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Techniques of Optimizing the Highway Asphalting Improvement Program Case Study: Hemmat Highway

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Abstract: The concept of pavement management and optimization has been existed since the existence of the pavements and it has been used from the late 1960s and early 1970s. In Iran there are no management and maintenance systems and because of lack of conditions, facilities and information in Iran there is no possibility to take advantage of the methods used in other countries. The method used in this paper is originated from annual optimization method and it is much simpler than other existing methods, but still it is much more practical. For case study the developed method has been used on a part of the top of East Hemmat Highway with the length of 1 km. In this procedure the intended PCI devices were measured, a short-term program of work was suggested and its effect on the previous PCI was evaluated and the amount of increase in the useful life of the road has been shown by the chart. The required budget and cost for each program was examined and proposed and in general the comparison was made between the cost, life and the usage of that part of the road. Also using AHP methods (analytic hierarchy process) the analysis were done and prioritizing of the options for repair and maintenance of the devices were conducted and finally these results will be reached that if in the country's highways network they make use of management and maintenance systems, there will be significant increases in the useful life of the road and also exorbitant costs of general paving of the roads will be reduced and it will avoid any delay and many problems that arise with destruction and damage of the road, will be prevented.

Key words: Pavement Management System (PMS) · Optimization · Maintenance and repair (M & R) · Pavement Condition Index (PCI).

INTRODUCTION

To prevent the destruction of roads, highways and in general in any way with overlay of asphalt, concrete and substructure and also to avoid the vanishing of useful life and optimum ways there should be a planning at proper times to prevent any problems and should not let the problem grow bigger and spread to other parts. For this matter we should use pavement management system (PMS) and take advantage of it and in this system a comprehensive and scheduled program is designed for the road network and all cases are already considered in it. In pavement management there are different models of optimization and decision making for planning the improvement of the highway states and we can achieve an analyzed progress in the state of highway network by spending the least cost.

A number of methods of the optimal approach are used by the city, state and national highway agencies to select and plan the reconstruction and maintenance projects of the highway networks. These methods can be divided into 4 groups, including ranking methods, annual optimization methods, real optimization techniques and exploration methods. In this study we have used annual optimization method that we will discuss it in the next parts.

Annual Optimization Methods: Annual optimization methods define an objective function where the optimization process can be expressed mathematically.

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The Objective Function Can Be of Two Types:

- To minimize the total cost of the current year's program
- To maximize the benefits obtained from the costs of available investment.

Each of these objective functions is performed by their limitations or constraints. Annual optimization techniques may not obtain a true optimization because these projects are not forward or backward in time to achieve the most cost-effective mix of options, projects and schedules.

Application of Research Techniques in Operations for Optimization: A number of research methods are available for operations of optimization which can almost be classified as algebraic and probabilistic methods. The main algebraic optimization techniques include linear programming, nonlinear programming, dynamic programming, integer programming and objective programming. The main methods of the potential optimization include Monte Carlo simulation, Markov decision processes, decision tree analysis and heterogeneous planning. Dynamic programming issues can be formulated as an algebraic or probabilistic matter.

Literature Review: Three conventional mathematical methods used by optimization procedure for PMS include linear programming (LP), integer programming (IP) and dynamic or dynamical programming (DP). In this section a brief review of the existing literature on the application of optimization approaches on PMS based on these three mathematical methods will be examined.

Various approaches been proposed in recent years to optimize the level of the project of scheduling the maintenance and reconstruction. Common elements of these approaches are as follows:

- Identifying the information system of project
- Assessment of current needs
- Defining the modification strategies
- Prediction of the situation of the future assets
- Development of optimization algorithms
- Selection of the appropriate corrections

Development of systematic optimization approaches for pavement management system (PMS) has received increasing attention in recent decades. The main framework of this approach is the use of mathematical programming methods. Correctness of the decision variables has directed most research efforts towards proper planning methods. In this chapter, the literature of the application of the PMS optimization approaches will be reviewed. Much research has been done in this area inside and out of the country that can be mentioned as follows:

Turnquist and Mbwana (3) described a pavement management system of a project by using a large-scale linear programming algorithm that to achieve optimization it is converted to dynamic programming formulation.

Markov's transition probabilities which were used in many previous studies in this area, such as in Chen's theory and…..were used in the model to predict the future state of pavement. Although Turnquist and Mbwana's formulation of Markov's decision process model assigns a certain identity to each defined part of the network. Thus, the maintenance identities related to each part are considered to be unique for the matter of optimizing the network level. Hence, this approach makes the transition from level planning of network to responds of project easier; because the specific pavement conditions are available. The developed model was used for the highway network in Nassau County, New York. Generated responses were observed and compared with the actions tracked in New York State. However Wang disliked it because of complexity of hypotheses and the possibility of the rejection of the pattern.

The other technique used in the modeling of optimizing matter of the project is scheduling of the target. Raviarala (4) preferred this method because of its strength in examining issues involving conflicting objectives with different levels of importance. Previous works published by Ravirarala and Grivas show that planning aims to achieve simultaneously the conflicting objectives are useful. Although planning target does not easily integrate some lack of advantage in Markov's transition probabilities with the optimization process. Also the proper planning used in this method is applicable and it is because of high computational needs in large-scale pavement networks. Hence, the proposed model by Raviarala uses a linear program instead of proper programs for the development of multiyear optimization maintenance program. A set of linear functions are defined as the decision variables of target planning for the optimization of the pavement network. Although this model is leading in assessment of the status of network and the specifications of the controller. Evaluation of

network conditions consists of definition of the conditions of pavement, data of inventories and discovery, while control specifications consists of three processes of the identification, improvement, implementation of the state - reform and estimation of the times of the transition state of the pavement.

The development of a reliable model of pavement performance prediction is as important as the algorithm used in the optimization model. Hence, Li (5) stressed the importance of a pavement deterioration model which examines the effect of a modification on the degradation rate of pavement following the maintenance. In contrast, the inhomogeneous Markov decision process (independent of time) rejects the effect of application of a modification for a pavement section and assumes that the application of a modification and reconstruction, regardless of the applied reconstruction, does not affect pavement deterioration rates. The hypothesis is incompatible with of what happens. Thus, the heterogeneous Markov decision process (time-related) was introduced by Li. The developed model by Li assumes that the application of maintenance reaction for pavement will cause a new degradation rate which is calculated based on the Ontario's degradation of the asphalt equation. Li also defined the unit cost of the pavement and he measured the effect of each strategy on the pavement due to a mutation in the PCI. Hence, the factor of being economical is created on the basis of priority of scheduling optimization problem in the project. This model accepts the correct planning approach by assuming that it produces the most economical maintenance program planned for each year. The goal of this model is maximization of the overall profit ratio - cost (the cost effectiveness) and makes comparisons between various improvements planned for each year in order to select the best set of the maintenance reactions for the available budget and other provided restrictions. This comparison is based on the unit cost of each reform strategy and it is the specific impact of every reconstruction on the future performance of the pavement. Efficiency of a particular reconstruction strategy is predicted as the multiplication of the area between performance curve and the minimum level defined as the multiplication of servicing wit by the length and the traffic volume which is being used in such a particular pavement approach. Cost-based comparison caused prioritization of the reform strategies and hence produces a maintenance program for each year.

Grivas (6) offered an LP model for planning the courses of transferring the budgets related to the network pavement management. LP was formulated for modeling of interactions between economical and engineering factors in an efficient method. These decisions about the type of modification, made possible the timing and amount of work that had to be performed at the same time. Both project level and network-level constraints in model can be imposed for the development of a pavement management which met the specific needs based on the requirements and budget. The developed methodology is implemented as part of the PMS representing the New York State thruway.

Mbwana and Turnquise developed a new formulation of a project level PMS based on a Markov decision process model using Markov transition probabilities for modeling the state of pavements and identifying specific network link in optimization. Integration of specific links in simpler translation models made the project level policies of decisions more possible than it previously was. This easy formula of integration made the application and agency costs as well as a variety of other limitations about the reactions possible.

Considerable research has been done to overcome the argument of dimension orientation in DP. A significant effort is found in Morin and Marsten's method to reduce the dimension orientation of state variables in which an algorithmic procedure is developed for solving multi-dimensional problems of DP by searching an institutionalized state space. The idea behind the institutionalized mode of approach is finding of the valid network which causes a skip in the function return values. Then the points of discontinuity are examined for feasibility and based on this data the set of impossible solutions are removed. As a result, the set of feasible and efficient solutions are defined as an institutionalized state and a step by step search is performed on these points.

Chen (7) used the IP model in the Department of Transportation of Oklahoma for strategic planning of reconstruction and maintenance of pavements and by doing this he provided a valuable tool for highway agencies for proper network management. In this application, the overall performance of all selected projects of maintenance and reconstruction are maximized in the 1-5 integer linear programming. And the limitations of it are the minimum servicing ability of pavement, existing funding and the source suppliers. However, proper planning is both computationally intensive and

inappropriately prolonged if it is applied on a large scale road network, especially on several periodic pavement maintenance strategies it can be considered as an option.

Li developed an integer planning based on the efficiency of costs in a road network with the budget constraints and required levels of pavement reconstruction ability. The goal of optimization system is to select the most efficient M & R projects for each year planning.

FWA (8) developed a procedure based on genetic algorithm for solving multiple problems of pavement maintenance planning in network level. Concepts of optimal solutions of Fareto and Suitability Evaluation based on rankings were adopted to select the optimal solution. IP formulation and development the algorithm of description answer were proofed by a numerical solution in which the analysis of hypothetical planning of the network level pavement maintenance were done for the three optimizations with 2 and 3 objectives.

The performance of genetic algorithms is affected by the methods used to control many of the restrictions in the formulation of resource assignment problems like the network pavement maintenance problem. Chen proposed a method based on the assignment of prioritized resources for maintenance activities and to maximize the use of resources. It was demonstrated that a genetic algorithm with the assignment of prioritized resources method is superior to traditional genetic algorithm.

Nemhauser and Wolsey (11) described almost a complete line of algorithms for a variety of problems of proper planning including Knapsack problems. Algorithms provide exact or almost exact solutions. Exact solution procedures, are basically of two types: An ambiguous counting approach or a multi-faceted approach. The exploring processes for an approximate solution consists of Prymal exploring process, Duval approaches and facilitating methods of using exploring processes such as linear programming facilitating, facilitated replacement and Lagrangian to obtain information about the optimized solutions. The ambiguous counting approaches are based on the B & B and DP methods. Since the counting is basically the degree of exponential, the number of decision variables in this approach makes it difficult. Thus, effective algorithms commonly use a decline pattern in which a sensitivity analysis are done for the adjustment of each possible number of variables on their optimal values before the starting of ambiguous counting. DP is an optimum public solution even in the non-converging planning issues. Although the application of this powerful technique for separate variable problems is limited through computational requirements and extensive computer savings.. These computational problems are more severe when: 1) the state variables are defined through a vector with more than 2 dimensions, 2) the modes be in a form of small dimension, but the number of discontinuities in the state of the algorithm grows exponentially.

Application of facilitation consists of calculating exchange between strength and speed. Facilitation of LP and Lagrangian are used extensively for bound taking. LP facilitation is not examined in this thesis. Bound consistency depends on the selection of constraints that should be released in the facilitation of Lagrangian.(For a general theory about releasing see Lagrange Fisher: a practical guide to free Lagrange with many examples, see Fisher, to release the Lagrange with the shortest path and constrained resources see Handler, Zang (12).

Morin and Marsten (13) have also demonstrated how the B & B method can be implemented in DP to reduce storage and computational requirements. The application of simple and effective method of B & B for removal of algorithms in DP is a in general approach that can be used for all finite dynamic programs. Both ideas of B & B and institutionalized mode approach are integrated by isolation and basic understanding provided through DP to produce a hybrid algorithms of B & B and DP.

Dyer (14) developed a hybrid algorithm B & B / DP to solve multiple-choice questions of Knap sack. The duality of Lagrange in an efficient method in terms of computationally is used to calculate its tight bounds on each node in the search tree. Lagrange dual application also made it possible to use a reduction process to reduce the size of the counting phase.

MATERIALS AND METHODS

The purpose of our work is on a part of Hemmat Highway (over 1 km), in a way that the intended PCI segments (10 segments and each segment with the length of 100 meters) are measured by the visual inspection and photographing and after viewing the results and viewing that piece, the short-term work program is proposed and its effectiveness is evaluated on previous PCI. For each program the budgetary and cost should also be reviewed and discussed and a general comparison is made between

the cost, life and the application of the that part of the road and the impact of implementation and non-implementation of this program is reported.

Similarly, by using AHP (analytic hierarchy process) to analysis and prioritizing of the options for repair and maintenance of parts are done and at the end results are presented.

Generally there are many difficulties in collecting information about the roads in Iran. The biggest problem is the lack of management and maintenance systems. Actually there are no information about the highways regarding the history of construction, traffic information and the thickness of the road and other things. Therefore, all data must be obtained in hard circumstances and with high costs and it should be done for a certain period of time. Taking photographs with cameras and visual inspection in the site and spending lots of time in the location and on the photos were other problems that due to traffic conditions in Tehran, in some cases, it was carried out at certain hours so that it caused low-quality images and extended work hours in some cases. Inflation and seesaw of costs were other difficulties in obtaining funding for the work program. And for this reason sometimes the application of program and the reliability of the system were under question.

The Process of Data Analysis: The purpose of this study was to generate a potential PMS network level based on the annual optimization process. The system should use the PCI method for pavement condition rating. To achieve this goal, an approach was developed to study the details. The basis of this goal was developed by a comprehensive literature review of existing works in this field of PMS. The main components of this research program were:

- Development of possible models to predict pavement performance based on experience
- Develop a prioritizing program
- Implementation of the models on the part with the length of 1 km in pavement networks of Hemmat Highway

The first step is to obtain PCI of the desired part. By the visual inspection and presence in the area and taking photographs of the parts, failures are identified and recorded. Then by putting the photos together, a photo roll with the length of about 1000 m is obtained. In the next step by viewing images and visual inspection of each

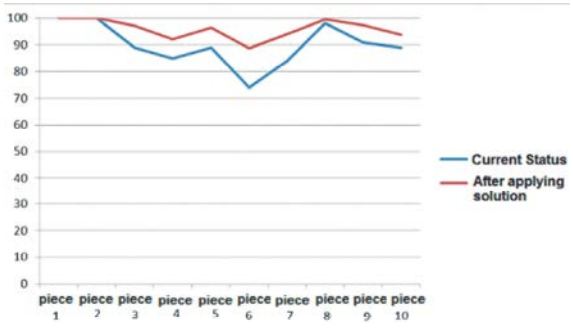

Fig. 1: Comparison of PCI both before and after applying the solution

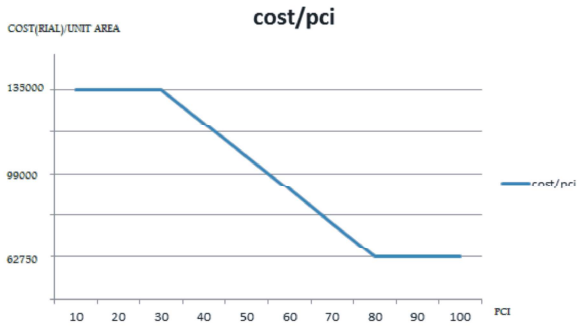

Fig. 2: Comparison of the cost and PCI

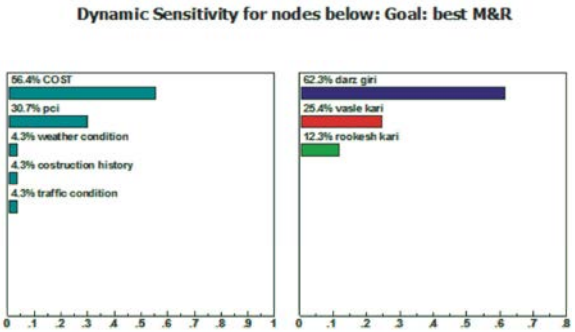

Fig. 3: Graph of dynamic sensitivity of prioritization between strategies by software

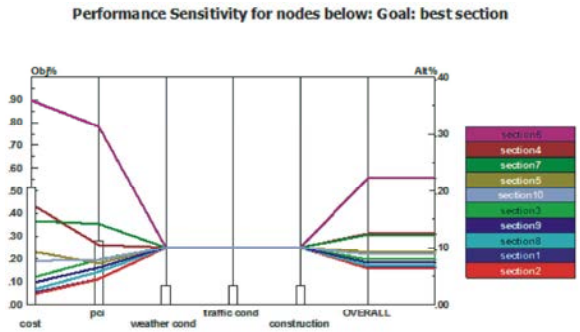

Fig. 4: Sensitivity analysis of efficiency of prioritizing between components by software Figure 5: Forecasting lifecycle.

Table 1: Cost of required solutions

Total Cost	Unit Cost (Rial)	Proposed solution	Damage Amour	Type of Damage	
0	0	Without Damage		Without Damage	Piece 1
0	0	Without Damage		Without Damage	Piece 2
899560	78000 + 48000	Stain removal and patch work	1.86 + 0.43 + 6.13	Cracks of Saurian skin,length and refective	Piece 3
1555200	48000	Stain removal	32.4	Length cracks	Piece 4
939000	78000 + 48000	Stain removal	1.94 + 10.43	Length and reflective cracks	Piece 5
2071560	78000 + 48000	Stain removal and patch work	11.09+4.1+20.07	Cracks of Saurian skin,length and refective	Piece 6
1209630	78000 + 48000	Stain removal and patch work	4.27+5.06+13.16	Cracks of Saurian skin,length and refective	Piece 7
341280	48000	Stain removal	7.11	Length cracks	Piece 8
619200	48000	Stain removal	12.9	Cracks of Saurian skin,length and refective	Piece 9
1256640	78000 + 48000	Stain removal and patch work	1.9 + 16.28	Length and Saurian Skin cracks	Piece10
8999880	Total cost of the pieces				

piece and failures and according to scale of images their length and quantity is measured. Then, according to terms obtained their intensity is achieved and having the dimensions and the type and severity of damage and by using the required tables and relationships the PCI of each piece is obtained.

After obtaining PCI and viewing the situation of each piece, measures and mechanisms are provided for short-term and one year planning based on experience and minimum standards in regulations and its impact on previous PCI is provided in the same way as above and a comparison is made between them. Then the estimate of the costs required to implement programs and policies according to rates are prepared. Cost of implementing policies in 92 (announced by Tehran Municipality) is produced and the overall budget for the program is obtained.

Finally, using relevant software, prioritizing is done among the available strategies as well as the parts.

The state of components before and after proposed strategies and options were measured and calculated. Then a comparison was done between the PCI which is provided below:

A comparison between the cost and the PCI is performed as follows:

The type and extent of any damage was determined and options were offered and costs of each option are separately examined and overall cost for 10 pieces is evaluated and they are described as follows:

Prioritizing is done be the AHP method between proposed options and strategies and also prioritizing of the parts is done separately which can be seen as follows:

As the asphalt pavement on the highway is implemented for about 5 years useful life (according to the executive director of Project Engineering Organization of Tehran Municipality's Highway)but which is about 3 years old, by modeling our case study and considering that less than a year is passed from the pavement of intended part, the forecast curve is drew for a 5-year life cycle and we have done a comparison on it assuming that the management and maintenance is done in a timely fashion, which can be observed as follows:

CONCLUSION

By viewing the obtained results and information, we realize the high importance of management and maintenance system of the roads in short and long time periods and we conclude that if we design a detailed work plan for the country's road network, we can prevent many problems and heavy and wasteful spending and by spending little and timely costs and also much easier implementation of strategies at the right time, we will have the roads which have more life and efficiently and the users and drivers will be more satisfied.

Timely implementation of strategies will increase the PCI of that section of the road and at that point in time, makes simpler and less costly ways to

prevent further decay and damage to other parts of the road pavement and the pavement will have a longer life.

However for a long-term and integrated system management and maintenance, we need information on the status and behavior of the road for each year (at least 5 to 7 years), in order to predict its future state (to age 5 to 7 years) and its curves should be drawn so according to the situation of the road in the future, maintenance costs and available funds, appropriate work programs can be proposed and prioritization is done among them.

When we have the information about the intended road and if we could predict the future situation of it, we can even plan using the newer and more accurate methods and we can benefit from many new features and but if we don't have the needed information about the situation of the road in the future, we can't predict anything and this matter will not be possible.

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