Development of Model for Budget Allocation in Integrated Pavement Management Systems with Preventive Maintenance

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Abstract: In recent years, the importance of pavement Preventive Maintenance (PM) and its considerable effects on reduction of costs is perceived increasingly. The complete effects of PM are perceived when these methods are completely integrated with Pavement Management System (PMS). The present study defined the activities for successful integration of PM treatments with PMS.

One of the basic questions in integrated systems is the budget allocation to each of maintenance, rehabilitation and reconstruction activities as the highest benefit is dedicated to network. The present study answers this question by applying linear optimization model defined as maximizing the pavement conditions with budget limitation and a percent of pavement that should be reconstructed and maintained is defined. Therefore, the budget dedicated to each class in order that the network achieves its best conditions is determined.

Keywords: Pavement management system; Preventive Maintenance; Linear Optimization Model; Budget Allocation

1. Introduction

Necessary funds to maintain the pavements in the existing condition level is more than the budget allocated to them; and it is clear that highway agencies can't continue to operate with traditional maintenance approaches because with this approaches and due to lack of funding pavement conditions are gradually deteriorate. So agencies must focus more of their money on maintenance and increasing efficiency of this money. One strategy to Increase efficiency is use of preventive maintenance (PM) treatment which is the periodic application of relatively inexpensive pavement treatments to an existing roadway system [1].

A pavement PM treatment is an action that corrects minor defects, future deterioration, and maintains or improves the functional performance of a highway pavement without substantially increasing its structural capacity [2].

It is well understood that applying appropriate PM treatments at the right time extends the service life of pavements [3]. As indicated in the NCHRP Synthesis 223, each dollar invested in PM at the appropriate time in the life of a pavement may save $3 to $4 in future rehabilitation costs.

With demonstrating that PM is cost-effective for roads, agencies must abandon the practice of project selection using the "worst first" criterion and moving towards pavement preservation. "worst first" strategy means the policy of spending all agency monies to repair the poorest roads first but pavement preservation should be carried out at early stage of the pavement life while it is still in good conditions.

Accepting this attitude is hard for most of the managers as they have always roads with poor conditions. Therefore, budget allocation to the roads with good conditions is a little hard and impossible. The successful experience of some of the agencies in using PM treatments causes that many agencies use these methods and integrate them with Pavement Management System (PMS).

One of the basic questions in integrated PMS with PM, based on limited budget is as how much budget is dedicated to each of maintenance, rehabilitation and reconstruction actions to achieve the maximum benefit by network. The present study attempted to develop a model for budget allocation to various actions or various pavement classes (suitable pavements to receive PM, rehabilitation and reconstruction actions) in order that the network achieves its best conditions. To do this, activities are defined for successful integration of PMS by PM treatments. It is observed budget division among various actions is one of the important parts of integrated PMS; so by linear optimization model defined as maximizing the pavement conditions, a percent of pavements that suitable for maintenance, rehabilitation and reconstruction is defined.

2. Integrating PM treatments with PMS

For successful integration of PM treatments with PMS, a series of activities should be performed. These activities are summarized in as:

2.1 Selecting integration method

The most sophisticated approach to integrate is to define specific PM treatments into the PMS and to

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develop performance models, treatment rules, cost functions, and impact models for each treatment that is defined [4].

However, this method provides the highest support for PM programs but the need to performance models development for all PM treatments caused that a few agencies can use this method.

Another integration method is putting PM treatments in pavement analysis models. For example, besides the estimation of rehabilitation and reconstruction, pavement management analyzes pavement sections for PM treatments that are used for pavements with relatively good conditions. This approach is relatively simple to implement and does not require very sophisticated analysis tools to use.

The proposed method in this study is using two short-term and long-term horizons. This method includes putting PM treatments in pavement analysis models in short-term horizon and collecting required data for development of performance models, method rules, costs function and the effect of models for all PM treatments defined in PMS in long-term to execute optimization methods based on life cost analyses in the network.

2.2 Classing pavements

Classing pavements is important activity for integrating PM treatment with PMS. The complexity of the pavement management problem can substantially be reduced if the M&R variables are assigned to pavement classes rather than to individual pavement sections [5]. A pavement class is one that contains pavement sections with relatively similar pavement distress conditions, therefore, the sections qualify for the same actions.

In this paper, treatment trigger levels are set to establish pavement classes at which various treatments are considered. So pavements divided in 4 classes:

1- Suitable pavements to receive PM treatments
2- Suitable pavements to receive light to moderate rehabilitation
3- Suitable pavements to receive heavy rehabilitation
4- Suitable pavements to receive reconstruction

2.3 Selecting criterion and evaluation of pavement conditions

To classify pavements, at first pavements should be evaluated and then a criterion as maximum or minimum acceptable value is determined. As the goal in this stage is being informed of pavement conditions, using a combined index is adequate. The present study applies pavement condition index (PCI) as a criterion. Therefore, some criteria as acceptable minimum should be considered for this index.

The proposed acceptable minimum PCIs are defined for four types of pavement in the previous section are defined as follows [6]:

1- Suitable pavements to receive PM treatments with $70 \leqslant PCI < 85$
2- Suitable pavements to receive light to moderate rehabilitation with $50 \leqslant PCI < 70$
3- Suitable pavements to receive heavy rehabilitation with $25 \leqslant PCI < 50$
4- Suitable pavements to receive reconstruction with $PCI < 25$

The pavement with $PCI \geqslant 85$ doesn't need maintenance unless they have local deterioration.

2.4 Budget allocation

Budge division among various actions is one of important parts of integrated PM treatments with PMS and it should be considered more.

One view for budget allocation is based on the fact that the pavement with good general condition with only local deteriorations and the pavements requiring crack filling and sealing should be maintained and repaired at first and then the rest of budget is planned.

The proposed method for budget allocation in this study is to provide the budget of pavement requiring local rehabilitation or crack sealing and then, the rest of budget is dedicated as the required network is optimized by maximization of pavement conditions in the network between each of the defined groups in the previous section.

3. Budget allocation model

Pavement management models were developed with one common objective, which is reducing costs of agencies.

Microscopic and macroscopic approaches are used in modeling the pavement management problem. The microscopic approach requires the identification, inspection, and rating of each pavement section whereas the macroscopic one requires only obtaining the pavement proportions in the various deployed classes [5]. The microscopic approach defines the maintenance, rehabilitation and reconstruction variables as integer variables representing the number of pavement sections that should be treated by the various applicable actions. Several pavement management models have deployed the microscopic concept using different modeling and optimization approaches [7,8].

Pavement management models that used the macroscopic approach define the maintenance, rehabilitation and reconstruction variables to

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represent the pavement proportions that should be treated by the corresponding various actions [9,10].

In Macroscopic models, the expected age of deployed actions is used for measure of performance. Therefore, in this models can be treated as a simple PMS since it does not require the incorporation of a complex pavement performance prediction model [11].

In this paper, a macroscopic optimum liner model is developed for budget allocation to pavements in network level. this model which is defined as maximizing the pavement condition represent the proportions of pavements in the various classes (Suitable to receive PM treatments, light to moderate rehabilitation, heavy rehabilitation and reconstruction) that should be treated by the corresponding various actions and also yields optimum budget allocation for a given pavement network. The model uses a simple but yet very effective long-term measure of pavement performance.

3.1 Maximization of Pavement Condition Model

The objective of this model is maximizing the pavement condition improvement that can take place on a given pavement network as a result of maintenance and rehabilitation works. The pavement condition improvement is defined as the net gain in age that can be added to the pavement network.

The expected ages of various deployed actions are the main pavement performance parameters used in the formulation of the model objective function. The ages of actions are estimated from experience of agencies. Objective function is as follows:

$$MAX.Condition = \sum_{j=1}^{6}\left(\frac{a_j \times P_j}{100}\right) \times A_j \times X_j \qquad (1)$$

In this equation :

a_j is area of pavements that are in j-th class

P_j is percent of pavements that are in j-th class

j is pavement classes (6 classes involve suitable pavements to receive Microsurfacing, Thin Hot-Mix Overlay, Seal Coat (PM treatments), suitable pavements to receive light to moderate rehabilitation, suitable pavements to receive heavy rehabilitation and suitable pavement to receive reconstruction)

Aj net gain in age due to applying j-th action (expected life of j-th action)

Xj percent of pavements that must receive j-th action

in this function, computing Xj (suitable pavements percent to receive various actions) are primary object till the network achieves its best conditions.

Objective function can be subjected to three sets of linear constraints. The first set is the cost constraint set, which represents the total cost associated with the actions applied to the entire pavement network. This total cost is equated to the total projected budget as provided in Equation (2).

$$\sum_{j=1}^{6}\left(\frac{a_j \times P_j}{100}\right) \times C_j \times X_j = B \qquad (2)$$

In this equation:

C_j cost of j-th action in US dollars per square meter of surface area

B is total budget of project

The second set of constraints is the limitation constraints placing upper limits on the deployed maintenance, rehabilitation and reconstruction variables as provided in Equation (3). The sum of the variables applied to a particular class shall not exceed the proportion of pavement that exists in that particular class.

$$X_j \le P_j \qquad \text{for } j = 1,2,3,4,5,6 \qquad (3)$$

The third set of constraints is the non-negativity constraints placed on all maintenance, rehabilitation and reconstruction variables as provided in Equation (4).

$$X_j \ge 0 \qquad \text{for } j = 1,2,3,4,5,6 \qquad (4)$$

Therefore, the presented optimization model can be summarized as provided in Equation (5).

$$MAX.Condition = \sum_{j=1}^{6}\left(\frac{a_j \times P_j}{100}\right) \times A_j \times X_j \qquad (5)$$

$$1)\sum_{j=1}^{6}\left(\frac{a_j \times P_j}{100}\right) \times C_j \times X_j = B$$

$$2) X_j \le P_j \qquad \text{for } j = 1,2,3,4,5,6$$

$$3) X_j \ge 0 \qquad \text{for } j = 1,2,3,4,5,6$$

Table 1 shows unit Costs of actions in US dollars per square meter of surface area and table 2 shows expected Life of actions. These values (which are based on the authors' experiences) will vary depending on the project location, quantities placed, and environmental conditions.

Various agencies based on their experience can change the costs and expected life of each of the actions.

Table 1. unit costs of actions

action	Cost/m^2
Microsurfacing	**1.7**
Thin Hot-Mix Overlay	**2.3**
Seal Coat	**1.1**
light to moderate rehabilitation	**6.8**
heavy rehabilitation	**19.7**
Reconstruction	**88.5**

Table 2. expected life of actions

action	Life (year)
Microsurfacing	**7**
Thin Hot-Mix Overlay	**8**
Seal Coat	**5**
light to moderate rehabilitation	**8**
heavy rehabilitation	**10**
Reconstruction	**15**

4. Conclusion

Today, most authorities focus on road maintenance and keeping great investment and in case of the lack of consideration, great costs are imposed on agencies. Regarding the limitation of budget, finding the low-cost maintenance methods with high impact is of great importance. Needs to finding low-cost methods leads to creation of PM treatments. But, PM treatments show their suitable efficiency if an organized and periodical program is considered on pavement. This issue and the lack of information of managers of this issue, lead into the unsuccessful implementation of these methods. Thus, successful fulfilling of these programs is putting PM treatments in PMS that these treatments are executed like other methods of rehabilitation and maintenance as regularly and their effects are observed by supporting PMS of these methods.

In integration issue, a good method with existing information and tools should be considered. Thus, by the existing facilities in many developing countries, a good method is presented for PM treatments with PMS.

Also, to evaluate pavement conditions and selecting criterion for pavement classification, PCI index is used that its calculation without using complex tools is possible.

Another challenge that agencies are encountered in integrated systems is budget allocation to each of maintenance, rehabilitation and reconstruction activities. Therefore, a model is developed defining budget allocation to each of defined pavement groups. This model helps the engineers to achieve good results with the less information.

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