - Dc, 1975.
- [6] HashimSaffaa Al Jazaeri "using operation research techniques in estimation of preventive maintenance cycle" Al-taqani Journal, Vol.18, Issue 4, 2005 (Reaffirmed: August 2007).
- [7] Ibrahim ZainabAllawi "A comparative study by computer to determine the optimum maintenance policy using a probabilistic model" Journal, The Iraqi Journal For Mechanical And Material Engineering Vol.15, No.4, 2015.

- [8] Ali, Azlan-Shah, et al. "Factors affecting housing maintenance cost in Malaysia," Journal of facilities management, 2010.