

Maintenance Modeling for Fuel Dispensers in a Chain of Gas Stations

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Abstract

Preventive maintenance is one of the main problems in operational activities, which involve equipment of any sort. In this paper we have studied preventive maintenance issues of dispensers in a chain of gas stations and presented models and scheduling procedures which would improve system performance by reducing operational costs. In particular, a company with 577 dispensers in 41 gas stations needed to improve its maintenance operations. The problem was studied in detail and operations research tools, including maintenance concepts and linear programming models were used to schedule the maintenance activities. Detailed cost analyses were carried out to determine feasibility of the proposed preventive maintenance schedules. The procedure proved to be valuable for the case application and could guide operation engineers to apply similar concepts to similar maintenance operations for improvements.

Keywords

Corrective Maintenance, Preventive Maintenance, Scheduling, Gas Stations, Dispenser Failures.

1. Introduction

Complex equipment and devices used in any system constitute majority of the capital invested in industry. Equipment is subject to deterioration with usage and time and deterioration is often reflected in higher operation costs and lower service quality. In order to keep operational costs down while maintaining good service quality, preventive maintenance (PM) is often performed on a scheduled basis. The cost of maintenance related activities in industrial facilities has been estimated by Mobley (1990) as 15–40% of total operation costs and the trend toward increased automation has forced managers to pay even more attention to maintain complex equipment and keep them in available state. If the equipment is maintained only when it fails, it is called corrective maintenance (CM), while preplanned maintenance is called preventive maintenance (PM). Traditionally it is known that the probability of failure would increase as equipment is aged, and that it would sharply decrease after a planned preventive maintenance (PM) is implemented. However, as indicated by Savaşar (2011), amount of reduction in failure rate due to introduction of a preventive maintenance has not been fully studied. In particular, it would be desirable to know the performance of a system before and after the introduction of PM. It is also desired to know the type and the rate at which a preventive maintenance should be scheduled or the maintenance policy to be implemented.

A gas station includes several facilities and equipment that need to be maintained. In particular, dispensers (gasoline pumps), storage tanks, car wash equipment and other ancillary equipment need to be kept in operational condition for effective performance and profitable service. The first gasoline pumps were developed in 1885 in Indiana by S. F. Bowser to be used for kerosene lamps and stoves. Later, when the automobiles were invented, these pumps were improved and used by adding a hose and several other safety measures. A modern fuel dispenser is divided into two main parts, including an electronic head and a mechanical section. Electronic head contains an embedded computer, which controls the action of the pump, drives the pump's displays, and communicates to an indoor sales system. The mechanical section, which is in a self contained unit, has an electric motor, pumping unit, meters, pulsers and valves to physically pump and control the fuel flow. There are many different variations of fuel dispensers in use today. The term 'gas pump' is usually used as an informal way to refer to a fuel dispenser.

In order to maintain functionality of a gas station, each equipment has to be maintained by preventive maintenance at scheduled times or repairs when failures occur. Every fuel dispenser is a combination of various small components and it is essential to ensure the appropriate performance of each component for profitable and high quality service in a gas station. Typical maintenance activities in a gas station include:

- Mechanical pumps, meters and lubrication equipment repair
- Electronic dispenser and electronic control console repair
- Automated system repair including: automatic tank gauging, release detection systems, Point-of-Sale systems (POS), price scanners, card readers, and communication links.
- Tank system repair including: tanks, pumps, leak detectors, piping, hoses, and nozzles.
- Car wash system and ancillary equipment maintenance and repairs.

Preventive Maintenance (PM) Programs are implemented to reduce annual repair costs and costs associated from equipment down time. While preventive maintenance and repair instructions of major equipments at gas stations are specified by the manufacturers, it is difficult to find specific studies related to maintenance analysis of such systems. However, extensive studies have been carried out in the areas of reliability and maintenance management in general. The existing body of theory on general system reliability and maintenance is scattered over a large number of scholarly journals belonging to a diverse variety of disciplines. In particular, mathematical sophistication of preventive maintenance models has increased in parallel to the growth in the complexity of modern manufacturing systems. Research work has been published in the areas of maintenance modeling, optimization, and management. Cho and Parlar (1991) presented surveys of maintenance models for multi-unit systems. Dekker (1996) also presented an excellent review of maintenance optimization models. Sheu and Krajewski (1996) presented a decision model based on simulation and economic analysis for corrective maintenance policy evaluation. Simeu and Descotes (1997) evaluated dependability of manufacturing systems. Waeyenbergh, et al. (2001) presented a case study for maintenance concept development. Also, Waeyenbergh, et al. (2004) discussed procedures, knowledge based concepts, and frameworks in maintenance policy development and implementation in industry. Komonen (2002) presented a cost model of industrial maintenance for profitability analysis. Abdulmalek et al. (2004) presented a simulation model and procedures for analyzing tool change policies in a manufacturing system. Chan et al. (2005) also presented a maintenance implementation for total productive maintenance in the context of a case study in electronics industry. Kyriakidis and Dimitrakos (2006) presents a maintenance model for a production system with intermediate buffers. Leon Hijes et al. (2006) presented a maintenance strategy based on equipment classification using a multi-criterion objective. Carnero (2006) presented a procedure for setting up a predictive maintenance program using detailed system evaluation. Savsar (2000) and Savsar and Aldaihani (2008) presented reliability models for Flexible Manufacturing Cells (FMC) and obtained FMC availability assuming only corrective maintenance is performed. Savsar (2005, 2006a) presented models for analysis of the effects of maintenance policies on FMC performance measures. Savsar (2006b) developed a discrete mathematical model to describe a serial production flow line with buffers and machine failures and incorporated it into a simulation model to study the effects of equipment failures and corrective maintenance operations on production line performance under different operational conditions.

While most of the studies related to reliability and maintenance analysis are theoretical, limited numbers of practical applications are published in the literature. In this study, maintenance modeling and analysis is carried out in the context of a chain of gas station system. In particular, models are presented for determination of various maintenance related activities. It is well known that equipment failures occur due to wearouts and random causes. While random failures can not be eliminated totally, wearout failures can be eliminated by PM operations and thus a reduction in CM can be achieved. The exact effects of PM operations in reducing CM frequency are modeled and applied to various components in the selected system. System down time and productivity are estimated before and after the introduction of PM. Finally, cost analysis of the system is carried out with respect to the effectiveness of PM operations. Models and analysis developed and presented in this paper will be useful for maintenance engineers and operation managers in practical applications.

2. Analysis of Preventive Maintenance Activities in Dispenser Areas

Gas station company considered in this study had a chain of 41 gas stations and a total of 577 dispensers. In order to perform the maintenance analysis, data related to dispenser failures at each gas station were collected and gas stations were grouped into three categories as high failure stations, medium failure stations, and low failure stations.

Grouping was necessary since it was not practical to analyze each of 41 stations separately. Each group was analyzed based on average failure and maintenance rates in order to have applicable results.

It is well known that performing preventive maintenance at scheduled points in time before an asset loses optimum performance can help in providing acceptable levels of operability in efficient and cost-effective manners. As the preventive maintenance is increased, the need for corrective maintenance is reduced and subsequently, the down time of the equipments will be reduced too. A study of rescheduling the preventive maintenance was performed by analyzing the effect of increasing the preventive maintenance on the mean time between failures.

The study was applied on the dispenser area for the three categories of high, medium, and low failure stations. The compound mean time between maintenance activities, $MTBM_{mt}$, must be obtained by combining the rates for corrective maintenance (CM) and preventive maintenance (PM) activities. Assuming that the CM and PM activities are independent, the compound maintenance rate for CM and PM activities is obtained by the adding the related rates. The following notations are used for the calculations.

λ = Corrective maintenance rate

π = Preventive maintenance rate

$MTPM_{ct} = 1/\lambda$ = Mean time between corrective maintenance (this is also referred to as MTBF)

$MTPM_{pt} = 1/\pi$ = Mean time between preventive maintenance

Combined maintenance rate is obtained from $\lambda + \pi$ and compound mean time between all maintenances is calculated from $1/(\lambda + \pi)$, which can also be expressed as:

$$MTBM_{mt} = \frac{1}{\frac{1}{MTBM_{ct}} + \frac{1}{MTBM_{pt}}} = \frac{1}{\lambda + \pi} \quad [1]$$

Mean rate of compound maintenance is defined as $\psi = 1/MTBM_{mt}$.

Failure rate can be expressed as a function of combined maintenance rate and the preventive maintenance rate by manipulating equation [1] as follows.

$$\lambda = \frac{1}{MTBM_{mt}} - \pi \quad [2]$$

Where $\pi = 1/MTBM_{pt}$. Since increasing preventive maintenance decreases the need for corrective maintenance, it is possible to alter the PM rate π in order to recalculate the estimated corrective maintenance. In this case, combine maintenance rate is kept constant and CM rate is estimated based on a given PM rate. Maintenance analysis is carried out for dispensers in each group of stations.

2.1. High Failure Stations

High failure stations category consists of 7 stations with a total of 133 dispensers. The average failure rate was found to be $\lambda = 0.002179$ failure/hour/dispenser which equals to 2539 failures per year. Currently, $MTBM_{pt}$ equals 4 months (30 days per month and 24 hours per day) and the preventive maintenance rate was calculated as follows:

$$\pi = \frac{1}{4 * 30 * 24} = 0.000347$$

By using the failure rate and the preventive maintenance rate, combined maintenance rate, $MTBM_{mt}$ was calculated using equation [1] and found to be 395.88 hours. By substituting the $MTBM_{mt}$ into equation [2] and changing the PM rate, several possible failure rates were estimated using the equation below.

$$\lambda = \frac{1}{395.88} - \pi$$

Table 1 summarizes the $MTBM_{ct}$ for different preventive maintenance schedules. From the results in the table, it can be shown that for the high failure stations, $MTBF_{ct}$ increases slightly when performing the preventive maintenance once every two months, but it increases highly when performing preventive maintenance once every month. Effectively, failure rate $\lambda = 1/MTBM_{ct}$ decreases significantly as PM is performed more frequently, such as every month.

Table 1. Increasing MTBM_{ct} as a result of decreasing MTBM_{pt} for High Failure Stations

MTBM _{pt}	MTBM _{ct} (hours)
4 months	459
3 months	485
2 months	546
1 month	877

2.2. Medium Failure Stations

Medium failure stations category consists of 17 gas stations with a total of 248 dispensers. The average failure rate was found to be $\lambda=0.001935$ failure/hour/dispenser which equals to 4204 failures per year. Currently, MTBM_{pt} equals 4 months and the preventive maintenance rate was calculated as follows:

$$\pi = \frac{1}{4 * 30 * 24} = 0.000347$$

By utilizing the failure rate λ and the preventive maintenance rate π , combined maintenance rate, MTBM_{mt} was calculated using equation [1] and found to be 438.212 hours. Finally, by utilizing this value and different values for PM schedules, a set of possible corrective maintenance rates were estimated using the equation below and tabulated in table 2. From table 2, it can be shown that for the medium failure stations, the MTBM_{ct} increases slightly when performing the preventive maintenance once every two months, but it again increases sharply when performing the preventive maintenance once every month.

$$\lambda = \frac{1}{438.212} - \pi$$

Table 2. Increasing MTBM_{ct} as a result of decreasing MTBM_{pt} for Medium Failure Stations

MTBM _{pt}	MTBM _{ct} (hours)
4 months	517
3 months	549
2 months	629
1 month	1121

2.3. Low Failure Stations

Low failure category of stations consists of 17 gas stations with a total of 196 dispensers. The average failure rate was found to be 0.00122 failure/hour/dispenser which equals to 2095 failures per year. Currently, MTBM_{pt} equals 4

months and the preventive maintenance rate was determined as follows: $\pi = \frac{1}{4 * 30 * 24} = 0.000347$

By utilizing failure rate and preventive maintenance rate, combined maintenance rate, MTBM_{mt} was calculated using equation [1] again and found to be 638.162 hours. Finally, failure rates were recalculated based on various values of preventive maintenances using the equation below.

$$\lambda = \frac{1}{638.162} - \pi$$

Table 3 summarizes the MTBF_{ct} for different PM. From table 3, it can be seen that for the low failure stations, MTBF_{ct} increases slightly when performing the PM up to once every two months, but it increases again sharply when performing PM once every month. These results will be used in the next section to optimize PM schedules for the dispensers in three categories of stations.

3. Preventive Maintenance Scheduling for Dispensers using LP Model

From the previous analysis, we found that the MTBF_{ct} for CM increases as the mean time between PM is decreased. But, we have some constraints that prevent us from performing the PM once every month for the 41 gas stations. In particular, numbers of technicians are limited and the PM cannot be performed on more than one station per day;

also it is not preferred to perform the PM monthly for the dispenser area. As a result, by comparing different situations for the three categories, it was found that the high failure stations have the lowest mean time between failures and the highest number of failures. Consequently, it was suggested to give them higher priority than the other stations.

Table 3. MTBM_{ct} based on MTBM_{pt} for Low Failure Group of Stations

MTBM _{pt}	MTBM _{ct} (hours)
4 months	820
3 months	909
2 months	1145
1 month	5650

A linear programming model was constructed to determine optimum PM schedule for the dispenser area. First, a pair wise comparison method was applied to assign weight to each failure category that will be used to formulate the objective function. Pair wise comparison is a kind of divide-and-conquer problem-solving method. It allows one to determine the relative ranking of a group of items. The first step is to identify the criteria. In our case we have three criteria, such as high failure, medium failure, and low failure stations. The second step is to arrange the criteria in an NxN Matrix, and compare the item in the row with respect to each item in the rest of the row by putting the category that we consider most important in each pair wise comparison. The matrix would be as shown in table 4.

Table 4. Pair wise comparison matrix

	High Failure Stations	Medium Failure Stations	Low Failure Stations
High Failure Stations	-	High	High
Medium Failure Stations	-	-	Medium
Low Failure Stations	-	-	-

The next step is to create the ranking of items by creating an ordered list of the items, ranked by the number of cells containing their names. This leads to:

- High failure stations (2)
- Medium failure stations (1)
- Low failure stations (0)

To get the weights, we will assume a linear proportion between all the weights and solve the following equation, since the total of all the weights must be 100%.

$$100 = 2x + 1x + 0x; \text{ Therefore, } x = 33.33$$

This leads to having the following approximate weights:

- High failure stations: 60%
- Medium failure stations: 30%
- Low failure stations: 10%

Note that final percentages are approximated by rounding them down and the "10%" for low failure stations resulted from summing the round-off values from other calculations. After getting the weights, a linear programming model was formulated for maintenance scheduling. The following notations are used in the LP model.

h = High failure stations; h = 1, 2, 3, 4, 5, 6, 7

d = Medium failure stations; d = 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24

l = Low failure stations; l = 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41

m = Months; m = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

Objective Function:

$$\text{Max. } z = 0.6 \sum_{h=1}^7 \sum_{m=1}^{12} x_{hm} + 0.3 \sum_{d=8}^{24} \sum_{m=1}^{12} x_{dm} + 0.1 \sum_{l=25}^{41} \sum_{m=1}^{12} x_{lm}$$

Decision Variables:

$$x_{hm} = \begin{cases} 1 & \text{if station } h \text{ is maintained in month } m \\ 0 & \text{otherwise} \end{cases}$$

$$x_{dm} = \begin{cases} 1 & \text{if station } d \text{ is maintained in month } m \\ 0 & \text{otherwise} \end{cases}$$

$$x_{lm} = \begin{cases} 1 & \text{if station } l \text{ is maintained in month } m \\ 0 & \text{otherwise} \end{cases}$$

Constraints:

$$\sum_{m=1}^{12} x_{hm} \geq 3 \quad \forall h$$

$$\sum_{m=1}^{12} x_{dm} \geq 3 \quad \forall d$$

$$\sum_{m=1}^{12} x_{lm} \geq 3 \quad \forall l$$

$$\sum_{m=1}^{12} x_{hm} \leq 6 \quad \forall h$$

$$\sum_{m=1}^{12} x_{dm} \leq 6 \quad \forall d$$

$$\sum_{m=1}^{12} x_{lm} \leq 6 \quad \forall l$$

$$\sum_{h=1}^7 x_{hm} + \sum_{d=8}^{24} x_{dm} + \sum_{l=25}^{41} x_{lm} \leq 13 \quad \forall m = 3, 4, 6, 8, 9, 11$$

$$\sum_{h=1}^7 x_{hm} + \sum_{d=8}^{24} x_{dm} + \sum_{l=25}^{41} x_{lm} \leq 14 \quad \forall m = 1, 5, 7, 12$$

$$\sum_{h=1}^7 x_{hm} + \sum_{d=8}^{24} x_{dm} + \sum_{l=25}^{41} x_{lm} \leq 12 \quad \forall m = 2$$

$$x_{hm}, x_{dm}, x_{lm} = \{0, 1\}$$

[3]

Where,

The objective function maximizes the total number of preventive maintenances to be performed so that total corrective maintenances are minimized.

The first, second, and third constraints insure that the preventive maintenance is performed at least 3 times per year for the high failure stations, medium failure stations, and low failure stations respectively. (As the current situation).

The fourth, fifth, and sixth constraints insure that the preventive maintenance will not be performed every month.

The seventh, eight, and ninth constraints insure that the labor capacity in each month will not be exceeded, provided that it takes 2 days to perform the preventive maintenance in each station with the new schedule.

The model was solved using GAMS software and optimal preventive maintenance schedule was found to be as follows:

- For the high failure stations, 6 times per year.
- For the medium failure stations, it was divided into three categories as:
 - 6 times per year for 3 stations.
 - 4 times per year for 6 stations.
 - 3 times per year for 8 stations.
- For low failure stations, 3 times per year.

As a result, 3 medium failure stations have the same schedule as the high failure stations and 8 medium failure stations have the same schedule as low failure stations. Therefore, we will assume that the 3 highest failure stations from the medium failure stations category will be added to the high failure stations, the 8 lowest failure stations from the medium failure stations category will be added to the low failure stations, and the remaining 6 stations will be kept as medium failure stations. In section 5, a cost analysis will be performed to compare the optimum PM schedules with the current PM schedules.

4. Maintenance Cost Analysis

Preventive maintenance involves a basic trade-off between the costs of conducting maintenance activities and the savings achieved by reducing the overall rate of occurrence of system failures. Although Gas Company is paying a fixed amount of money per month regardless of the number of failures occurring per month, a study of the effects of changing the PM schedule on the total maintenance cost was performed to make sure that the new PM schedule will not cause them paying more money. The total maintenance cost was found using equation [4] below.

$$\text{TMC} = \text{CMC} + \text{PMC} + \text{DTC} \quad [4]$$

Where, TMC= Total Maintenance Cost per year

CMC= Corrective Maintenance Cost per year calculated by:

CMC= (Number of Failures per Year)*(Corrective Maintenance Cost per Failure)

PMC= Preventive Maintenance Cost per year calculated by:

PMC = (Number of Preventive Maintenance per Year)*(Cost per Preventive Maintenance)

DTC= Down Time Cost per year calculated by:

DTC= [(Number of failures/year)*(Average Repair Time + Average Waiting Time)]*

[Cost per Down Time hour]

Total corrective maintenance cost for the dispenser area was provided by the Gas Company as 23,170 KD/year. The total number of failures in the dispenser area for the 41 stations was 6869 failures/year. Thus, cost per failure, which resulted in corrective maintenance, was calculated by $23170/6869 = 3.4$ KD/Failure. This cost is the same for all categories of dispensers in all stations. Similarly, the PM cost for the dispenser area was provided by the Gas Station Company as 1704 KD/year. Currently PM is scheduled to be performed once every 4 months, or 3 times per year, in each of the 41 stations which resulted in a total of $3 \times 41 = 123$ PM per year. By dividing the PM cost by the total number of preventive maintenances, cost per preventive maintenance was found to be $1704/123 = 13.85$ KD/PM. This cost is also the same for all categories of dispensers in all stations. Downtime cost was not considered in the total maintenance cost based on the assumption that the sale will not be lost due to a dispenser failure as the customer will use another dispenser instead of leaving the system. Economic analyses are performed for each category of stations under the current (old) and proposed (new) PM policies.

4.1. High Failure Stations

As it was mentioned before, under the current PM schedule a PM is performed once every 4 months. As a result, high failure stations have 3281 failures/year, which results in 3281 CM operations/year, and 3 PM per station per year. Equation [4] is utilized in cost calculations for dispensers in each category of stations. Note that 3 stations from the medium failure category are added to the high category due to same frequency of PM as obtained from LP model. Thus, using equation [4], maintenance costs for the current schedule for dispensers in high failure stations

are calculated as: **CMC**= 3281 failures/year*3.4 KD/failure = 11156 KD/year; **PMC**= 3 PM/station/year *10 stations*13.85 KD/PM= 416 KD/year; and **TMC**= 11,572 KD/year;

Under the proposed PM schedule, where PM is to be performed once every 2 months, number of failures is expected to be 3047 failures/year and 6 PM are performed per station/year. Thus, the maintenance costs are calculated by equation [4] as: **CMC**= 3047 failure/year * 3.4 KD/failure = 10360 KD/year; **PMC**= 6 PM/station/year * 10 stations * 13.85 KD/PM= 831 KD/year; and **TMC**= 11,191 KD/year. These maintenance cost for the current and proposed PM schedules are compared in table 5, where system parameters are also listed. It can be seen that extra cost of PM is justified since the total costs are reduced from 11,572 KD to 11,191 KD for this category of stations.

4.2. Medium Failure Stations

For the medium failure stations, it was proposed to have a PM once every 3 months, i.e. 4 times per year. Currently, PM is performed once every 4 months or 3 times per year. Thus, the maintenance costs for the current and proposed schedules are calculated as for high failure stations using equation [4] based on the parameters given in table 5. The final cost results are also listed in the table. Note that 3.4 KD/failure and 13.85 KD/PM are common parameters for all cases. The cost results are compared in table 5. PM costs are justified for this category also since total maintenance costs are reduced from 7,394 KD/year to 5,076 KD/year.

4.3. Low Failure Stations

As it was mentioned earlier, PM was proposed to be performed once every 4 months, which is the same as the current schedule. Therefore, the costs would be the same for the current and the proposed schedules.

Table 5. Various parameters and maintenance cost comparisons for 3 categories of dispensers

Category	Number of Failures/Year	Number of PM/Station/Year	No. of Stations	CMC	PMC	TMC
High Failure Stations-Under Current PM	3281	3	10	11,156	416	11,572
High Failure Stations-Under Proposed PM	3047	6	10	10,360	831	11,191
Medium Failure Stations-Under Current PM	2101	3	6	7,144	250	7,394
Medium Failure Stations-Under Proposed PM	1395	4	6	4,743	333	5,076
Low Failure Stations	Current and proposed PM schedules are the same and thus the costs are not affected.					

5. Conclusions

Maintenance is one of the major operational activities in industrial systems. In particular, implementation of a PM program requires detailed and careful analysis to justify the related costs since maintenance costs are significant part of operational costs. Implementing a PM has to be justified by analyzing its effect on reducing CM costs. In this paper, a gas station company with a chain of 41 stations is considered and detailed procedures are presented for maintenance analysis. After analyzing the current system, a linear programming model is used to determine optimum PM activities to be performed for each category of gas stations. Furthermore, detailed cost analyses are performed for the dispensers to establish cost saving PM schedules. LP model and the economic cost analysis procedures proved to be effective for the company considered. The models and procedures utilized in this paper could be used by operational engineers in maintenance analysis in other industrial settings in order to improve productivity and to reduce related operational costs.

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