Abridgment

Economic Models for Setting Priorities for Road Maintenance and Rehabilitation in Israel

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Various general models have recently been used in an engineering-economic study to determine the road maintenance efficacy of the interurban road network in Israel. These models contain deterioration curves for various maintenance and rehabilitation policies, together with the preparation and overlaying costs, routine maintenance costs, and road users' costs, all as a function of overall pavement grade values. These models led, after the determination of an overlaying policy, to establishment of a purposive model for computing a priority ranking as a function of various parameters. The model obtained was found to be sensitive mainly to the annual average daily traffic.

Because of the poor condition of interurban roads in Israel, the Israeli Department of Public Works (DPW) decided to conduct an engineering-economic study that would respond to (a) analysis of the existing situation and scope of investment required to bring the interurban road network up to an acceptable level; and (b) economic justification, from the point of view of the national economy, of investing in road maintenance.

To respond to these points, a data bank was needed that would include the parameters of the condition of the pavements over time, in addition to models of agency and road user costs. Even in the absence of some of the required statistics, however, it is possible to determine the missing details on the basis of comparable work from other sources. This method leads to the construction of general fundamental models for pavement deterioration, and maintenance, rehabilitation, and road users' costs, and it enables, at a stage at which full data are needed, the calculation of a basic model for setting priorities for maintenance and rehabilitation work.

The answers obtained by this method are reported elsewhere (*1*). The derivations and results were given in a detailed report recently presented to the Israeli DPW (*2*). Because other authorities are also to be found at the stage before a full pavement management system (PMS) it will prove helpful to present the findings of the general models developed in this study.

NATURAL DETERIORATION CURVE

The deterioration curve of the pavement condition constitutes the key to any study dealing with the economic and engineering aspects of the maintenance of a given road system. In Israel, the two parameters that show this condition are:

1. Distress grade (SN) from 1 to 5, or from a perfect condition of no surface cracks or other distress modes to a state of surface distress of great intensity; and
2. Level-of-service grade (PSI) from 5 to 0, or from best condition in terms of riding quality to a state of complete failure.

These two grades make up the overall pavement grade (PR) according to the following relationships, based on the PMS program of the state of Washington (*3*). Thus,

$$PR = DR \times RR = (125 - 25SN)(1.06 - 0.30/PSI^{1.06}) \qquad (1)$$

where DR is the grade for a condition of pavement distress, from 100 (excellent condition) to 0 (worst condition), and RR is the grade for the ride quality of the pavement surface, from 1 (excellent quality) to 0 (worst quality).

The transitional expression from SN to DR, which expresses a simple linear transition, was empirically proven, whereas the transitional expression from PSI to PR was computationally derived.

Translation of the SN and PSI grades into the PR grade enables the use of the natural deterioration equation, that is, with no routine maintenance treatment of the Washington State program. In Israel, these PR statistics were in effect for one measurement year, 1985. It was necessary, therefore, to construct a single deterioration curve for the whole system, as follows:

$$PR = 100 - 0.25A^{2.301} \qquad (2)$$

where A is the number of years since the construction or rehabilitation of the pavement. This curve is based on the data analysis and on practical considerations for which a new pavement deteriorates to a grade of 50 PR after 10 years, or in other words for which the need for overlaying is manifested after 10 years of service.

DETERIORATION CURVE UNDER ROUTINE MAINTENANCE

In order to determine the economic advantages of a policy of routine maintenance, the effect of this policy on the natural deterioration curve must be known. This effect is derived from

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a differential equation on the basis of data previously published (4,5). From numerical integration of this differential equation, the following results were obtained (see Figure 1):

$$(PR)_m = 100 - 0.356A^{1.99} \quad (3)$$

$$(A_{50})_m = (A_{50}) \times 1.2 \quad (4)$$

$$(A_0)_m = (A_{50}) \times 1.7 \quad (5)$$

where

$(PR)_m$ = pavement condition grade for a pavement receiving routine maintenance;
$(A_{50})_m$ = time in years to reach $(PR)_m = 50$ in a pavement that is treated by routine maintenance;
$(A_0)_m$ = time in years to reach $(PR)_m = 0$ in a pavement that is treated by routine maintenance; and
A_{50} = time in years for reaching PR = 50 in an unmaintained pavement.

In Figure 1, Curve 1 is the natural deterioration curve, Curve 2 is the retarded deterioration curve as a result of routine maintenance operation, and Curve 3 is the retarded determination curve as a result of deferment of routine maintenance for d years. The effect on the deterioration curve of deferred routine maintenance can be found in the same way [i.e., the values of $(A_{50})_{md}$ and $(A_0)_{md}$ shown in Figure 1].

DETERIORATION CURVE FOR A REHABILITATED PAVEMENT

The deterioration curve of a rehabilitated pavement is naturally conditional on the following factors: the deterioration curve of the pavement before its rehabilitation, the pavement

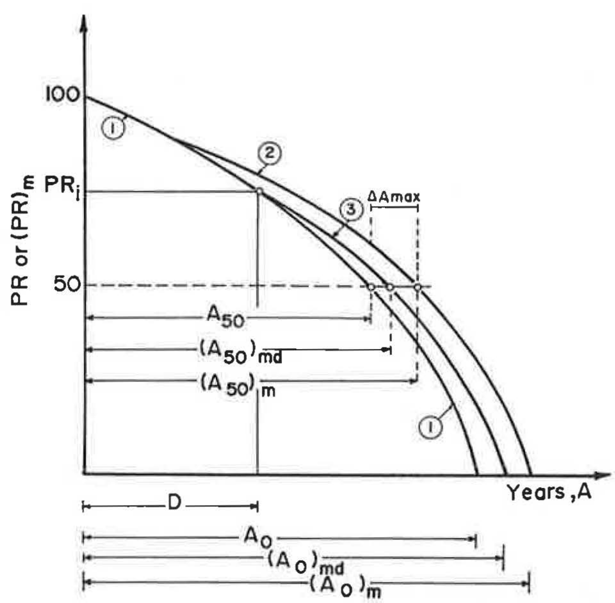

FIGURE 1 Deterioration curves as a result of immediate implementation of routine maintenance or as a result of deferment of routine maintenance work (2).

grade at the time of the rehabilitation work, and the rehabilitation solution itself. Generally, when rehabilitation is carried out with the pavement reaching a grade of PR = 50 or more, the rehabilitation is manifested in asphaltic overlaying at a thickness of d_a. For these cases, the deterioration curve for a rehabilitated pavement can be expressed as

$$(PR)_R = 100 - 0.25\, A_R q_R \quad (6)$$

$$q_R = (\log 200)/[\log F + \log (A50)] \quad (7)$$

$$F = 0.20 + 0.16d_a \quad (8)$$

where

$(PR)_R$ = the grade of the condition of the rehabilitated pavement;
A_R = the time, in years, since the last rehabilitation work; and
d_a = the asphaltic overlaying thickness, in centimeters.

Equation 6 is based on the assumption that an overlaying of 5 cm of asphalt renews the pavement to its starting condition, (i.e., $F = 1$, thus A_{50} for the rehabilitated pavement is equal to that for the original pavement). This condition happens only when the overlaying is carried out above the PR = 50 boundary line.

In pavements for which overlaying is undertaken at less than this value, an identical deterioration curve to that expressed in Equations 6 through 8 will be obtained, except for the relationship between d_a and F. Clearly, when the 5-cm overlaying, for example, is done after the pavement has deteriorated below PR = 50, this work cannot renew the pavement to its original condition, but only to a state in which F is smaller than 1. Rehabilitation of a condition in which PR = 0 necessitates an overlaying thickness of about three times the value required, had the rehabilitation been carried out at PR = 50 to attain the same operational level. The value of F in this condition is given by the following expressions:

$$F = 0.20 + \frac{0.16 \times 0.8}{Y}\left[(d_a)_e - 25\left(1 - \frac{Y}{0.8}\right)\right] \quad (9)$$

$$Y = 1 - 0.000\,406(100 - PR)^{1.585} \quad (10)$$

where $(d_a)_e$ is the overlaying thickness in centimeters, in cases for which PR < 50 (as opposed to the thickness of d_a for which PR > 50), and Y is the relative decline in the bearing capacity value of the pavement from a grade of PR = 50 (for which $Y = 0.8$), down to a grade of $PR = 0$ (for which $Y = 0.4$). Naturally, when P = 100, $Y = 1.0$.

Finally, the combination of routine maintenance work and overlaying leads to a deterioration curve that is calculated in accordance with the principles presented in this section.

AGENCY AND USERS' COSTS

To conduct economic and budgetary calculations, it is essential to know the agency and users' costs. The agency costs are the total expenditures for the routine maintenance and rehabilitation work, and for the traffic delay caused by construction. On the other hand, the differences in the road users' costs (before and after upgrading) are the benefits gained from investment in the maintenance and rehabilitation work.

The examination of the agency's costs for various overlaying and rehabilitation work in Israel led to the relationship, shown in Figure 2. In Figure 2, the cost of the overlay is given by $C_a = 7.0 \times 1{,}000\,(2.0 + 1.6\,d_a)$ and \$1 = 1.6NIS. In Israel, the road user costs, which depend on the condition of the pavement, are found to stem principally from operating costs. The cost of the value of time is calculated only for professional drivers (about 40 percent of those on the road), and therefore this cost can be disregarded. For the same reason, the traffic delay time caused by construction is also disregarded. Operating cost was analyzed from various studies (*2*), and its value in Israeli prices was determined as

$$C_u = 2.455(\mathrm{AADT}/1{,}000)I \qquad (11)$$

$$I = 130.41 - 0.604\mathrm{PR} + 0.000\,018\,5\mathrm{PR}^3 \qquad (12)$$

where

C_u = daily (varying expenses only) operating cost of all vehicle types per 1-km trip in NIS;
AADT = average daily traffic volume (both directions); and
I = operating cost index (varying expenses only).

PURPOSIVE MODEL FOR SETTING PRIORITIES

The various models that have been presented enable an examination of the purposive model for setting priorities in undertaking road maintenance and rehabilitation. This model must include the DR and RR grades or, alternatively in Israel, the SN and PSI grades, together with AADT, which is the traffic intensity traversing the given road. To find such a model, it is necessary to decide on the economic factor that dictates this order of priorities. In Israel, this factor is generally the first year rate of return (*P* percent) obtained for the given rehabilitation investment. Calculation of this rate of return for 1,219 additions of SN, PSI, and AADT through the available models led to the following regression expression (with coefficient R^2 equals to 0.76):

$$P\% = k \times \mathrm{SN}^{3.72} \times (5 - PSI) \times (\mathrm{AADT}/1{,}000) \qquad (13)$$

The order of priorities is clearly set according to the *P* percent values computed from Equation 13 in which *k* is a numerical constant, the same for all cases. At the top of the priority list is found the project for which the *P* percent value is the highest. The striking feature of this order of priorities is the effect that AADT values have on *P* percent values. For example, for identical PSI values, a project with AADT = 10,000 and SN = 3 will have a priority identical to another project with AADT = 5,000 only when SN = 4. This means that roads with high traffic intensities supplant roads with lower intensities even when the condition of the latter is significantly worse. Furthermore, roads with low traffic intensities will be found in general at the bottom of the list of priorities, even when their condition is one of complete failure.

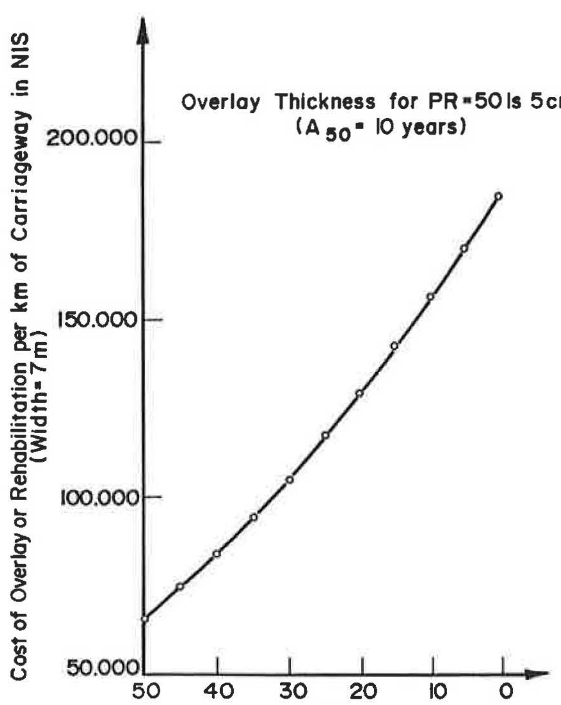

FIGURE 2 Relationship between pavement condition and the cost of overlay or rehabilitation C_a (*2*).

SUMMARY AND CONCLUSION

Various general models have recently served engineering economic studies for determining the efficacy of road maintenance of the interurban road network in Israel. These general models contain the deterioration curve for the following road conditions: without any maintenance at all, with only routine maintenance work, and after rehabilitation, with or without routine maintenance. This last condition depends on the PR value at the time of the rehabilitation work, which is manifested in the deterioration curve. In addition to this model, other models were presented, such as preparation and overlaying costs, routine maintenance costs, and of course, the road users' costs, depending on their PR values. These models can serve other agencies at their work in PMS phases before complete data are available.

The models mentioned herein enable, after the determination of an overlaying policy, the establishment of a purposive model for computing an order of priorities for carrying out the various maintenance projects. The model obtained was found to be affected mainly by the AADT value.

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