Ranking Versus Simple Optimization in Setting Pavement Maintenance Priorities: A Case Study from Egypt

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The success of a maintenance management system depends largely on the efficiency of the maintenance program that is produced. An efficient maintenance program is the program that identifies what maintenance action to be taken and where and when to apply it so that the most cost-effective results are obtained. The process used to answer these questions is called the maintenance priority setting. Three priority-setting techniques are presented along with the results of their applications on the data collected from the Egyptian road network. The first technique is a simple ranking based on current year condition data. The second is a modified ranking technique that considers the future condition of pavement sections, and the third is a near optimization, one that considers both time (current and future) and space (entire network). A comparison of the techniques in terms of network condition over time and budget deficit is presented. The results indicate a considerable difference in future network performance under the three techniques, with the optimization technique producing the best results.

A typical pavement maintenance management system (PMMS) would consist of several components, including

- Network identification and coding,
- Inventory of network physical features,
- Network condition assessment,
- Maintenance needs assessment,
- Comparison between needs and available resources to establish priorities,
- Production of the maintenance program, and
- Monitoring the execution of the program.

In fact, these components should cover three basic responsibilities of a decision maker: the abilities to

1. Describe the current condition of the network;
2. Select the best maintenance program (i.e., which maintenance action to do and where and when to do it, so that a maximum utilization of the available resources is achieved); and
3. Monitor the execution of the maintenance program.

With that in mind, the process of setting the maintenance priorities is of utmost importance to the entire PMMS process. This may be because the priority setting is the step after which a final decision is to be made on the maintenance program to be executed. In addition, and even more important, the quality of the priority setting directly influences the effectiveness of available resources, which, in most cases, is a prime goal of a decision maker. The massive efforts typically allocated to the phases of data collection and needs assessment may very easily be wasted if the appropriate priority schemes are not applied.

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Priority-setting techniques as used in the PMMS cover a wide spectrum of methods and approaches ranging from simple priority lists based on engineering judgment to complex network optimization mathematical models. In most cases, the effectiveness of the techniques, particularly in the long range, is directly proportional to the complexity of the scheme.

The degree of complexity, or comprehensiveness, of a priority-setting scheme is generally a function of the time and space dimensions when dealing with the network condition as shown in the following (*1–5*):

Time Dimension	*Space Dimension*
Current year	Section by section
Future years	Simultaneous consideration of all sections
– End of analysis period	
– Each year in analysis period	

For instance, the simplest form of priority-setting schemes as used in PMMS would be the one that considers only the current year condition on a section-by-section basis. On the other hand, a complex scheme would be the one that considers the yearly condition of the sections comprising the network in a simultaneous manner so that the effect of changing the condition of a section on the rest on the network could be assessed. Several levels exist in between these extremes.

A key issue in this concern is the choice of the appropriate priority-setting scheme. It is not necessarily that the most comprehensive one will be the best to use, at least from the point of view of the decision makers. Data availability plays an extremely important role in such selection, particularly in developing countries. In fact, the titles of some such techniques may discourage the decisions makers from proceeding. Therefore, it is of paramount importance to take a special care when introducing such techniques and concepts to decision makers.

The purpose of this paper is to demonstrate the use and the expected benefits of three priority-setting techniques: (a) a simple ranking based on a pavement's current year condition, (b) a ranking based on a pavement's current and future conditions, and (c) a near optimization technique. Although the three techniques could be classified as simple ones, it is believed that they are appropriate for use in developing countries, particularly at the early stages of applying PMMS.

BACKGROUND

In 1986–1988 a network study was conducted in Egypt with the aid of a team of international consultants through a project funded by the World Bank (*6*). The intent of the study was to provide the basis of a framework for decision making in road maintenance, one based on a ranking methodology that relies on an objective approach with regard to need and standard rather than custom and practice.

The study undertook the normal steps of a PMMS as described earlier. Network identification and coding in terms of links and sections was completed and followed by a comprehensive inventory of the physical features of the network and traffic volumes. In addition, a pavement evaluation in terms of a visual inspection was performed. Finally, an intervention logic was developed to assess maintenance needs on the basis of the collected pavement condition data (Table 1).

After these basic steps, a ranking model using the current pavement condition was developed. This model was used to identify sections to be included in the current year's maintenance program. This model proved to be insufficient in several ways, as will be discussed later. A special research study was initiated at Cairo University, Egypt, to improve the model (*7,8*). This research resulted in two other models. The ranking model and the other two models will be discussed in the following sections. The three models will be referred to hereafter as

- Model 1: ranking model developed by the 1986–1988 Egypt road network study.
- Model 2: modified ranking model developed by a special research study, Cairo University.
- Model 3: a near optimization model developed by a special research study, Cairo University.

The three models are based on the condition data and the intervention logic developed by the 1986–1988 study. This, in fact, was necessary to demonstrate that the differences between the models could be attributed to the priority techniques rather than to the condition data or the intervention logic.

MODEL DESCRIPTION

Model 1

The intervention logic presented in Table 1 was used to determine the appropriate maintenance treatment for each section. To establish a priority measure, a treatment index associated with each section was calculated as follows:

$$\text{priority index} = \frac{\text{defect length}}{\text{traffic factor} * \text{defect factor}}$$

The traffic factor took on values of 0.1, 0.5, and 1.0 for average daily traffic levels of less than 2,500 vehicles per day (vpd), between 2,500 and 10,000 vpd, and more than 10,000 vpd, respectively. The defect factor, on the other hand, was assigned to each section on the basis of the defect type and the required treatment, as presented in Table 2.

The priority index for the entire section was then calculated as the sum of the priority indexes for both the highway and the shoulder. This way, the higher the traffic level is and the more severe the defect, the higher the section index.

After the calculation of section indexes, sections were ranked in descending order according to the index values. The resulting list was considered to be the priority list and was con-

TABLE 1 Maintenance Treatment Intervention Levels

MAINTENANCE TREATMENT	INTERVENTION LEVELS	DISTRESS SEVERITY
Rehabilitation	- alligator cracking > 0.5 km - alligator cracking > 3500 sq.m. - open potholes > 0.5 km - reflection cracking < 10 m.	- High Severity - High Severity - Medium & High - High Severity
Reshape and Overlay	- rutting > 0.5 km. - old patches > 50% and bad ride quality	- Rut Depth > 0.2 cm - High Severity
Overlay	- old patches > 50%	- High Severity
Surface Dressing	- lean texture (bleeding)	- High Severity
Edge Patching	- edge fretting > 1.0 km.	- High Severity
Shoulder treatment	- low shoulder > 2.0 km.	- Shoulder Drop > 5 cm
Recurrent Maintenance	- for pavement distresses with severity levels or quantities less than those shown above	

TABLE 2 Assignment of Defect Factor

Defect	Treatment	Defect Factor
Open potholes	Rehabilitation	0.10
Alligator cracking	Rehabilitation	0.15
Reflection cracking	Rehabilitation	0.20
Rutting	Reshape and overlay	0.30
Old patching	Overlay	0.50
Lean surface texture	Surface dressing	0.70
Edge fretting	Edge patching	1.00
Low shoulder	Shoulder works	1.00

verted to a costed list by using the appropriate maintenance treatment unit costs. The top sections with total cumulative costs equal to the allowable budget were selected for the current year's maintenance program.

Model 2

Both the condition survey data and the rating algorithm used in Model 1 were used in this model to determine the required maintenance treatment and the calculation of the priority indexes. Model 2, however, differs from Model 1 in two ways. First, pavement sections were arranged according to road type and traffic level into four classes. This classification was then used to determine the average treatment ages. An average age of a treatment is the number of years after which a new (or renewed) section would require that treatment. For example, 15 years was found to be the average age for rehabilitation for pavement sections in a desert environment subjected to heavy traffic. The corresponding average age for sections in an agricultural environment (roads surrounded by canals, drains, or agricultural fields) is about 5 years. The second difference is that predetermined budget shares were reserved for different maintenance treatments (rehabilitation, overlay, and surface dressing).

The mechanism of this ranking model could be summarized as follows:

- Surveyed sections were grouped according to the four classes mentioned.
- The average ages of treatments were used to identify sections requiring different treatments.
- According to the identified treatments, section priority indexes were calculated and sections were ranked in a descending order of importance according to the calculated priority indexes.
- A costed list was produced for each treatment using the appropriate unit costs.
- The reserved budget share for a specific treatment was distributed on sections with highest-priority indexes that require that treatment. This was repeated for other treatments.
- The process was repeated for each year in the analysis period. At the beginning of each year, section ages were updated as follows: (a) sections selected for last-year programs were assigned ages equal to zero, and (b) ages of other sections were increased by 1 year.

The main output of this model was in the form of a yearly maintenance program including the locations (sections) and the suggested maintenance treatment.

Model 3

Model 3, the annual optimization model, was considered to be a direct extension to the ranking Model 2. The mechanism of this model is identical to that of Model 2. The only difference between the two models is in the way that the budget share of a specific treatment is distributed among the candidate sections. In Model 2, only the top sections in a treatment priority list are selected, but in Model 3, a simple optimization problem is solved to select a set of sections (projects) such that maximum section priorities are achieved.

For a specific year and specific treatment with budget share identified the following formulation was used to select the optimal set of sections:

Maximize

$$\sum_{i=1}^{n} a_i x_i$$

subject to

$$\sum_{i=1}^{n} c_i x_i \leq B \qquad x_i = 0 \text{ or } 1$$

where

n = number of projects in need of specified treatment,
a_i = priority index of ith section,
c_i = treatment cost of ith section, and
B = budget share of specified treatment.

This way, three optimization problems were run, one for each treatment for each year in the analysis period. The set of candidate sections for different treatments and the priority indexes used in this model were provided by running Model 2, and the resulting list of sections and their indexes were then used as input to this model.

COMPARISON OF MODELS

The three models were compared to evaluate their efficiency. First the results of applying the three models on Egypt's road network will be presented, then their relative efficiency and possible reasons behind their differences will be assessed.

An analysis period of 5 years was assumed. It was thought that longer periods would lack accuracy in prediction. Besides this, 5 years is a typical planning period in Egypt. The analysis period therefore was considered from 1987 to 1991. The results of the 1987 Egypt network condition survey were used in all models as the basis for identifying the 1987 maintenance needs (*6*). To evaluate the efficiency of the models, two main indicators were considered:

1. The yearly budget deficit, which indicated the difference between the cost of maintenance actions required to fully upgrade the network to a perfect condition and the available budget.
2. The yearly deficient portion of the network, which represented the general condition of the network in terms of the

percentage of the total network that was in need of major maintenance (rehabilitation or overlay).

Generally, the higher that either of the two indicators is, the less efficient the model.

Figure 1 shows the resulting deficit values under each of the three models, and Figure 2 shows the deficient portions of the network. It is obvious that Model 3 produced the best results, followed by Models 2 and then 1. The deficit and deficient portions increased over time under Model 1, whereas they decreased under the other two models. The results of Model 1 indicated an increasing gap between the desired and actual conditions, a situation in which actual would never catch desired. This is, however, a typical result of using such year-by-year and section-by-section simple ranking methods, as will be discussed. On the other hand, the other two models showed a situation in which a continuous improvement in the outputs can be achieved. For instance, under Model 2, a first-year deficit of about £E243 million (£E5.36 = $1.00 U.S., 1993) has improved over the 5 years to a value of about £E132 million. The corresponding values under Model 3 are £E243 million and £E101 million, respectively. The same trend can be observed for the deficient portions, where under Model 2, an initial value of about 35 percent deficiency has improved to about 17 percent at the end of the analysis period. The corresponding values under Model 3 are 35 and 14 percent, respectively. In the following paragraphs, an interpretation of these results will be presented.

The poor performance of Model 1 may be because

- The model is good for 1 year only (current year) since it did not consider future condition of the pavement sections. This has created a situation in which it was very difficult to introduce project timing in the process.
- The model is based on a section-by-section approach that ignored the relative effect of selecting a section for maintenance, on the network condition.
- The model produced one priority list with only the top sections are eligible for selection, which has led to a situation in which the available budget was consumed by sections in need of heavy maintenance (rehabilitation), leaving other sections with moderate need (overlay or surface dressing) for further deterioration. This produced the endless cycle mentioned earlier.

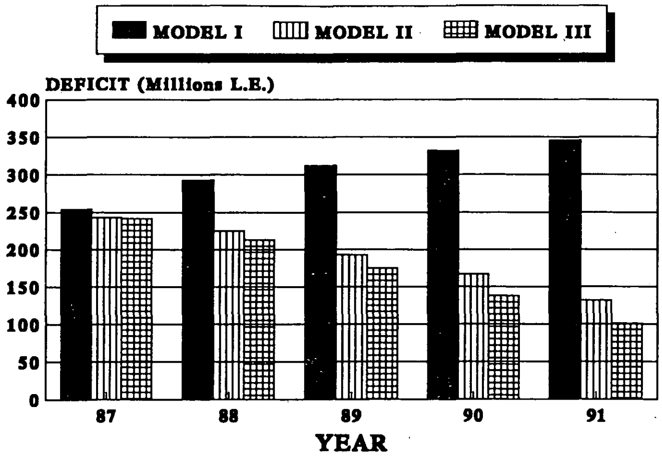

FIGURE 1 Budget deficit values.

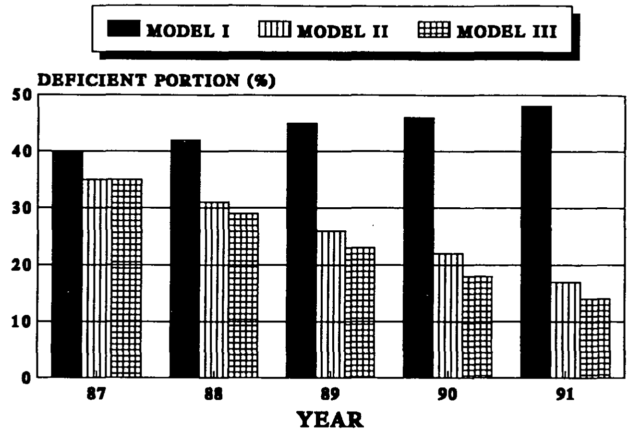

FIGURE 2 Network deficient portions.

The relative improvements in the outputs of Models 2 and 3 were basically due to the avoidance of some of the shortcomings of Model 1. For instance, in Model 2, the average age intervention logic allowed the consideration of project timing. And reserving predetermined budget shares for different treatments allowed the possibility of selecting sections in moderate need of maintenance instead of leaving them for further deterioration. One basic disadvantage of Model 2, however, was the section-by-section approach in which only the top sections on the list of each treatment consumed the reserved budget share. This disadvantage was, however, avoided by using the simple optimization solution to select the best set of sections within each treatment list so that maximum sum of priorities was achieved. This way, section selection was not constrained to the top.

SUMMARY AND CONCLUSIONS

Three priority-setting techniques were presented in this paper: a simple ranking technique based on first-year condition, a modified ranking technique based on first- and future-year conditions, and a simple annual near optimization technique. The data used in the comparison of the three techniques were obtained from a comprehensive survey of the Egyptian road network. The results indicated the superiority of the optimization model in terms of improved budget deficit and network condition over the analysis period.

Although the techniques can be classified as simple ones, the optimization model with its relative complexity is a suitable means for roadway agencies in developing countries—or for agencies in developed countries in their early stages of applying a PMMS—by which to allocate available funds. The data requirement for such techniques is minimal and can be easily collected and monitored.

REFERENCES

1. R. L. Lytton. From Ranking to True Optimization. *Proc., North American Pavement Management Conference*, Vol. 3, Toronto, Ontario, Canada, 1985.
2. M. Hussain. Pavement Management Based on a Ranking Method. *Proc., North American Pavement Management Conference*, Vol. 2, Toronto, Ontario, Canada, 1985.
3. C. S. Bergreen, P. Ultidz, and P. H. Simonsen. Optimization Long Term Pavement Rehabilitation Investments for a Network of Roads. *Proc., 10th International Road Federation World Meeting*, Rio de Janeiro, Brazil, 1984.
4. G. B. Way. Network Optimization System for Arizona. *Proc., North American Pavement Management Conference*, Vol. 2, Toronto, Ontario, Canada, 1985.
5. M. Y. Shahin, S. D. Kohn, R. L. Lytton, and W. F. McFarland. Pavement M&R Budget Optimization Using the Incremental Benefit-Cost Technique. *Proc., North American Pavement Management Conference*, Vol. 2, Toronto, Ontario, Canada, 1985.
6. *Road Maintenance Project*. Final Report. Ministry of Transport, Cairo, Egypt, 1988.
7. M. Roushdy. *Highway Maintenance Priority Setting*. Master's thesis. College of Engineering, Cairo University, Giza, Egypt, 1989.
8. E. A. Sharaf and M. Roushdy. Development and Application of New Techniques for Highway Pavement Maintenance Priority Setting in Egypt. *Arab Roads Journal,* Vol. 2, Cairo, Egypt, 1990.