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# MATHEMATICAL FAILURE-THEORY (MFT) METHODOLOGY IN PAVEMENT MANAGEMENT SYSTEM FOR REHABILITATION AND REPAIR METHODS SELECTION

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**ABSTRACT**

Pavement rehabilitation and repair methods selection is one of the key issues many road organizations and researchers have occupied. Not only road management cost but also road user's cost and cost for inhabitants and community should be included in the life cycle cost in order to help infrastructure investment judgment. Thus in estimating life cycle cost, Pavement rehabilitation and repair methods selection is essential even if technological capabilities of evaluation are not sufficient.

In order for Pavement Management Systems (PMS) to be effective, they must be based on a reliable, statistically sound means for the rehabilitation and repair methods that are present on the system. To make sensible life cycle cost decisions in design and rehabilitation, pavement engineers must be able to account for distress phenomena and repair methods.

This paper will present a Mathematical Failure-Theory (MFT) methodology for incorporating statistical and probabilistically Factors into life cycle cost analysis and PMS. This approach gives the engineer the ability to statistically and probability consider different rehabilitation and repair method and statistically and probability factors in computing the life cycle costs for rehabilitation and repair methods selection.

**Keywords**: mathematical failure-theory, rehabilitation, repair, pavement, index, management systems, life cycle cost.

## 1. INTRODUCTION

Since; economically; maintenance of road is very important; and being careless will make a lot of discommendable losses .It will be important how to allocate timely credits; time schedule and planning for maintenance and repair of road. Today in Iran all the decisions are made based on the personal experiences and engineering judgment for maintenance and repair of pavement operations so that sometimes the decisions are made based on the non-technical and non-economical considerations while the necessary budgets of maintenance and repair are less than the allocated ones. By making an effective permanent management; a suitable tool will be provided for the managers of the country transportations by which they will be able to determine the maintenance method and select the rehabilitation and repair option. Mathematical failure-theory is one of the most applicable methods maintenance and repair for the industrial equipment using the method as a developing industry; is a considerable thing.

It is important to plan performing the maintenance and repair operations so far a lot of methods have been provided; will be discussed. in the researches of "CHEN" and "WESMIN" or Texas university method ; some main parameters of selecting the maintenance and repair have been given this three parameters are Pavement Condition Index (PCI) and Hour Average Daily Traffic (HADT) and the road type for whichever we have a trouble and consider a score for every one of indexes; based on the tables.

In other research of "HEGI" the used method performance is considered based on the 3 parameters the road compression; population compression and PMO number (Prime Minister Office, this number has been announced by government) [2]. In Iran "Equiponderant" method is used for determining the economical expenses and credits: and selecting financial expenses of the maintenance and repair [3]. In another paper; the Iranian researchers have examined the guidelines of the maintenance and repair method based on the Analytical Hierarchical Process [4].

PCI can be considered as an accidental variable of which values have the possibilities of the pavement. A mathematical possibility distribution shows the possibilities of the accidental variable values. The time possibility curve; is given for every chosen PCI value; as shown in Figure-1 the possibility will decrease from 1 to zero and shows a percent of the pavement so that with a PCI larger than a chosen value will continue servicing during the time [5].

## 2. THE PAVEMENT REHABILITATION AND MAINTENANCE METHODS

The pavement rehabilitation and maintenance methods will be discussed in 3 groups:

Local (detail) rehabilitation: consisting of patching and filling the cracks; the local rehabilitation and maintenance are used as temporary and procrastination tools or a preventive one.

Fundamental Repair and maintenance: it will be economical; if it is used as a preventive tool (Surfacing).

Replacement: it consists of reconstruction and recovering the pavements. This method is used to improve the structural and performance conditions of pavements. The replacement method is often used for the broken pavements specially; when the pavement failure happens very soon.


**Figure-1**. The time-possibility model for a determined value PCI in one pavement of U.S.A, Newjersy.

Fundamental repair will be performed before a determined failure happens for pavement; but as soon as the pavement failure happens; minor repair will be done. Failure doesn't mean that whole pavement is completely out of order but ht means that the pavement servicing isn't within the necessary ranges. The most important issues of fundamental and minor repair are as follows:

The time interval of the fundamental repair; this endless time means that it is necessary to perform the fundamental repair and the minor repair will be enough. As above-mentioned; the fundamental repair is capable of being preventive so that the minor repair is performed as local failure happens to eliminate the deficits. Pavement maintenance and repair consist of local repair, Replacement and other methods. As above-mentioned; the pavement situation can be calculated; quantitatively; with PCI index; so that the index of pavement is classified based on the range and intensity of the failures (for example cracks) the range is from 100 to 0 (from the best to the worst).

The pavements of the different conditions require the different operations of maintenance and repair the conditions of the pavements are classified as from the best to the worst the applied methods of maintenance and repair have a high range of the usual minor maintenance and complicated repair. Table-1 shows the maintenance and repair for the different conditions.

**Table-1**. The different options of the suggested maintenance and repair PMS and the applied classification [7].

| PCI | PMS method | | This research method | |
|---|---|---|---|---|
| | **Pavement condition** | **PMS classification** (suggested) | **Pavement condition** | **Repair method** |
| 75-95 | Very Good | Current Maintenance | Good | Insignificant Repair |
| 60-75 | Good | Preventive Maintenance | Good | Insignificant Repair |
| 50-60 | Average | Suspension Activity | Failure | Insignificant Repair |
| 25-50 | Poor | Maintenance and Repair | Failure | Fundamental Repair |
| 0-25 | Very Poor | Reconstruction | Failure | Reconstruction |

In this paper; the mentioned conditions: the fundamental and minor maintenance and repair never change the previous pavement into the new one .so in addition to; reconstructing the pavement is considered only as one solution. The maintenance and repair for achieving to the goal. One possibility-engineering model has been given to determine the maintenance and repair after examining the previous method. The life of the pavement; the maintenance and repair methods can be determined in every period. As per the information of the expenses and failure possibility in the classifications periods, so in every time; it can be decided whether the fundamental repair operations are performed or reconstruction is done. Table-2 shows the maintenance and repair cost for the different methods.

**Table-2.** Maintenance and repair cost for different methods [7].

| **Maintenance and repair methods** | **Cost** ($\$/m^2$) | **Numbers assign in this research** |
|---|---|---|
| Cheap seal | 0.7-1 | 100 |
| Slurry seal | 0.85-1.35 | 200 |
| Micro surfacing | 1.25-1.75 | 500 |
| Thin HMA overlay 25mm | 1.8-3.4 | 1100 |
| Thin HMA overlay 100mm | 4.2-9.6 | 1200 |
| Reconstruction | 10-30 | 1500 |

The decisions will be made for different conditions of the of the pavement failure. The conclusions of this research show that what kind of decisions are made so that the whole expenses of maintenance and repair and losing the servicing of the pavement in "N" periods are decreased.

## 3. DECISION-MAKING MODEL FOR DETERMINING THE PAVEMENT MAINTENANCE AND REPAIR METHOD

In this model, the best decision can be made by minimizing the whole expenditure of the pavement maintenance and repair method and so a special decision will be made in the pavement maintenance and repair operations for the future periods.

### 3.1 Optimizing model of the expenditure

The following theories are considered in making maintenance and rehabilitation methods [9]:

I: pavement case (suitable situation or failure); when starting the time period

J: pavement case (suitable situation or failure); in the end of the time period

a: decision is made when starting the period (fundamental repair; minor repair or reconstruction)

$P_{ij}^{a}$: Possibility of changing the pavement situation "I" into situation "J" in one period if making decision "a"

$C_{ij}^{a}$: Expenditure of every period for changing pavement situation I into situation J under decisions a (expenditure of fundamental repair $C_o$; minor repair $C_r$; reconstruction $C_t$). The aim is to make "a" policy consisting of the fundamental and minor repair and reconstruction as a complex; so that the whole expenditure of the maintenance and repair and losing the pavement suitable servicing will be decreased during "N" period of time.

$f_n(I)$ Shows the minimum of the whole expenditure the condition in which nth period continues until the life of the pavement lives and in the beginning of the period the pavement is in situation "I". $C_{ij}^{a}$ Shows the expenditure of the first decision in the beginning of nth period. The made decision will be "a" and the pavement situation will be "J" and the possibility will be $P_{ij}^{a}$ . If the decision "a" is made the different conclusions will be expected. So the expenditure of the decision "a" can be calculated by $C_a$ from the relation (1):

$$C_e = \sum_{J=1}^{N} C_{IJ}^{a} \quad P_{IJ}^{a} \tag{1}$$

Which "N" shows the possible cases in the end of the period and in the following calculations the situation "I" with possible $P_{ij}^{a}$ will be considered so the expenditure of the decision can be calculated by $C_e$ from the relation (2):

$$C_e = \sum_{J=1}^{N} P_{IJ}^{a} \; f_n - 1(J) \tag{2}$$

So beginning from situation "I" and with "N" period previously by making decision "a" and achieving the situation "J"; the expenditure of $C_{et}$ will be calculated for "N" period from the relation (3):

$$C_{et} = \sum_{J=1}^{N} C_{IJ}^{a} P_{IJ}^{a} + \sum_{J=1}^{N} P_{IJ}^{a} \; f_{n-1}(J) \tag{3}$$

Or

$C_{et}$ = The expenditure of making the first decision + the future expenditure

The best decision "a" made; for the situation in which the pavement is in situation "I" and will live a life n period as long as the pavement exists; one of the best decisions is minimizing the relation (3). $f_n(I)$ Shows the whole expenditure; it can be calculated from the relation (4) with the best decision "a":

$$f_n(I) = Min[c_{et}] = \min_a \left[ \sum_{J=1}^{N} C_{IJ}^{a} P_{IJ}^{a} + \sum_{J=1}^{N} P_{IJ}^{a} f_{n-1}(J) \right] \qquad n \geq 1 \tag{4}$$

As the relations from (1) to (4); all of the possibilities are considered in analyzing the expenditures. The relation (4) can be solved by "Inversion method" with the first conditions (5) and (6):

$$f_0(I) = 0 \tag{5}$$

$$f_1(I) = \min_a \left[ \sum_{J=1}^{N} C_{Ij}^{a} P_{IJ}^{a} \right] \tag{6}$$

The solving process will be examined with the model number in a special study.

### 3.2 Numerical solving

In the beginning of study period; the pavement may have one of the two situations the suitable pavement situation shown by "G"; that is; PCI>75 and failure shown by "F" PCI<50. As above mentioned; the pavement situation is capable of accepting one of these two situations in the beginning of the period "J", Also; in the end of the period; the pavement situation; "J" can be suitable with the failure so that it can be shown by "G" and "F" [10].

We have three possible decisions "a" fundamental repair "O"; minor repair "R"; replacement "T". If the pavement is in the situation "G"; the fundamental repair "O"; or the reconstruction "T" will be performed. If we want to perform the fundamental repair; the possible that the pavement is in a suitable situation in the end of the period; it will be $P_{GG}^{a}$. $P_{GF}^{a}$ Shows that it is possible that the pavement is in the failure situation .if we make decide

to reconstruct the pavement; the possibilities will be equal with $P_{GG}^{a}$ and $P_{GF}^{R}$ showing the pavement is in the suitable or failure situation. If the pavement is in the situation "F"; replacement or minor repair will be performed. In this research the possibilities are shown in Table-3.

**Table-3.** The different decisions and the possibilities failure in pavement.

| Pavement condition beginning of study period | Maintenance and repair methods | Pavement condition end of study period | |
|---|---|---|---|
| | | Suitable | Failure |
| Suitable | Fundamental repair Reconstruction | $P_{GG}^{O}=0.75$ $P_{GG}^{T}=0.95$ | $P_{GF}^{O}=0.25$ $P_{GF}^{T}=0.05$ |
| Failure | Minor repair Reconstruction | $P_{FG}^{O}=0.60$ $P_{FG}^{T}=0.95$ | $P_{FF}^{O}=0.04$ $P_{FG}^{T}=0.05$ |

The expenditure of every period $C_{ij}^{a}$ is shown in Table-4. As per the Table-4, if the pavement is in the suitable situation and repaired fundamentally; the whole expenditure will account for 200 units (the expenditure of the fundamental repair). But if the failure happens during the period; the expenditure will be 1200 units (the expenditure of the fundamental repair and unsuitable servicing of the pavement).

The aim is to determine a policy of optimizing the maintenance and repair; so that the whole expenditure is minimized during 4 periods. (The life of period is classified into one 7 years; two 5 years; and one 3-year Periods). So it is observed that if the pavement is in a suitable situation "G". For 0.75 it is possible that the pavement is in the same situation in the end of the period. If the pavement is in a failure situation in the beginning of period "F", so the expenditure will be 200 units (the expenditure of the fundamental repair). In this case; the expenditure of the pavement of the failure will be 1200 units (200 units of the fundamental repair and 1000 units because of losing suitable serviceability of the pavement) the possibility of this situation is 0.25.

**Table-4.** The different decisions and the expenditure the kinds of the maintenance and repair methods.

| Pavement condition beginning of study period | Maintenance and repair methods | Pavement condition end of study period | |
|---|---|---|---|
| | | Suitable | Suitable |
| Suitable | Fundamental repair Reconstruction | $C_{GF}^{O}=200$ $C_{GF}^{R}=0.95$ | $C_{GF}^{O}=1200$ $C_{GF}^{R}=1500$ |
| Failure | Minor repair Reconstruction | $C_{FG}^{R}=100$ $C_{FG}^{T}=500$ | $C_{FF}^{R}=1100$ $C_{FF}^{T}=1500$ |

### 3.2.1 Pavement with the maintenance and repair period

As per relation (6); when I=G; one period of maintenance and repair; two policies can performed;

$$f_1=(G)=\min\begin{bmatrix}\sum_{J=1}^{N} C_{GI}^{O} P_{GI}^{O} & \text{Fundemental Re pair}\\ \sum_{J=1}^{N} C_{GJ}^{T} P_{GJ}^{T} & \text{Re construction}\end{bmatrix}$$

If the fundamental repair is performed;

$$\sum_{J=1}^{N} C_{GJ}^{O} P_{GJ}^{O} = C_{GG}^{O} P_{GG}^{O} + C_{GF}^{O} P_{GF}^{O}$$

$$= 200\ (0.75) + 1200\ (0.25) = 450$$

If deciding to reconstruct,

$$\sum_{J=1}^{N} C_{GJ}^{T} P_{GJ}^{T} = C_{GG}^{T} P_{GG}^{T} + C_{GF}^{T} P_{GF}^{T}$$

$$= 500\ (0.95) + 1500\ (0.05) = 550$$

So

$$f_1(G) = \min\begin{bmatrix}450\\550\end{bmatrix} = 450$$

The best decision for minimizing the future expenditure is to decide performing the fundamental repair.
When I=F; and we have one period of maintenance and repair; calculating will be done as per relation (8).

$$f_1 = (F) = \min \begin{bmatrix} \sum_{J=1}^{N} C_{FJ}^{r} P_{FJ}^{r} \\ \sum_{J=1}^{N} C_{FJ}^{R} P_{FJ}^{R} \end{bmatrix} \quad \begin{matrix} Minor \quad \text{Re}pair \\ \text{Re}construction \end{matrix} \qquad (8)$$

$$= \min \begin{bmatrix} 100\ (0.6) + 1100\ (0.4) \\ 500\ (0.95) + 1500\ (0.05) \end{bmatrix}$$

$$= \min \begin{bmatrix} 500 \\ 550 \end{bmatrix} = 500$$

So the best decision is to perform the minor repair; for minimizing the whole and future expenditure.

### 3.2.2 Pavement with two periods of maintenance and repair

If two periods exist until the end of the pavement life; the calculation will be done by the relation (9).

$$f_2(i) = \min_{a} \left[ \sum_{J=1}^{N} C_{IJ}^{a} P_{IJ}^{a} + \sum_{J=1}^{N} P_{IJ}^{a} f_1(J) \right] \qquad (9)$$

When I=G; and there are two periods of the maintenance and repair. Calculations will be done as follows:

$$F_2(G) = \begin{bmatrix} C_{GG}^{O} P_{GG}^{O} + C_{GF}^{O} P_{GF}^{O} + P_{GG}^{O} f_1(G) + P_{GF}^{O} f_1(F) \\ C_{GG}^{R} P_{GG}^{R} + C_{GF}^{R} P_{GF}^{R} + P_{GG}^{R} f_1(G) + P_{GF}^{R} f_1(F) \end{bmatrix} \quad \begin{matrix} Fundamenta & \text{Re}pair \\ \text{Re}construction \end{matrix}$$

$$= \min \begin{bmatrix} 450 + 450\ (0.75) + 500\ (0.25) \\ 550 + 450\ (0.95) + 500\ (0.05) \end{bmatrix}$$

$$= \min \begin{bmatrix} 912.5 \\ 1002.5 \end{bmatrix} = 912$$

The best decision for minimizing the future expenditure is to decide performing the fundamental repair.
When I=F; and we have one period of maintenance and repair; calculating will be done as per relation (8).

$$f_2(F) = \min \begin{bmatrix} 970.0 \\ 1002.5 \end{bmatrix} = 970$$

So the best decision is to perform the minor repair; for minimizing the whole and future expenditure.

### 3.2.3 Pavement with several periods of maintenance and repair

With continuing the calculations; Table-5 can be determined for value to 4 by the same method. It is observed that if there are 4 periods of time and the pavement in a suitable conditions "G" ; the expenditure of deciding to do the fundamental repair will be 1841 units. So as the table we can make a suitable decision for every special period. For example; if the pavement is in a suitable situation "G" in the beginning of the period; the best decision will be performing the minor repairs. This Numerical solving is a case study. For another situation, budget distribution has done whit pay attention to management cost and repair methods [11].

### 3.3 Analyzing the model

To analyze the model of this research some changes are made in the inputs values and the expenditure results are shown at least with the Figures-2 and 3. As this model and change the following results will be made in the input parameters:

a) In the minor repair, the expenditure of the maintenance and repair until is increased up to 10% and averagely the expenditure of the pavement maintenance and repair will be increased up to 4%.
b) In the fundamental repair with increasing 10% in the expenditure of the maintenance and repair averagely the expenditure of the pavement maintenance and repair will be increased up to 5%.

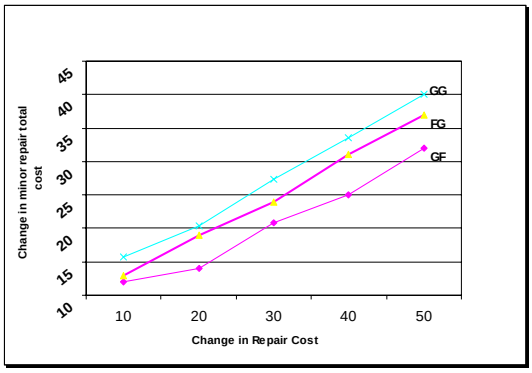


**Figure-2.** The effect of the changing the input parameters on the expenditure of the pavement maintenance and repair (the pavement minor repair)

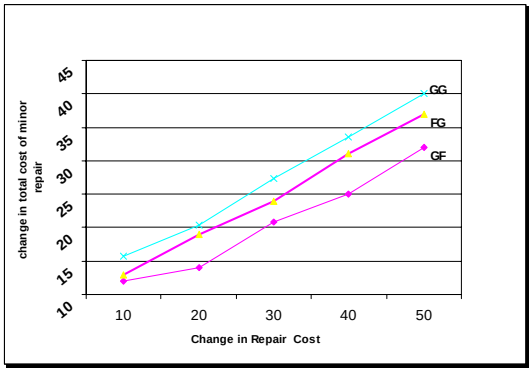


**Figure-3.** The effect of the changing the input parameters on the expenditure of the pavement maintenance and repair (the pavement fundamental repair).


## 4. CONCLUSIONS

In this paper; we came to this conclusion that minimizing the whole expenditure causes making the best decision for the pavement maintenance and repair. So if we decide to perform the fundamental repair of the pavement; we should determine the time (*n*) and the kind of the maintenance and repair (replacement or overall repair) method will be performed.

In this paper; it was supposed that the pavement was in a suitable situation "G" or failure "F" and the possibility of changing the pavement situation; that is; transferring from "G" to "F" was examined under the different conditions of the maintenance and repair; so that it is necessary to examine and determine the pavement situation more accurately (a case between the absolute suitable situation and absolute failure).

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