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Fuzzy Logic Model for Selecting Optimum Maintenance Strategies: Case Study in the Jordanian Food Industry

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ABSTRACT
The primary purpose of this research is to develop a model to predict the optimum maintenance strategy, which will lead to high production and better line efficiency.This research shows some expert opinions about criterions that usually used in the food industry to select maintenance strategies. A survey was statistical analyzed to give each criterion a weight of importance to choose a maintenance strategy for any machine then Fuzzy Logic used to build a model to predict the optimum strategy. Sixcriterions were used and ranked; cost, historical data, add value, feasibility, safety, and equipment status. All criteria were found to have a similar level of importance and the most important one was found to be historical data at 18.8% of the total of the six criteria and the lowest one was feasibility with 12.8% of the total. These criterions were used as inputs for the fuzzy set theory model to predict which maintenance strategy is suitable for the machine, mainly three maintenance strategies will be the output, eithercorrective maintenance, preventive maintenance, and condition-based maintenance.

KEYWORDS: Maintenance strategy, fuzzy logic, maintenance food industry, corrective maintenance, preventive maintenance

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I. INTRODUCTION

Maintenance is one of the most critical and vital issues in today's competitive manufacturing environment. Deviation in operations needs some adjustment or modification in the selected maintenance strategy to be suitable for the new requirements. The selection process itself is becoming critical to achieving the highest performance. Such decisions that profoundly affect technology are generally dealt with in a technically founded manner [1].

Improving and implementing a maintenance program is an iterative process that involves different decision-makers, who could have different and conflicting goals. In controlling these objectives, maintenance managers often try to achieve multiple and sometimes conflicting objectives such as maximizing productivity, availability, and quality subject to boundaries on production plan, available spares, workforce, and skills [2].

A selection of optimal maintenance strategies is very important to increase availability and reliability levels of production facilities without a significant increase in cost. The selection of maintenance strategies is a typical multiple criterion decision-making (MCDM) problem [3].

Many maintenance strategies were reviewed in this research as well as the factors that make the decision-maker's job very difficult, critical and essential. For this reason, they should balance between so many limitations and challenges; such as reducing, machine downtime, the number of failures, and maintenance cost[4].

Also, one of the most critical issues that could affect the selection of the optimum maintenance strategy is the lake of skills and how to balance between high backlogs and the maintenance team; all of these criteria will be discussed in this research.Many philosophies in the literature classified the maintenance strategies by:

A) The expectation of failure: this includes planned and unplanned maintenance.
B) Using tools: This includes predictive maintenance that may use special tools to predict the failure.
C) Repetition, time, and duration: this includes preventive (fixed time) maintenance.
D) Response time: this includes emergency and breakdown.
E) Industries: maintenance strategies that work for one industry may not work for another.

Many strategies may use more than one of the above points based on the differences in management systems and followed philosophy. Their overall aim is to reduce the loss of production due to breakdowns and also to fulfill requirements and make rapid improvements in the industrial systems.Maintenance strategies can be verifiedthrough maintenance management, which consists of using a maintenance program derived from many criteria to evaluate equipment importance.

Many maintenance strategies have been presented in the literature, corrective maintenance (CM) was considered as the less efficient because it can lead to serious damage to related facilities, personnel, and environment [3],[5],[6], [7], [8], [9], [10] and [11]. It basically waits until the machine or part fails then perform the act of maintenance, some authors prefer to call named it as firefighting or failure based maintenance (FBM)[12]. Some think this maintenance strategy has advantages such as no overhead cost of condition monitoring or planning, and machines are not overmaintained [13]. However, some studies show that on average it costs about three times more to repair a machine that has been allowed to run to total failure compared to the cost to repair the machine before failure [14].

Time-based preventive maintenance (PM), is considered as a higher level than (CM) maintenance strategy, it is focused on preventing the failure before it happens by changing the part which is possible to fail periodically using a based schedule [3].High level of CM (repair and breakdown) or high level of PM lead to high costs[3],[5],[6], [7], [8], [9], [10], and [11]. For this reason,it is important to preserve the balance of using both types at optimum points. Increasing the level of preventive measures leads to anincreasein overall equipment effectiveness and decreasesthe number of breakdowns[3]. Preventive maintenance can be described by the bathtub curve[15]

Condition-based maintenance (CBM)uses many sensors that should be of help by giving feedback on the condition of the machine parts. Based on this feedback, the required maintenance can be done. The monitored data of equipment parameters could tell engineers whether the situation is normal, or allowing the maintenance staff to implement necessary maintenance before failure occurs [3], [6], [7], [8], [10] and [11].

Predictive maintenance (PdM), this strategy is similar to CBM but the difference is thatPdM is the development of fault prognosis techniques; whereby the fault of any part can be predicted before it happens by studying and analyzing the sensor's feedback behavior. Variation in the signal would mean-variance in the part or machine. In other words,PdMcan forecast the temporary trend of performance degradation and predict the faults of machines by analyzing the monitored parameter data)[3],[5],[6], [7], [8], [9], [10] and [11].

Opportunistic Maintenance (OM), its focus on how PM should be carried out, for instance, some of PM activities can be done by choice or based on the physical condition of the system [16]. The possibility of applying opportunistic maintenance is determined by the nearness or concurrence of control or substitution times for different components of the same machine or plant. This kind of maintenance can be done by shutting down the whole plant at set times to do all relevant maintenance activates at the same time[7], [8] and [9].

Some other authors defined the maintenance strategies as Operate to Failure (OTF) which is similar to corrective maintenance, Fixed Time Maintenance (FTM), which is the same as preventive maintenance, Skill Level Upgrade (SLU) which depend on the operator skills, in these instances, there is need to increase the operator's training and skills so they can fix or prevent failures, and Design out Maintenance (DOM), this kind of maintenance should be proposed when the machine has a high duration of downtime with a high stop frequency. In this case, the studied machine or equipment should be redesigned.[17], [18], [19], [20], and [4].Authors prefer to define the maintenance strategies as planned maintenance and unplanned maintenance[21].

The main purpose of this research is to use a fuzzy logic model to develop a tool that helps the decision-makers on selecting the optimum maintenance strategy that will improve the machine status and reduce the cost. Four main maintenance strategy was used in this study CM, PM, PdM, and CBM. The model will use six independent criteria to predict the optimum maintenance strategy (cost, historical data, add value, feasibility, safety, and equipment status), those are the highest-ranked variables for the food industry in Jordan [22].

II. METHODOLOGY

The proposed criteria are ranked in the Al Meanazel et. al (2020), as shown in Table 1. The study indicates that the historical data which related the frequency of failure and number of downtime is the most important criteria with a score of 18.8%, then come addthe value of the maintenance to the production line in term of spare parts, production loss, and fault identification with a score of 18.3% of importance, third comes the safety of the environment and people with importance score of 17%, fourth is the equipment status in term of the frequency of use and surrounding atmosphere with a score of 16.8%, fifth in the rank is the cost of hardware, software, and labor which has 16.3%, and last is the feasibility which defines by the acceptance by labor and available technology with a score of 12.8%. The study indicates that if the maintenance managers in the food industry in Jordan want to choose a maintenance strategy they will focus first on the historical data of the machine, then the added value, then the safety, then equipment status, cost, and the feasibility come at last of their interest [22].

Table 1: Criteria and Percentage of Importance [22]

Rank	Criteria	Importance percentage
1	Historical data	18.8%
2	Add value	18.3%
3	Safety	17%
4	Equipment status	16.8%
5	Cost	16.3%
6	Feasibility	12.8%

The criteria shown in the table will be used to build a fuzzy logic model to select one of the four main maintenance strategies; (1) Corrective Maintenance, (2) Preventive Maintenance, (3) Predictive Maintenance, (4) Condition-based Maintenace. The experts and authors believe that the CBM is the most efficient among all strategies; However, it requires a lot of planning and resources, then comes PdM which requires less effort of implementing that CBM, PM is better than CM but less efficient than PdM, the least efficient is the CM which requires no planning and may cause a lot of production problem [12].The Fuzzy Logic tool was created in 1965, also by Lotfi Zadeh, and explained how to use it with Matlab in a book written by Sivanandam et. al, (2007) [23].

For the case,six inputs were distributed as three possible choices "Low", "High" or "Very High" effective by using membership function"trimf" (triangle membership function) and the effect of "Low" will be started from 0% to 30% and then it will be considered less "Low" and more "High" from 30% to 70% also the "High" will be started from 30% increasing to 70%, from 70% to 90% full "High" and from 90% to 100% will be less "High" and more "Very High" until reach to 100%), see Figure1.

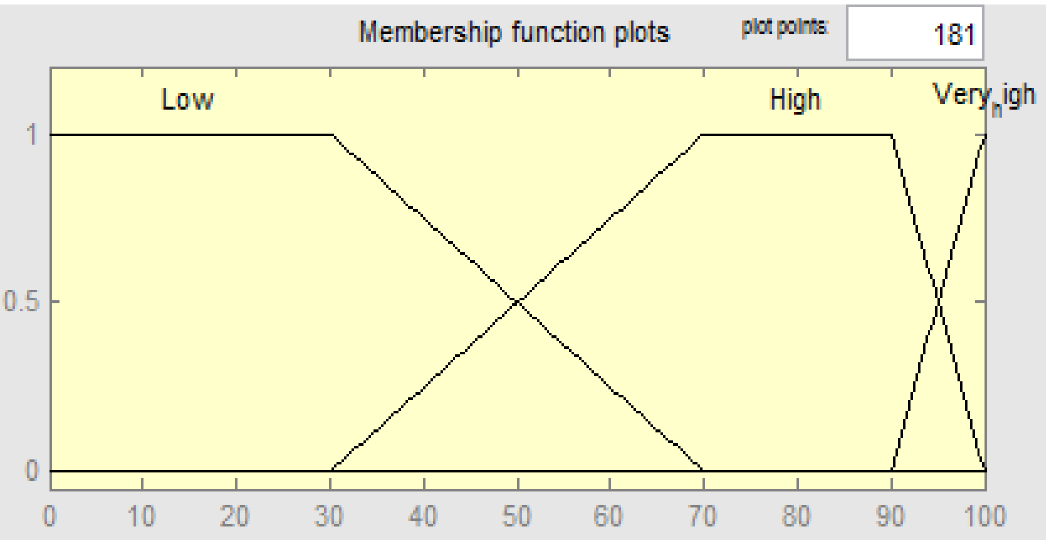

Figure 1 Membership function

For instance, if maintenance managers find that historical data is only 40% important to choose the maintenance strategy, then the input value of this variable will be 0.4*18.8=7.52, this is lay in two areas low and high (30% < 40% < 70%), this means this variable is 75% low important and 25% high important.The fuzzy logic tool then will calculate the rest of the variables and a similar result for the optimal maintenance strategy, for example, the output could be 60% corrective maintenance is recommended and 20% preventive maintenance and 10% predictive maintenance. So the manager may choose CM with the confidence of 60% and may use preventive maintenance with only 20%. Table 2 shows the range and values of variables membership functions.

Table 2: Input Variables Membership Function

Variable	Range	Parameters		
		Low	High	Very High
Historical Data	[0 18.8]	[0 0 5.64 13.16]	[5.64 13.16 16.92 18.8]	[16.92 18.8 18.8]
Add value	[0 18.3]	[0 0 5.49 12.81]	[5.49 12.81 16.47 18.3]	[16.47 18.3 18.3]
Safety	[0 17]	[0 0 5.1 11.9]	[5.1 11.9 15.3 17]	[15.3 17 17]
Equipment Status	[0 16.8]	[0 0 5.04 11.76]	[5.04 11.76 15.12 16.8]	[15.12 16.8 16.8]
Cost	[0 16.3]	[0 0 4.89 11.41]	[4.89 11.41 14.67 16.3]	[14.67 16.3 16.3]
Feasibility	[0 12.8]	[0 0 3.84 8.96]	[3.84 8.96 11.52 12.8]	[11.52 12.8 12.8]

Output will contain four maintenance strategies as discussed before:

1- Corrective maintenance: this strategy will start from the lowest criticality of the studied machine (equipment) and will be decreased with the increasing importance of the machine and each criterion.

2- Preventive maintenance: this strategy will be started from a total of20% of the criticality of the studied machine (equipment) and will be increased until 100%.

3- CPM: this strategy will start to be used from 60% of the total criticality of the studied machine (equipment) and will be increased until 100%. The increase of CPM unlike preventive maintenance which is mean at 0 % will not cover any part of equipment whereas 100% will cover all parts of the equipment and between 0% to 100% should be the coverage of parts which increase symmetrically with the increasing of criticality.

4- Predictive Maintenance: this strategy will start to be usedwhen any criteria haveincreased to very high or if one criterion is very high and the other is not low.

The increase of predictive maintenance like CPM which is mean at 0 % will not cover any part of the equipment, 100% will, however,cover all parts of the equipment and between 0% to 100% should be the coverage of parts which will increase symmetrically with the increasing of criticality.

All sets (cases) of these probabilities have a maintenance strategy. That strategy can be explained by giving the “Low” zero rank and the “High” full rank of each criterion then by summarizing the ranking we can sort each case and write its conditional statement. SIMULINK in Matlab was used to record the output from these models, Figure 2 shows the model and how it should work. The input data is the one that the maintenance manager should enter based on experience data collection and self-judgment on the machine for each variable, then the model will translate the input to input for the fuzzy model then apply the fuzzy rules to it then it will give percentages for each maintenance strategy.

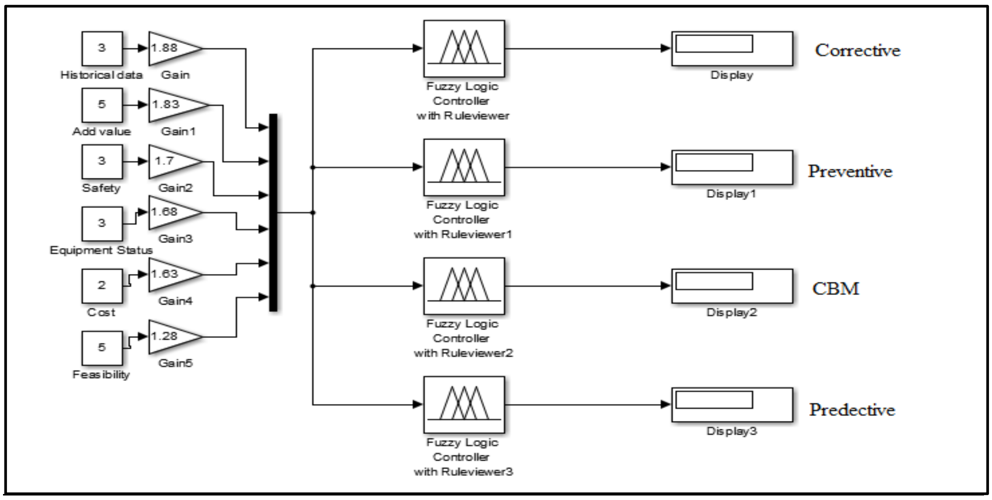

Figure 2: Simulation Module

Table 5illustrates 14 examples with the suitable maintenance program that should be carried out, in example 1, if the historical data is (8/18.8), Add value (14/18.3), safety (6/17), equipment status (7/16.8), cost (3/16.3) and feasibility (0/12), the maintenance program should be:

a) Corrective maintenance (62/100) means: the main maintenance used should be corrective maintenance as a maximum of 62% of the total maintenance should be done in the machine. If the corrective maintenance is more than 62% the criteria evaluation should be reviewed.

b) Preventive maintenance (38/100) that means:
a. Routine maintenance should be done as the manual requests.
b. Weekly, monthly and annual preventive maintenance should be done.
c. Any part should be changed after a certain number of running hours and must be changed if needed. These parts should be monitored weekly.
c) CBM (38/100) that means: the sensor and monitoring equipment should cover 38% of the main parts in the machine.
d) Predictive maintenance (0.5/100) that means: no predictive maintenance should be applied in this machine.

In example number 14 from Table 5, if the historical data is (8/18.8), Add value (17/18.3), safety (16/17), equipment status (0/16.8), cost (1/16.3) and feasibility (11/12), the maintenance program should be:
a) Corrective maintenance (47/100) that means: the main maintenance should be corrective maintenance. A maximum of 47% of total maintenance should be done in the machine if the corrective maintenance is increased to more than 47% the criteria evaluation should be reviewed.
b) Preventive maintenance (53/100) that means:
a. Routine maintenance should be done as the manual requests.
b. Daily, weekly, monthly and annual preventive maintenance should be done.
c. Any part should be changed after a certain number of running hours or if needed and the parts should be monitored weekly.
c) CBM (53/100) that means: the sensor and monitoring equipment should cover 53% of the main part of the machine.
d) Predictive maintenance (53/100) that means: the sensors signal and monitoring equipment that is used in CBM should be analyzed and prevent any failure by predicting the failure.

Table 3Examples

0.5= zero	Historical data	Add value	Safety	Equipment Status	Cost	Feasibility	corrective	Preventive	CBMs	Predictive
1-	8	14	6	7	3	0	62	38	38	0.5
2-	15	9	12	11	9	1	43	57	57	0.5
3-	17	14	15	4	8	8	34	66	66	0.5
4-	3	15	11	6	2	3	60	40	0.5	0.5
5-	13	4	3	10	1	3	66	34	0.5	0.5
6-	10	17	9	6	1	3	54	46	46	0.5
7-	11	5	3	15	14	7	45	55	55	0.5
8-	0	7	2	7	8	0	76	24	0.5	0.5
9-	7	11	0	7	10	9	56	44	44	0.5
10-	3	2	14	9	16	11	45	55	55	0.5
11-	7	15	3	15	2	6	52	48	48	0.5
12-	18	7	0	12	13	7	43	57	57	0.5
13-	9	15	6	4	10	11	45	55	55	0.5
14-	8	17	16	0	1	11	47	53	53	53

III. CONCLUSION

The demand for high production and high quality has increased. This has increased the importance of manufacturing and high expectations regarding reliability and availability.This has led manufacturers to look for new ways to decrease or eliminate production line failure and shutdown and therefore effective maintenance of machinery has become a big concern. There is a need to find maintenance strategies to achieve increased production and decrease the number of failures and downtime. For this reason, maintenance is now considered as an investment thathelps to increase the institution's profit.

There is a need to understand the criteria that should be used to determine the optimum and suitable maintenance strategies and programs to preserve machines and equipment in the production lines. After much research, it was found that most focused on six dimensions which are:

1- Cost
2- Safety
3- Add value
4- Historical data
5- Feasibility
6- Equipment status.

After studying, muchliterature was reviewed and it was found that the most strategies used are corrective maintenance, preventive maintenance, condition-based maintenance, and predictive maintenance.

To ascertain thesuitablemaintenanceprogram: a way was found using the fuzzy logic tools box in Matlab. This helped to create a maintenance program that can be considered suitable, optimum and reliable and gain the best performance for the production lines with the lowest cost. Once known, these can be tested in the future to create maintenance programs for a manufacturing plant and hopefully be applied.

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The authors declare that they have no conflict of interest.

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