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# Application of Mathematical Models for Optimizing Inspection Frequency in Maintenance and Management of Pavement

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**Abstract:** Mathematical optimization, also called mathematical programming, is the process by which the best answer (according to a set of criteria) is selected from a set of possible answers to a particular problem. Today, optimization problems are used in all quantitative fields such as computer science, engineering, operations research, economics, and more; one of the engineering disciplines in which optimization is very important is road and transportation engineering. Road repair is one of the most important components of pavement management that requires regular road inspection by road specialists. One of the most important measures to prevent failure is maintenance inspection; Assessment of the condition of road surfaces to ensure their performance, while the road still provides maximum safety for existing traffic, should be done to ensure timely and effective repair and reconstruction operations. But exactly when these inspections should take place and when they are effective is an issue that is addressed in this study. The aim of this study is to optimize the frequency of maintenance inspections for a high-traffic suburban road by optimizing the frequency of inspections with a certain degree of reliability; so, the breakage function was considered as a pavement condition index (PCI). The results show that in order to pave the suburban road with high traffic in order to perform the desired pavement with 95% reliability, 218 inspections should be carried out annually (on average once every two days).

**Keywords:** Mathematical optimization functions, inspection frequency, maintenance, suburban road, road safety

## 1. Introduction

Among the types of buildings built by humans, roads are one of the most essential buildings (Ziari et al., 2007) and new and recycled materials are used to help the environment (Nabiun & Khabiri, 2016). Increasing social and cultural relations, growth and expansion of economic relations will not be possible without roads, so the existence of roads is an important factor in the progress of human civilization. As a result, human beings seek to expand it, Therefore, as the road network is expanding, the importance of road maintenance is increasing (Dong et al., 2021); So that, in the developed countries of the world, most of the work done in the field of road repairs is preventive nowadays (Siriborvornratanakul,2018). Improving access, comfort and safety of road users during its lifetime is one of the policies of road management organizations in countries ( Ziari & Khabiri, 2006; MoghadasNejad et al.,2016) known as pavement management (Zimmerman, 2017); In fact, (P.M.S) pavement

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management system is a purposeful tool for managers that is designed to evaluate, repair, keep and maintain pavements at an acceptable level in order to increase efficiency in decision making and find effective and economical strategies (Terzi, 2007); Road repair is one of the most important components of pavement management that requires regular road inspection by road specialists (Dodson, 2021). Of course, today, special roads such as mining roads in the construction, repair, and maintenance, with a technical perspective are more carefully considered by experts, engineers, and researchers (Saberian & Khabiri, 2017). Now, road maintenance inspections are considered as one of the effective factors in road safety, which has been paid special attention by global road agencies (Cafiso et al., 2011; Urano et al., 2019); On the other hand, it is the most important measures to prevent failure (Faqih & Karimi,.2021; Ahadi et al 2021). In this research, the symbols used in the box below are introduced.

| | |
|---|---|
| $P(t)$ | Failure time probability density function |
| $R(t)$ | Reliable |
| $\lambda(n)$ | Failure function |
| $n$ | Consecutive inspections |
| $T_i$ | Frequency of consecutive inspections |

Road inspection is one of the key processes of the pavement management system that provides the necessary information to implement the appropriate policy of road infrastructure maintenance and planning for temporary repairs and renovations (Staniek, 2017). Of course, this assessment of the condition of road surfaces to ensure their efficiency, when the road still provides maximum safety for existing traffic, should be done, so that repair and reconstruction operations are timely and effective (Fan et al., 2019). Numerous studies have been conducted so far; for example, in a study to inspect Polish roads, Budzinski et al. state that the thing which is important in road inspections is the quantity of inspections; This means that the inspector records a numerical value for each parameter. Qualitative evaluation is the inspector's mental perception and creates an error in the inspection results (Budzyński et al., 2017). Mukherjee et al. in 2021 study emphasized that road maintenance inspections, which are closely related to road safety, are usually a critical and critical task that requires great care. Therefore, they propose an accurate method using advanced techniques in artificial intelligence and computer vision to inspect road maintenance (Mukherjee et al., 2021). In another study, entitled “The Study of the Application of Remotely Guided Bird Systems in Inspection and Maintenance of Construction Projects” by Rajabi and Sadeghi, they found that inspection and maintenance of structures and construction activities are associated with problems in data collection and are costly and time consuming that the drone system has the ability to gather accurate and comprehensive information about the project being designed or implemented, reducing inspection time and increasing safety (Rajabi & Sadeghi., 2019). Also in a study done by Khordehbinan et al. they found prioritizing road safety inspections using multi-criteria decision-making models for urban road safety network, since one of the main responsibilities of any government is a safe living environment for its residents, inspection of roads safety and urban thoroughfares in all its implementation stages, even after operation in order to maintain it, will be one of the essential priorities of the relevant organizations (Khordehbinan et al., 2015). Another study by Rock et al. in 2019 found that road authorities have a duty to maintain road safety, and this is not possible without constant inspection (Roque et al., 2019). Today, advanced methods and devices which are used for pavement inspection that perform the inspection operation more accurately and easily. But the simple and old method that is still used today is the inspection of pavement by experts with checklists’ help called the failure data collection form. Where the amount, type and severity of failure is recorded. An example of a failure data collection form is shown in Fig. 1.

As mentioned, several studies have been conducted on the importance and method of maintenance inspections, but none of them addressed the time interval and optimization of the frequency of maintenance inspections. Therefore, this study was conducted to optimize the frequency of maintenance inspections for a high-traffic suburban road, because on suburban roads due to high traffic speed, the issue of safety is very important (Elvik et al., 2019) and in case of any problems at the pavement level, albeit minor, the probability of an accident is doubled (Chen et al., 2017; Kabi & Sarfaraz.,2019). For this purpose, the method of optimizing the frequency of inspections with a certain degree of reliability was used.

## 2. Scientific Principles and Research Methods

This study is based on a document entitled “Optimizing the frequency of maintenance inspections for a certain degree of reliability”, which was conducted by Faqih in 1988 in order to determine the appropriate inspection interval in the industry that this method is used in this research for pavement management (Faqih.,1989).

### 2.1 Reliability at the End of Inspection Intervals

If for reliable pavement R(t) the density function of the probability of failure times (reduction of pavement condition to critical) is shown with P(t), the failure rate will be defined as equation 1.

$$r(t)=\frac{P(t)}{R(t)} \tag{1}$$

Also, the relationship between the reliability function and the density function is the probability of failure times as equation 2.

$$R(t)=1-\int_0^t P(t)dt \tag{2}$$

The derivation of this relation results in equation 3.

$$\frac{dR(t)}{dt}=-P(t) \tag{3}$$

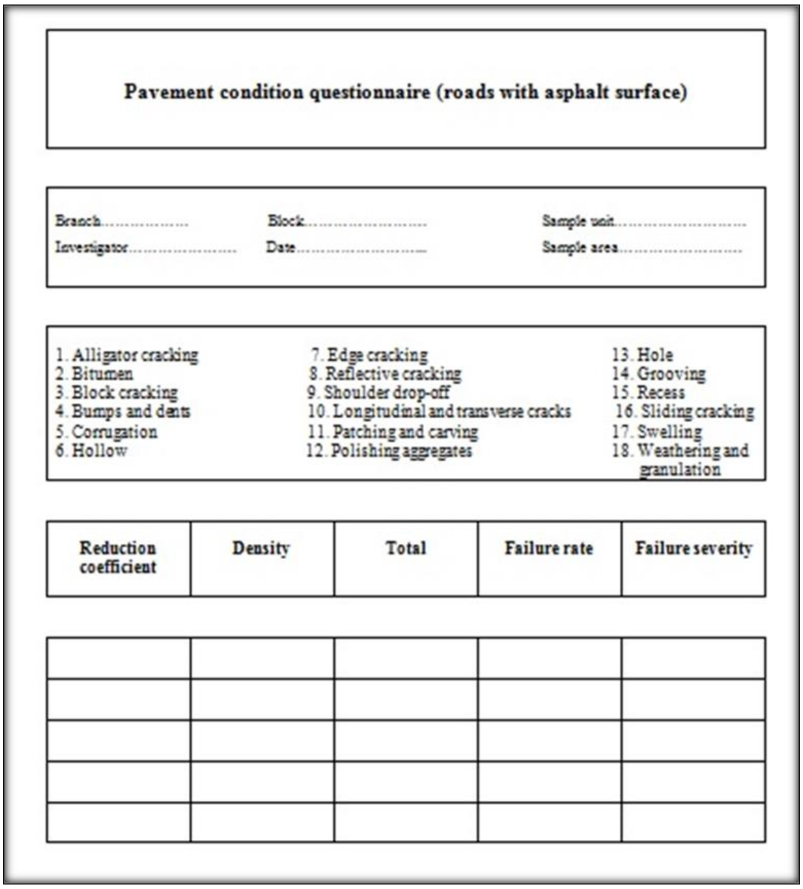
And by substituting equation 3 for equation 1, equation 4 results.

$$\frac{dR(t)}{dt}=-R(t)r(t) \tag{4}$$

Equation 4 can be written as Equation 5 and obtained by integrating it into equation 6.

$$\frac{dR(t)}{R(t)}=-r(t)dt \tag{5}$$

$$\int_0^t \frac{dR(t)}{R(t)}=-\int_0^t r(t)dt \tag{6}$$



**Pavement condition questionnaire (roads with asphalt surface)**

Branch.................. Block.......................... Sample unit..............................
Investigator...................... Date.......................... Sample area..........................

1. Alligator cracking
2. Bitumen
3. Block cracking
4. Bumps and dents
5. Corrugation
6. Hollow
7. Edge cracking
8. Reflective cracking
9. Shoulder drop-off
10. Longitudinal and transverse cracks
11. Patching and carving
12. Polishing aggregates
13. Hole
14. Grooving
15. Recess
16. Sliding cracking
17. Swelling
18. Weathering and granulation

| Reduction coefficient | Density | Total | Failure rate | Failure severity |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Fig. 1 - An example of a failure data collection form**

Given that the reliability at the time source is equal to one, R(0) = 1, so $\ln R(0) = 0$, so equation 7 is obtained.

$$\ln R(t) = -\int_0^t r(t)dt \tag{7}$$

In case the failure rate and lack of pavement quality is constant, equation 7 is reduced to equation 8:

$$R(t) = \exp[-\int_0^t \lambda dt] = \exp(-\lambda t) \tag{8}$$

In addition, Equation 8 belongs to the case that the distribution of failure times follows the exponential probability function.

At normal pavement life, it can be assumed that the failure rate remains constant between inspections and the failure time distribution follows the exponential probability function. On the other hand, it is obvious that if the frequency of inspections increases, the failure rate will decrease. Therefore, the failure rate, λ(n), will be a function (descending) of the frequency of inspections, n. So equation 8 will become equation 9:

$$R(t) = \exp[-\lambda(n)t] \tag{9}$$

Then, assuming that after each inspection, the machine is in the desired operating condition, the pavement reliability is calculated at the end of the sequence of consecutive inspections from equation 10.

$$R(T_i) = \exp[-\lambda(n)t] \ , \ t = T_i = \exp[-\lambda(n)T_i] \tag{10}$$

T_i is the frequency of successive pavement inspections and is calculated from equation 11.

$$T_i=\frac{1}{n} \tag{11}$$

Where n is the frequency of inspections pavement, in other words, the number of inspections performed per unit time. Equation 11 is written as Equation 12 after replacing equation 10:

$$R(T_i) = \exp[-\frac{\lambda(n)}{n}] \tag{12}$$

Therefore, knowing the frequency of inspections (n) and the specificity of the function λ(n) (relationship between failure rate and inspection frequency), it is possible to calculate reliability at the end of each inspection interval using Equation 12 (Faqih.,1989).

## 2.2 Optimization of Pavement Inspection Frequency

Optimization of pavement inspection frequency is now being considered to obtain a minimum degree of reliability. If the reliability at the intervals of successive inspections and before the next inspection is to be equal to a certain value of R (or in other words, the reliability at inspection intervals is not to be reduced to a minimum such as R) equation 13 is derived from equation 12.

$$R(T_i) = exp[-\frac{\lambda(n)}{n}] = R \tag{13}$$

Which Equation 14 is obtained from equation 13.

$$\lambda(n)=-n\ln R \tag{14}$$

Usually the shape of the function λ(n) can be determined in practice (using available statistics, archives, experiences, experiments, etc). By placing it in equation 14 when the function λ(n) is known, the value n (optimal frequency of inspections) can be used to achieve a certain (minimum) reliability of R. If for a device, the function λ(n) is equation of 15.

$$\lambda(n)=\lambda(0)\exp[-\frac{n}{\lambda(0)}] \tag{15}$$

Where λ (0) indicates the failure rate of the device if the inspection operation is not performed, in which case by placing equation 15 in equation 14, we will have equation 16.

$$\frac{n}{\lambda(0)} + \ln\frac{n}{\lambda(0)} = -\ln(-\ln R) \tag{16}$$

Or if the function λ(n) is in the form of equation 17, it is obtained in a similar way to equation 18, by solving which the optimal frequency is calculated (Faqih.,1989).

$$\lambda(n)=\frac{\lambda^2(0)}{n+\lambda(0)} \tag{17}$$

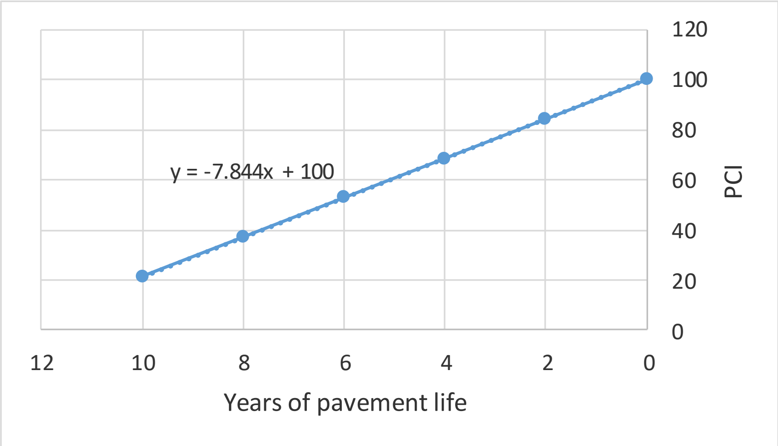
$$n^2+\lambda(0)n+\frac{\lambda^2(0)}{\ln R}=0 \tag{18}$$

# 3. Results and Discussion

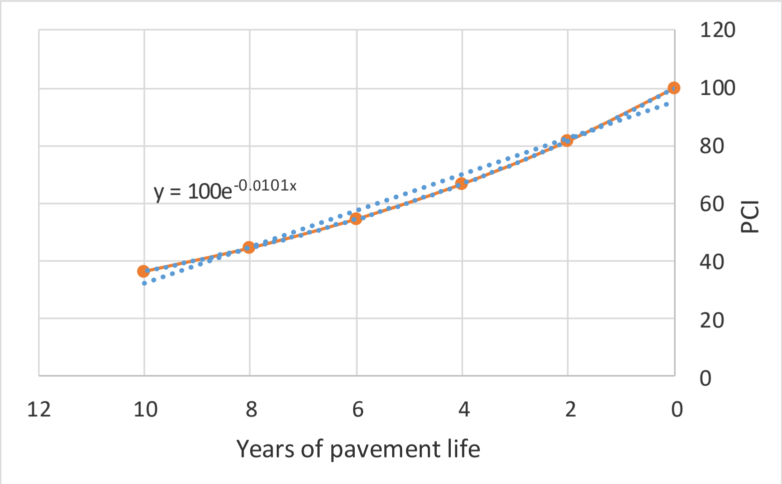
In the matter of pavement, the failure function can be considered as a function of Pavement condition index (PCI); Because the pavement condition index is a simple, easy, inexpensive and common way for monitoring the road surface condition, identifying maintenance and renovation needs, as well as ensuring that road maintenance budgets are wisely used (Karim et al.,2016). Moghadasnejad et al. in a study entitled “Determining the pavement performance curve using a case study”, presented the pavement status functions for a suburban road pavement with high traffic using SPSS statistical software according to Table 1 (MoghadasNejad et al.,2016) . Fig. 2 also shows the relevant relationships with the help of Graffer software.

**Table 1 - Evaluation of fitted curves for suburban roads with high traffic [5]**

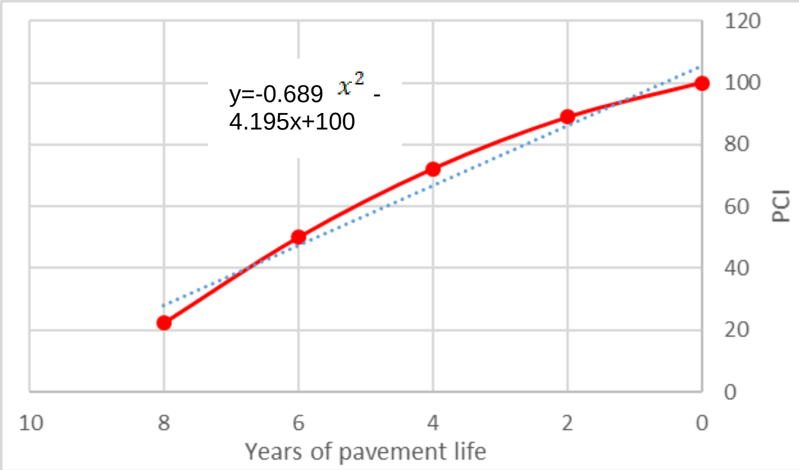
| function | Fitted curve relation | $R^2_{Adj}$ |
|---|---|---|
| Linear | PCI=-7.844×(year)+100 | 0.88 |
| Exponential | $PCI=100e^{-(0.01\times(year)}$ | 0.84 |
| quadratic | $PCI=-0.689(year)^2-4.195(year)+100$ | 0.92 |
| cubic | $PCI=0.276(year)^3-2.692(year)^2-0.978(year)+100$ | 0.92 |



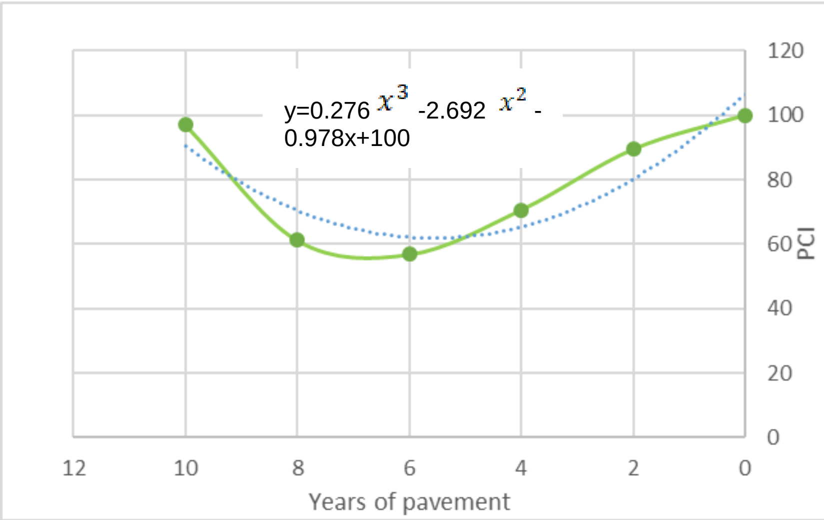

**(A)**




**(B)**




**(C)**




**(D)**

**Fig. 2 - Fitted curves of the pavement condition function A-linear B-exponential C-quadratic D-cubic**

The exponential relationship of PCI (equation 19) is in accordance with equation 15, so with the help of equation 16, the optimal inspection frequency can be achieved by considering a 95% confidence factor (equation 20).

$$\mathrm{PCI} = 100 \times e^{-(0.01\times(\text{year}))} \quad (19)$$

$$\frac{n}{100} + \ln\frac{n}{100} = -\ln(-ln0.95) \quad (20)$$

By solving equation 20, the optimal inspection frequency (n) is 218; In other words, in order for the desired pavement to perform optimally with a 95% confidence level, 218 inspections should be performed annually. Nowadays, it is recommended that suburban roads be inspected daily, every two days or weekly, depending on the type of road and their importance, so that in case of any problems and failure, timely maintenance operations are carried out and do not reduce safety (Fan et al., 2019).

## 4. Conclusion

This study was conducted to optimize the frequency of maintenance inspections for a high-traffic suburban road, by optimizing the frequency of inspections with a certain degree of reliability, because on suburban roads due to high traffic speed, safety is very important and in case of any problems at the pavement level, the chances of an accident are doubled. For this purpose, the failure function was considered as a pavement condition (PCI) index. The results show that in order to pave the suburban road with high traffic in order to perform the desired pavement with 95% reliability, 218 inspections should be performed annually.

## Acknowledgement

The main reference of this study is a research entitled Optimization of maintenance inspections for a certain degree of reliability conducted by Dr. Nizamuddin Faqih and a study to determine the performance of pavement using a case study conducted by Fereydoun Moghaddas Nejad, Reza Maskani and Reza Iman that in this regard, the first author of these articles is praised. Also, the research officials of Yazd University for providing the situation for this research as well as supporting the researchers are appreciated.

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