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 in order 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 indicate 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 reveals that the number of preventative maintenance selected by the uncertainty model is more than that of the deterministic model. The number of preventative maintenance is increased from 36.67% to 40.91% if uncertainty is considered in the problem, and it can be postulated that the uncertainty model tries to allocate budget to more segments so as to reduce the likely negative impacts of budget fluctuation on the project.

KEYWORDS

Pavement management, Maintenance, Uncertainty, optimization, Stochastic programming.

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1. Introduction

According to road maintenance and transportation organization, 97% of passenger transportation and 91% of goods transportations are conducted by pavements [1], 2019 #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], 2019 #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 in order 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.

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, a multistage stochastic integer programming is introduced in this study so as to prevail 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 the pavement condition index. Because this index directly correlates the pavement's surface features, it plays a crucial role in the driver's safety and feeling convenience. To estimate the deterioration rate of the pavement condition index, the model introduced by Tsunokawa and Schofer is applied in the optimization problem modeling [4].

2.2. The deterministic model

In the pavement network, $I=\{1,2,3,\ldots,I\}$ sections are considered. Meanwhile, $K=\{1,2,3,\ldots,K\}$ 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 as a discrete parameter $T=\{1,2,3,\ldots,T\}$. Thus, the formulation of the deterministic model is as follow:

$$Minimize \sum_{i=1}^{I} \left| IR_{i5} - IR_i^{*} \right| \quad (1)$$

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

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

$$IR_{it} \ge IR_{min} \qquad \forall t \in T \quad (4)$$

$$IR_{it} \le IR_{max} \qquad \forall t \in T \quad (5)$$

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

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

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

$$X_{ikt} \in \{0,1\}, IR_{it} \ge 0 \quad (9)$$

Where, the equation (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. Equation (2) represents the budget constraint. Equation (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. Equations (4) and (5) are set in order to restrict the range of IRI. Based on equation (6) and (7), the weighted average of IRI for the network pavements cannot violate a particular range. Based on equation (9), only one selection can be made for each section in a year. Furthermore, the decision variable of this model in binary, and this statement is indicated in equation (10).

2.3. The uncertainty model

In the uncertainty model, by virtue of a 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 a 5 year period (2^5).

3. Case study

To analyze the effects of uncertainty on the 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 indicated in Table 2 [1, 5, 6].

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

4. Results and discussions

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 from the results of this figure, 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.

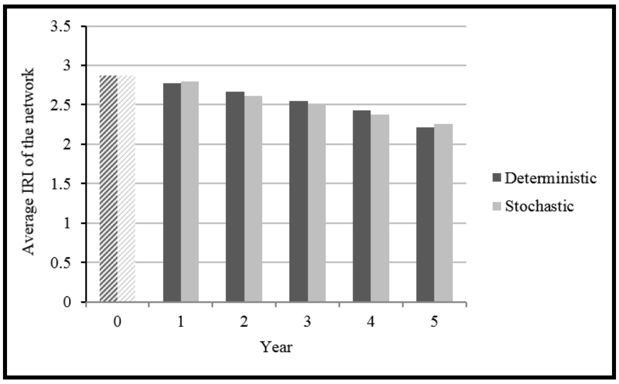

Fig. 1. The average value of pavements condition for deterministic and uncertainty budget models

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

year\model	Deterministic	Uncertainty
1	1646927000	1552299500
2	1674199000	1547609250
3	1644046000	1531469375
4	1332295000	1429989513
5	1656954000	1412068497
Sum	7954421000	7473436134

5. Conclusions

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.

6. References

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