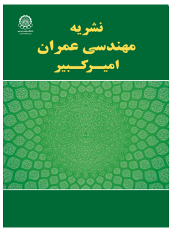

Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(7) (2021) 609-612
DOI: 10.22060/ceej.2020.17502.6583

# Pavement Maintenance and Rehabilitation Planning Considering Budget Uncertainty

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**ABSTRACT:** Maintenance and rehabilitation planning plays a pivotal role in the implementation of an efficient pavement management system. The variables are generally considered deterministic to solve the problem. Nevertheless, this problem tackles with a high level of uncertainty. For instance, the budget, as one of the essential criteria, is fluctuated owing to resource limitation, and policy alteration. If the budget is taken into account as deterministic, the result of the problem may be considerably different from the absolute optimal solution to the problem. This investigation aims to solve a maintenance and rehabilitation problem by consideration of a novel and powerful uncertainty approach. To this end, a multi-stage integer linear uncertainty model is introduced to find a solution, which is feasible and optimal in all of the uncertainty modes. The case study of this paper is a network, including six pavements. The outcomes indicated that the proposed model is competent to consider budget fluctuation, and it introduces a solution that is optimal for all uncertainty scenarios. The comparison of deterministic and uncertainty models revealed that the number of preventative maintenance selected by the uncertainty model is more than that of the deterministic model. The number of preventative maintenance was increased from 36.67% to 40.91% via considering uncertainty in the problem. It can be postulated that the uncertainty model tries to allocate budget to more segments to reduce the likely negative impacts of budget fluctuation on the project.

**Review History:**

Received: Dec. 08, 2019
Revised: Feb. 09, 2020
Accepted: Mar. 10, 2020
Available Online: Apr. 03, 2020

**Keywords:**

Pavement management
Maintenance
Uncertainty
Optimization
Stochastic programming

## 1. INTRODUCTION

According to road maintenance and transportation organization, 97% of passenger transportation and 91% of goods transportations are conducted by pavements [1]. Accordingly, this massive number of transportation leads to increasing the deterioration rate of pavements in the network and increasing the required budget for pavements maintenance and rehabilitation [1]. To this end, the optimization of pavements maintenance and rehabilitation has been an immense concern.

Furthermore, the majority of pavements maintenance and rehabilitation models consider the budget constant. Nonetheless, estimating the annual budget in advance is not feasible owing to some economic and political problems. Hence, consideration of budget uncertainty can be an appropriate approach. Wu and Flintsch [2] considered budget uncertainty in a network, including 16000 pavements. They applied a Markov process to consider uncertainty in the pavements maintenance and rehabilitation problem [2]. Similarly, Gao *et al.* [3] took budget uncertainty into account in the pavements maintenance and rehabilitation problem. They considered a case study, which contained 16400 km linear pavements. To this end, the budget uncertainty was analyzed with the application of the Markov process.

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According to the aforementioned concepts, budget uncertainty has been generally analyzed by the Markov process. Nonetheless, the Markov process cannot separate the pavements section in the network and cannot consider the condition of pavement individually. To this end, multistage stochastic integer programming is introduced in this study to prevail over this deficiency.

## 2. METHODOLOGY

This study is classified into three sub-parts, including selecting the pavement condition index and detecting the required models applied in the optimization problem, expansion of the deterministic pavements maintenance and rehabilitation problem, and solving the pavements maintenance and rehabilitation problem under uncertainty.

### 2.1. Pavement condition index

In this study, the international roughness index (*IRI*) is taken into consideration as the pavement condition index. Because this index directly correlates with the pavement's surface features, it plays a crucial role in the driver's safety and feeling of convenience. To estimate the deterioration rate of the pavement condition index, the model introduced by Tsunokawa and Schofer was applied in the optimization problem modeling [4].

**Table 1. The initial characteristics of network' sections**

| Section ID | Length (km) | Area ($m^2$) | Annual average daily traffic (vehicle per day) | Initial *IRI* (m/km) |
|---|---|---|---|---|
| 1 | 6.58 | 90146 | 14378 | 2.45 |
| 2 | 2.83 | 58771 | 14378 | 2.88 |
| 3 | 3.67 | 48759 | 14378 | 2.41 |
| 4 | 7.45 | 95360 | 14378 | 4.30 |
| 5 | 3.15 | 43305 | 14378 | 2.32 |
| 6 | 3.74 | 51238 | 14378 | 2.90 |

**Table 2. The unit cost and the improvement of each treatment**

| Treatment ID | Treatment type | Cost (Toman/$m^2$) | *IRI* improvement |
|---|---|---|---|
| 1 | Do nothing | 0 | 0 |
| 2 | Preventive | 5000 | 0.3 |
| 3 | Light rehabilitation | 15000 | 1.2 |
| 4 | Medium rehabilitation | 32000 | 2 |
| 5 | Heavy rehabilitation | 65000 | $IRI_{new}$=1.5 |

## 2.2. The deterministic model

In the pavement network, $I=\{1,2,3,\dots,I\}$ sections are considered. Meanwhile, $K=\{1,2,3,\dots,K\}$ treatments are taken into account in which $K$ provides the highest level of improvement and it is the most expensive operation. The years in the analysis period are considered discrete parameters $T=\{1,2,3,\dots,T\}$. Thus, the formulations of the deterministic model are as follow:

$$\text{Minimize } \sum_{i=1}^{I} |IR_{i5} - IR_i^*| \tag{1}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} A_i C_{ikt} x_{ikt} \le B_t \qquad \forall t \in T \tag{2}$$

$$IR_{it} = IR_{i0}\exp(\beta t) + \sum_{j=1}^{t}\sum_{k=1}^{K-1} x_{ikt} e_{ik}\exp(\beta(t-j)) + (IR_{new} - IR_{i0}\exp(\beta t))x_{iKt} \quad \forall i \in I \tag{3}$$

$$IR_{it} \ge IR_{min} \qquad \forall t \in T \tag{4}$$

$$IR_{it} \le IR_{max} \qquad \forall t \in T \tag{5}$$

$$\overline{IR}_t = \frac{\sum_{i=1}^{I} IR_{it} A_i}{\sum_{i=1}^{I} A_i} \qquad \forall t \in T \tag{6}$$

$$\overline{IR}_t \le IR_t^{network} \qquad \forall t \in T \tag{7}$$

$$\sum_{k=1}^{K} X_{ikt} = 1 \qquad \forall i \in I, \forall t \in T \tag{8}$$

$$X_{ikt} \in \{0,1\}, IR_{it} \ge 0 \tag{9}$$

Where, Eq. (1) is the objective function of the deterministic problem, which minimizes the distances of pavements *IRI* and an ideal level in the last year of the analysis period. Eq. (2) represents the budget constraint. Eq. (3) implies a method that applies to calculate the *IRI* of sections based on the deterioration rate and improvement of treatment applied to the mentioned section. Eqs. (4) and (5) are set to restrict the range of *IRI*. Based on Eqs. (6) and (7), the weighted average of *IRI* for the network pavements cannot violate a particular range. Based on Eq. (8), only one selection can be made for each section in a year. Furthermore, the decision variable of this model is binary, and this statement is indicated in Eq. (9).

## 2.3. The uncertainty model

In the uncertainty model, under multistage stochastic integer programming, all feasible types of budget allocation are analyzed. That is to say, two levels of budget are taken into consideration for each year. Accordingly, 32 types of budget allocation can be available for 5 years ($2^5$).

## 3. CASE STUDY

To analyze the effects of uncertainty on pavement maintenance and rehabilitation planning, a case study, including 6 sections with a total length of 28 km, is taken into account. The mentioned sections are located on the Tehran-Garmsaar highway. The initial condition and characteristics of sections are shown in Table 1. Furthermore, The *IRI* improvement of treatments and treatment unit costs are given in Table 2 [1, 5, 6].

## 4. RESULTS AND DISCUSSION

The average condition (*IRI*) of the network for the deterministic and uncertainty models during a 5 year analysis period is illustrated in Fig. 1. As can be seen, the *IRI* is steadily reduced in the deterministic and uncertainty models. However, the performance of the deterministic model is a bit better than that of the uncertainty model. The deterministic model reduces the average *IRI* of the network from 2.87 to 2.25 m/km.

The comparison of the required cost to conduct the introduced solutions of the deterministic and uncertainty models is demonstrated in Table 3. Drawing on the results of this Table, the uncertainty model introduces cheaper optimal solutions than the deterministic model, and it may be because of considering uncertainty and budget reduction. Hence, it can be postulated that the uncertainty model is highly qualified to compensate for the effects of budget fluctuation on the performance of the network.

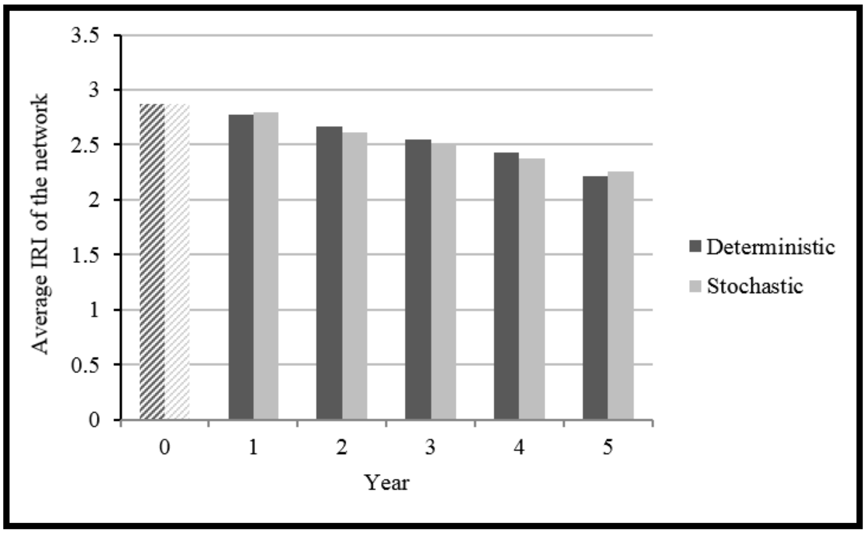


**Fig. 1. The average value of pavements condition for deterministic and uncertainty budget models**

## 5. CONCLUSION

The uncertainty model introduced in this study can control budget variation. Besides, in the analysis period, decision-makers can adjust the maintenance planning with the current circumstance.

**Table 3. The total cost that spends on the network in budget models of deterministic and uncertainty**

| Year\Model | Deterministic | Uncertainty |
|---|---|---|
| 1 | 1646927000 | 1552299500 |
| 2 | 1674199000 | 1547609250 |
| 3 | 1644046000 | 1531469375 |
| 4 | 1332295000 | 1429989513 |
| 5 | 1656954000 | 1412068497 |
| **Sum** | 7954421000 | 7473436134 |

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**HOW TO CITE THIS ARTICLE**

*A. Golroo, A.H. Fani, H. Naseri, S.A. Mirhassani, Pavement Maintenance and Rehabilitation Planning Considering Budget Uncertainty, Amirkabir J. Civil Eng., 53(7) (2021) 609-612.*

**DOI:** 10.22060/ceej.2020.17502.6583