User Cost Methodology for Investment Planning and Maintenance: Management of Roads and Highways

WAHEED UDDIN AND K. P. GEORGE

A user cost and life-cycle analysis methodology is developed to quantify cost-effectiveness of alternative strategies for investment planning and maintenance management of roads and highways. The proposed methodology evaluates user costs based on the vehicle operating cost data from FHWA in conjunction with the deterioration models developed in the World Bank and NCHRP studies. Various scenarios of new construction alternatives and maintenance and rehabilitation strategies for asphalt-surfaced or portland cement concrete pavements can be analyzed to establish cost-effectiveness of competing alternatives. The methodology considers a user-specified maintenance intervention policy. The results of the present model compare well with those of the World Bank's Highway Design and Maintenance-PC program, especially for pavements in poor condition. For well-maintained pavements in good condition, the proposed methodology predicts relatively lower user costs. Life-cycle analysis with user cost demonstrates that timely maintenance treatments can be very cost-effective. The USER microcomputer program is well suited for investment analysis, maintenance programming, and network-level pavement management applications.

The development of a rational annual work program and budget for roads and highways in the jurisdiction of a public work agency requires life-cycle analysis of all agency cost streams and user costs associated with pavement conditions during the analysis period. Various construction and maintenance, rehabilitation, and reconstruction (MR&R) strategies will result in different life-cycle costs. This approach can lead to cost-effective investment planning of new roads and to MR&R work programming for the existing network. The life-cycle analysis approach based on agency and user costs is equally applicable in project-level pavement designs in establishing priority ranking of candidate roads and in selecting competing MR&R treatment alternatives for network-level pavement maintenance management applications. Another application is in providing a rational basis for comparison of effectiveness of innovative maintenance strategies developed in the Strategic Highway Research Program (SHRP) with other standard MR&R treatments. The quantification of user cost savings as a result of improved pavement condition, following the implementation of an appropriate MR&R treatment, can be used as a surrogate for "benefit." Vehicle operating cost (VOC) is the most significant component of road user cost. The other quantifiable component of user cost stream is traffic delay cost (TDC), resulting from temporary road closure or traffic diversion during MR&R activities.

The life-cycle analysis for investment planning, new pavement design, overlay design, and selection of pavement type has been a recognized approach since the 1970s (*1*–*7*). Toward this end the World Bank and other organizations abroad have developed pavement deterioration and VOC models (*8*). The World Bank Highway Design and Maintenance Standards Model (HDM) is probably the most comprehensive user cost and life-cycle analysis methodology that considers the existing pavement distress and roughness condition and includes a rational procedure to calculate VOC components of the user cost (*8*). It is noteworthy that HDM-VOC parameters are derived from road user cost studies conducted during the 1970s and 1980s in Brazil, Kenya, and India. However, the HDM methodology is currently applicable to asphalt surfaced and unpaved roads only.

This paper describes a comprehensive user cost methodology for life-cycle analysis of asphalt surface and portland cement concrete (PCC) pavements. The methodology incorporates the results of the state-of-the-art pavement deterioration and performance models developed by the World Bank (*8,9*) for asphalt pavements, PCC pavement deterioration models developed in an NCHRP study (*10*), and the VOC studies (*11,12*) conducted by FHWA. The methodology is directly applicable in planning and budget analysis using the pavement management system (PMS) data bases as well as maintenance management system (MMS) data bases. The proposed methodology can be readily incorporated in (a) project-level pavement design applications and (b) economic evaluation of competing scenarios for capacity and level-of-service improvement studies.

USER COST METHODOLOGY DEVELOPMENT

The user cost is computed in four steps:

1. Cumulative traffic prediction by vehicle type over the analysis period and hourly traffic prediction for the period of MR&R treatment intervention.
2. Pavement deterioration prediction over the analysis period for each pavement type on the basis of the current condition, with cumulative traffic being the primary causal factor.
3. Calculation of VOC stream for each year of the analysis period as a function of pavement condition, vehicle type, and associated VOC parameters and geometrical characteristics.

Department of Civil Engineering, Universty of Mississippi, University, Miss. 38677.

4. Calculation of traffic delay cost streams for each year of MR&R treatment intervention.

Figure 1 illustrates the key components and logic used in compiling the USER cost and life-cycle analysis program. The methodology is primarily developed as an application program that can be used alone or with a PMS/MMS data base and analysis software. The USER software can analyze a single homogeneous road section with up to nine alternatives or all sections in a road/highway network.

Input Data Requirements

The input data for user cost calculations generally are available from the inventory and condition data base files of a PMS/MMS data base. The input data can be categorized into four groups.

1. *Section-Specific Data*. These data elements include road section identification data, section length and width, pavement type, grade, curvature, last construction date, traffic volume [annual daily traffic (ADT)] and year of traffic count, growth rate, 18 kips (80 kN) equivalent single-axle load (ESAL) factors, subgrade California bearing ratio, structural number, joint spacing (for PCC pavements only), selected environment data, rural or urban area designation, typical initial running speed and speed adjustment factor (for congestion and posted speed), average section international roughness index (IRI) (meters per kilometer) and equivalent present serviceability rating (PSR) or present serviceability index (PSI), traffic de-

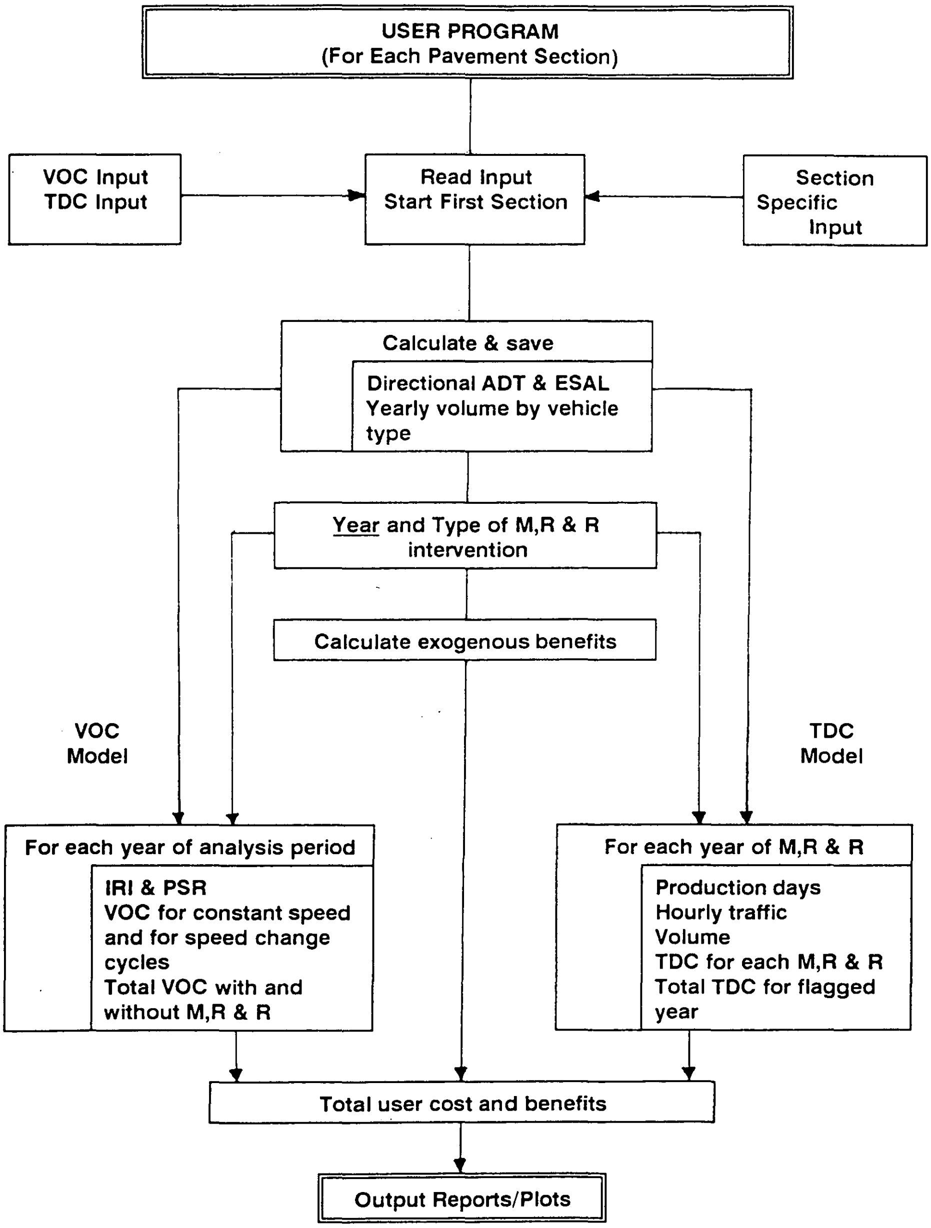

FIGURE 1 USER methodology.

tour model, construction/widening and MR&R unit costs, and data on travel time and accident cost savings.

2. *Decision Criteria.* The decision criteria applicable to each pavement type include analysis period, maintenance intervention criteria (minimum acceptable PSR) at which major MR&R treatment is triggered, and the adjusted PSR (or IRI) after MR&R treatment.

3. *Input for VOC Model.* The inputs for the VOC model include typical distribution of vehicle types in the traffic stream, 18-kip (80-kN) equivalency factor for each vehicle type, and the following VOC unit costs, for each vehicle type:

- –Repair unit cost (for routine vehicle maintenance) in dollars per 1,000 mi,
- –Oil unit cost (for oil consumption) in dollars per quart,
- –Fuel unit cost (for fuel consumption) in dollars per gallon, and
- –Cost of new vehicle (for depreciation) in dollars per new vehicle.

4. *Input for Traffic Delay Cost Model.* Inputs for the traffic delay cost model apply to all sections and include data on detour distance, time of traffic control, number of open lanes, percentage of vehicles affected, average vehicle delays, and hourly traffic distribution.

Procedure for User Cost and Benefit Analysis

A simplified flow chart of user cost and benefit analysis is shown in Figure 1.

- Step 1. Assign section input, as described in Item 3 of the preceding list.
- Step 2. Assign common user cost input, as described in Items 2 through 4.
- Step 3. Calculate directional ADT and corresponding ESAL and number of vehicles of each vehicle type for each year of analysis.
- Step 4. Check and identify year and applicable MR&R type from the condition prediction model and maintenance intervention criteria.
- Step 5. Predict IRI/PSR in each year; adjust for MR&R intervention of sections flaged in Step 4; calculate VOC stream for each year considering the pavement condition and other consumption parameters as identified in Item 3.
- Step 6. Calculate hourly traffic volume during the predicted period of MR&R activity in the intervention year identified in Step 4; calculate total traffic delay cost (TDC) in the intervention year.
- Step 7. Calculate user benefits resulting from a reduction in total VOC caused by MR&R intervention compared with a "do-nothing" policy. Also, calculate exogenous user benefits resulting from travel time savings and reduction in traffic accident cost.
- Step 8. Perform present worth analysis of agency cost and user cost and benefits, priority rank the analyzed sections and alternatives, and generate reports.

PAVEMENT DETERIORATION MODELS

Pavement deterioration prediction is basic to the user cost methodology and long-term budget analysis. Ideally, a pavement deterioration model (or pavement performance model) should include the effects of traffic, pavement strength, age, environment, and initial pavement condition. The time-series empirical models (*13*) are applicable only for local conditions and cannot account for all of the stated effects. The state-of-the-art deterioration models incorporated into the USER program are selected from the literature, ensuring that all of the important causal factors are accounted for.

Deterioration Models for Asphalt Surfaced Pavements

The World Bank road deterioration and maintenance model used in the HDM program is a comprehensive roughness progression model for asphalt road performance with independent variables of road surface distresses, environment, subgrade strength, traffic loads, and time. The model has been used in many field applications around the world (*8,9,14*) for life-cycle economic analysis. This incremental roughness prediction model has the following functional form:

$$\begin{aligned}(\mathrm{IRI})_t = {} & f\,(\text{pavement structure and strength, traffic loading, extent of cracking, thickness of cracked layer, and rut depth variation}) \\ & + f\,(\text{increment in cracking, patching, and pothole area}) \\ & + f\,(\text{nontraffic parameters such as environment parameter, initial roughness, and time})\end{aligned} \qquad (1)$$

Using a data base generated from numerous HDM computations, Paterson and Attoh-Okine (*9*) proposed a new simplified roughness progression model for applications in flexible pavements, particularly in roads with an area of cracking not exceeding 30 percent. The model is applicable to the full roughness range of up to 12 m/km of IRI as expressed below;

$$(\mathrm{IRI})_t = 1.04e^{mt}[(\mathrm{IRI})_0 + 263 \times (1 + \mathrm{SNC})^{-5}\,(\mathrm{CESAL})_t] \qquad (2)$$

where

$(\mathrm{IRI})_t$ = roughness at time t (m/km IRI);
$(\mathrm{IRI})_0$ = initial roughness at time t equal to 0 (m/km IRI);
t = time since last construction/rehabilitation (years);
m = environmental coefficient, which varies between 0.01 and 0.70 (from dry, nonfreeze to wet, freeze environment);
SNC = structural number modified by subgrade strength, as used in HDM program; and
$(\mathrm{CESAL})_t$ = cumulative ESAL applications at time t (millions).

This simplified World Bank deterioration model has been incorporated in the USER methodology. Several road sections at different distress levels were investigated using both HDM and USER programs, and the results show that the USER program predicts a relatively slower rate of deterioration, as illustrated in Figure 2, for an asphalt concrete road

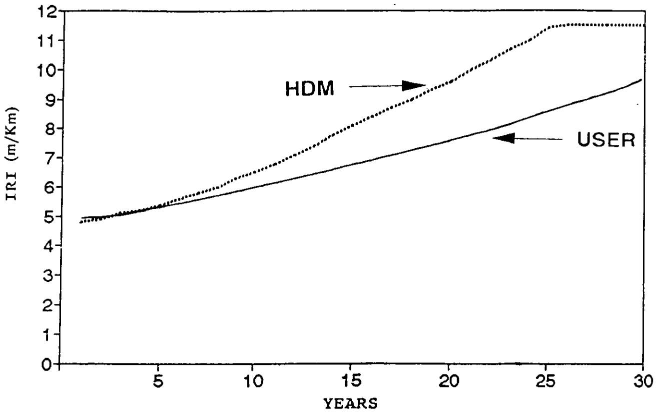

FIGURE 2 Comparison of pavement deterioration predictions using HDM and USER programs: County 4, SR12E, mile 0.000.

in poor condition, without MR&R. Table 1 presents pertinent inventory and condition data for the two asphalt road sections, SR 12 E/0.000 and SR 14 E/14.614, that are used for illustration throughout this paper.

Deterioration Models for Concrete Pavements

The COPES jointed concrete pavement performance models, developed in a nationwide NCHRP study (*10*), have been incorporated in the user cost methodology. These models predict PSR at time t, $(PSR)_t$ as a function of initial PSR or $(PSR)_0$, cumulative ESAL applications at time t in millions or $(CESAL)_t$, environment parameters and pavement strength. Separate COPES models are included for jointed reinforced concrete pavements (JRCP) and jointed plain concrete pavements (JPCP).

JRCP Model

$$(PSR)_t = f\,[(PSR)_0,\ (CESAL)_t,\ \text{edge stress/PCC modulus of rupture, dummy variables (for transverse joint spacing, reactive aggregates and base type), freezing index, average annual precipitation, average monthly temperature}] \qquad (3)$$

JPCP Model

$$(PSR)_t = f\,[(PSR)_0,\ (CESAL)_t,\ \text{edge stress/PCC modulus of rupture, average annual precipitation, average monthly temperature}] \qquad (4)$$

Continuously Reinforced Concrete Pavement Model

The USER program incorporates a simplified stepwise linear model (rate of deterioration with years) for continuously reinforced concrete (CRC) pavements. The default user-defined model is based on Texas data (*6*).

Effect of Maintenance Intervention on Pavement Deterioration

The USER program accounts for the effects of current and future maintenance treatment intervention on the pavement condition by initializing the $(IRI)_0$ or $(PSR)_0$ to the appropriate expected condition after the overlay or other major maintenance treatment. The following three decision criteria are used in the algorithm:

1. Inbuilt asphalt concrete overlay option when $(PSR)_t$ reaches 2.0, or $(IRI)_t$ approaches 5.10. (This is the default

TABLE 1 Summary Inventory and Condition Data for Two Asphalt Surface Road Sections Used in Illustrative Examples

Summary Data	Road Sections	
	Poor Condition	Good Condition
Road/Beginning Mile	SR 12 E/0.000	SR 14E/14.614
Section Length	1.96 km (1.22 mile)	8.32 km (5.17 mile)
Number of Lanes	2	2
Lane Width	3.36 m (11 ft.)	3.05 m (10 ft.)
Pavement Surface Type	Asphalt	Asphalt
Date of Last Construction	1972	1982
Structural Number (SN)	3.2	3.2
CBR	10%	10%
Assumed Daily Traffic Volume	5000 ADT	5000 ADT
Assumed Traffic Growth	5%	5%
Truck Percentage	15%	15%
1991 Condition Survey		
IRI (m/km)	4.60 m/km	2.50 m/km
(PSR)	(2.17)	(3.31)

criterion; it can be modified by the user.) The default PSR after major MR&R treatments is 4.0.

2. Other major MR&R treatment options with the year of intervention, as generated by the maintenance policy specified by the user.

3. Annual routine and emergency maintenance and localized minor maintenance treatment not considered because these do not have significant effect on pavement performance.

Because the program uses IRI and PSR deterioration models, respectively, for flexible and rigid pavements, and because the intervention criterion is in terms of PSR, the World Bank IRI-PSR relationship, as listed in Equation 5, is utilized in the USER program.

$$\text{IRI} = 5.5 \log_n (5/\text{PSR}) \qquad (5)$$

The effects of maintenance intervention on two asphalt pavements, each at various condition levels, are shown in Figure 3. In the good-condition pavement [Figure 3 (*top*)], with the initial IRI of 2.5 m/km, the HDM model prescribes a rehabilitation treatment of some 11 years compared with 27 years according to the USER model. On the contrary, in a poor-condition pavement [Figure 3 (*bottom*)] both models predict MR&R intervention in Year 3.

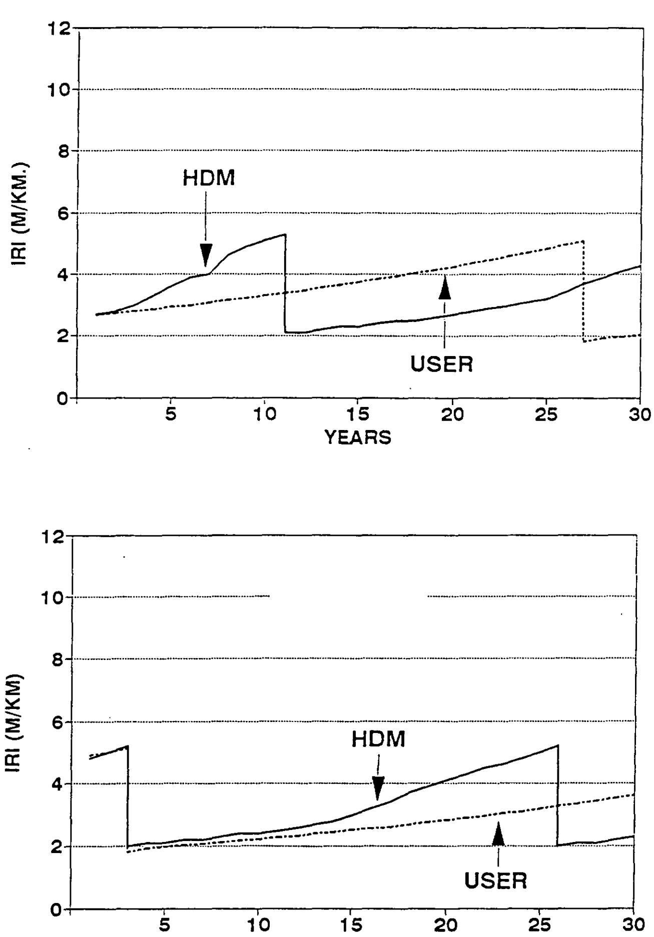

FIGURE 3 Comparison of maintenance intervention effect on pavement deterioration predictions by HDM and USER programs: *top*, County 4, SR14E, mile 14.614; *bottom*, County 4, SR12E, mile 0.000.

VOC COMPUTATIONS

The VOC associated with fuel consumption, tire wear, repair and maintenance of vehicles, depreciation, and pavement condition history over the analysis period are calculated by the user cost program relying on the built-in VOC consumption rate tables. These tables were originally developed in a comprehensive FHWA study of VOCs (*11*). The consumption rate for each VOC attribute is a function of the vehicle type and yearly volume, constant running speed, speed change cycles, and grade and curvature of the road section. The average running speed and consumption rates are adjusted for the prevailing pavement condition. These VOCs are calculated for each analysis year using the following generalized relationships.

$$(\text{VOC})_{cy} = \sum_{i=1-5} \sum_{j=1-8} [(\text{CONSTANT})_j(\text{CONSUMPTION})_j (\text{DADTY})_j(\text{UNITCOST})_j]_i \qquad (6)$$

where

$(\text{VOC})_{cy}$ = total VOC for year y, at constant speed;
i = ith VOC attribute, where
  $i = 1$, VOC associated with fuel consumption,
  $i = 2$, VOC associated with oil consumption,
  $i = 3$, VOC associated with tire wear,
  $i = 4$, VOC associated with vehicle repair, and
  $i = 5$, VOC associated with vehicle depreciation;
j = jth vehicle type, where
  $j = 1$, small car,
  $j = 2$, medium car,
  $j = 3$, large car,
  $j = 4$, pick-up and buses,
  $j = 5,6$, single-unit trucks, and
  $j = 7,8$, semitrailer and combination;
CONSTANT = a constant for constant-speed VOC calculation, a function of section length and consumption rate unit for each VOC attribute;
CONSUMPTION = consumption rate from VOC consumption tables, a function of vehicle type, speed, grade, curvature, and pavement condition;
DADTY = directional traffic volume for year y and vehicle type j; and
UNITCOST = unit cost associated with each VOC attribute.

The VOC calculation for speed-change cycles $(\text{VOC})_{sy}$ is calculated using Equation 7.

$$(\mathrm{VOC})_{sy} = \sum_{i=1-5} \sum_{j=1-8} [(\mathrm{CHANGE})_j(\mathrm{CONSUMPTION})_j (\mathrm{DADTY})_j(\mathrm{UNITCOST})_j]_i \qquad (7)$$

where CHANGE is a constant for speed-change cycle VOC calculation for each vehicle type. It is a function of vehicle type and associated number of speed-change cycles. The method of estimating speed-change cycles is based on FHWA's Highway Performance Monitoring System program (*12*).

$$\text{total VOC for each year } (\mathrm{VOC})_y = (\mathrm{VOC})_{cy} + (\mathrm{VOC})_{sy} \qquad (8)$$

The VOC analysis programmed in the study enables us to calculate user costs arising from maintenance deferment and differential user costs (or indirect benefit) for improved pavement condition (major maintenance intervention to improve PSR/IRI) and improved road capacity and traffic flow (relieving traffic congestion and increasing the vehicle running speed).

TRAFFIC DELAY COSTS CAUSED BY MAINTENANCE INTERVENTION

The proposed methodology calculates TDC arising from expected traffic delays or interruptions, or both, as a result of maintenance intervention in the maintenance intervention year. The user cost referred to here is associated with overlay placement, reconstruction, or any other major MR&R treatment that requires traffic control and diversion or closure of one or more lanes, or both of these. The model developed in Texas (*4,6*) and used in the LCC1 program (*7*) is adopted in the USER software.

The TDC model considers a number of user-specified traffic diversion scenarios depending on the road classification and geometry. It first predicts the delay times incurred by each vehicle as it passes through the restricted work zones of MR&R treatment. These times are calculated using the production rates and quantity of work. TDC is calculated as a function of the calculated delay time, traffic volume, and inbuilt user delay unit cost (per unit time).

TOTAL USER COST AND VOC BENEFIT

After the VOC is calculated at both constant speed and according to speed change cycles and the traffic delay cost, the total user cost is estimated as follows:

$$\text{total user cost (for each year } y\text{)}, (\mathrm{USCOST})_y = (\mathrm{VOC})_y + (\mathrm{TDC})_y \qquad (9)$$

The user cost methodology is also used as a surrogate for user benefit. Accordingly, the VOC user benefit is calculated by comparing the total life-cycle user cost (USCOST) for the base "do-nothing" alternative (with no improvement in pavement condition, capacity, or traffic flow) to the reduced life-cycle user cost for the recommended alternative strategies.

EXOGENOUS USER BENEFITS

Inputs can be provided for calculation of the following exogenous user benefits associated with each strategy being analyzed. These user benefit calculations are particularly useful in transportation investment planning of new facilities, network expansion, alternate routes for the existing facilities, or in selecting the most cost-effective maintenance strategy to improve pavement condition. Two categories of exogenous benefits are recognized:

- *Travel time cost savings*—Estimated from total travel time savings for each vehicle, travel time unit costs, and traffic volume.
- *Accident cost savings*—Estimated from expected reduction in the number of accidents (fatal, nonfatal, and property damage–only) unit cost per each accident type, and traffic volume.

APPLICATION OF USER SOFTWARE

The user cost and benefit methodology, assembled in the USER software described herein, can be used as a standalone program for project-level applications of transportation planning and pavement maintenance management. The USER software can also be integrated with the existing network-level PMS/MMS software packages with appropriate interface programs. The USER software provides customized reports for project-level applications and output files for integration with PMS/MMS software.

Figures 4 and 5 illustrate the VOC predictions of the USER software as compared with the HDM predictions for an existing pavement in good condition and another in relatively poor condition, respectively. The HDM program overpredicts the VOC in both pavements; however, the difference is substantial in the pavement in good condition.

Compared in Figures 6 and 7 are the VOC predictions (considering maintenance intervention) for the good- and poor-

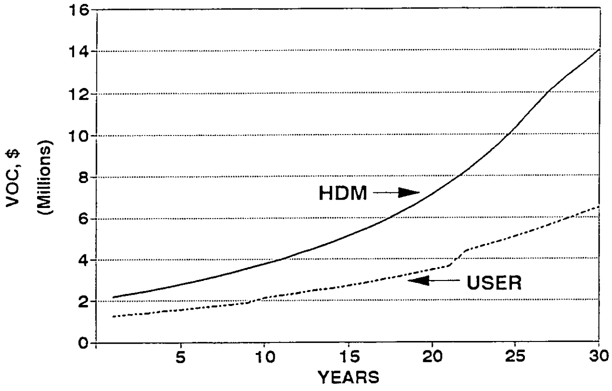

FIGURE 4 Comparison of VOC predictions by HDM and USER programs (without maintenance intervention) for a good pavement: County 4, SR14E, mile 14.614.

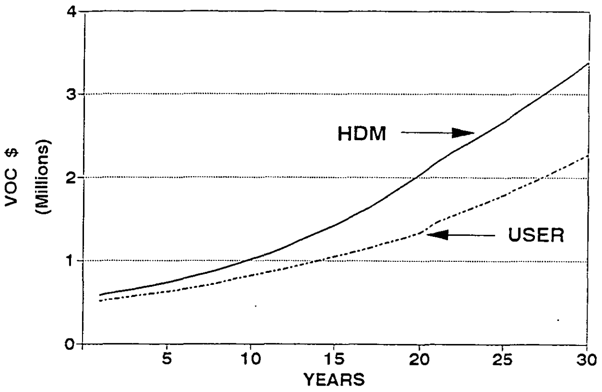

FIGURE 5 Comparison of VOC predictions by HDM and USER programs (without maintenance intervention) for a poor pavement: County 4, SR12E, mile 0.000.

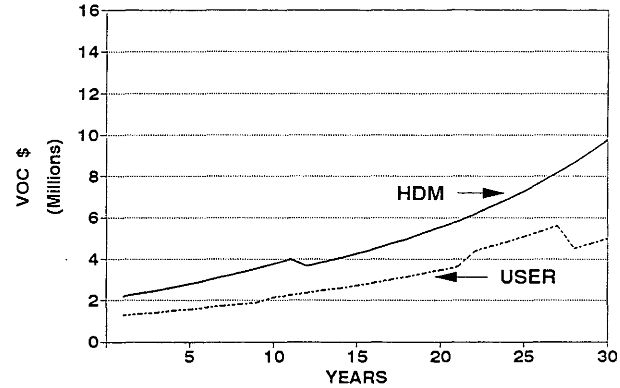

FIGURE 6 Comparison of maintenance intervention effect on VOC predictions by HDM and USER programs for a good pavement: County 4, SR14E, mile 14.614.

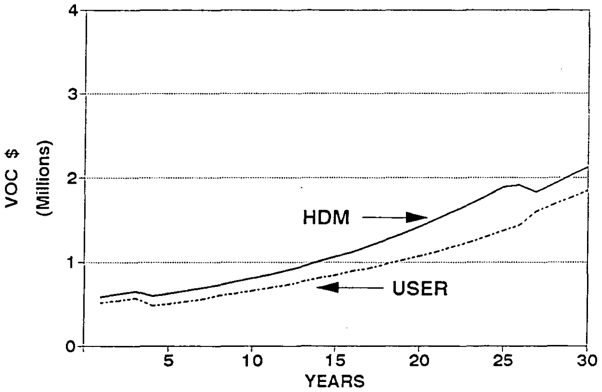

FIGURE 7 Comparison of maintenance intervention effect on VOC predictions by HDM and USER programs for a poor pavement: County 4, SR12E, mile 0.000.

condition pavements, respectively. Again, the HDM overpredicts the VOC in both cases with the difference less pronounced in the poor-condition pavement.

The costs in dollars per vehicle mile, according to HDM and USER, are tabulated in Table 2. Comparing the VOC figures with and without maintenance, the life-cycle VOC decreases when the pavement is repaved at the opportune time as per the specified maintenance intervention policy. The USER analysis further indicates a substantial reduction in VOC if timely maintenance is performed on a pavement section in poor condition compared with that for a pavement in good condition. As predicted by the USER program, the user benefits from a VOC reduction in the case of adequately maintained pavements are $5.4 million/mi and $0.49 million/mi for the two scenarios (poor and good condition), respectively. These VOC user benefits are reduced by a small amount because of the traffic TDC associated with the maintenance treatments.

SUMMARY AND CONCLUSIONS

A comprehensive user cost and life-cycle analysis methodology is developed and coded in a microcomputer software USER for stand-alone project-level applications or for integration with existing network-level PSM/MMS software packages. Applicable in both flexible and rigid pavements, it incorporates the state-of-the-art pavement deterioration models, VOC parameters, and traffic delay cost methodology. The proposed life-cycle analysis methodology is applicable for quantifying the cost-effectiveness of timely and improved maintenance and rehabilitation alternatives and for calculating benefits for improved transportation investment planning scenarios associated with capacity and traffic flow and congestion and safety management.

Comparisons are made with the VOC analysis of flexible pavements by using the World Bank's HDM program. The results compare reasonably well in pavements in poor condition. However, the HDM program overestimates VOC for pavements in good condition.

TABLE 2 Summary of VOC Analysis

VOC Analysis Condition	Vehicle Operating Cost, $/Vehicle Mile			
	Good Pavement		Poor Pavement	
	HDM	USER	HDM	USER
(a) Without Maintenance	0.58	0.29	0.65	0.46
(b) With Maintenance Intervention	0.46	0.28	0.47	0.37

REFERENCES

1. W. R. Hudson, F. N. Finn, B. F. McCullough, K. Nair, and B. A. Vallerga. *Systems Approach to Pavement Design, System Formulation, Performance Definition and Materials Characterization.* Final Report, NCHRP Project 1-10. Materials Research and Development Inc., March 1968.
2. F. Moavenzadeh, E. Fernandez, and B. Brademeyer. *The Road Investment Analysis Model: General Framework for Capital Budgeting and Programming.* Series on Road Transport Planning Program for Developing Countries, Vol. 4. TAP Report 77-7. Technology Adaptation Program, Cambridge; Massachusetts Institute of Technology, Cambridge; Agency for International Development, U.S. Department of State, 1977.
3. W. R. Hudson, R. K. Kher, and B. F. McCullough. A Working Systems Model for Rigid Pavement Design. In *Highway Research Record 407,* HRB, National Research Council, Washington, D.C., 1972, pp. 130–145.
4. R. F. Carmichael and B. F. McCullough. *Modification and Implementation of the Rigid Pavement Design System.* Research Report 123-26. Center for Highway Research, University of Texas, Austin, Jan. 1975.
5. E. S. Lindow and J. J. Brown. A System for Life-Cycle Design of Pavement. Presented at International Conference on Concrete Pavement Design, U.S. Army Construction Engineering Research Laboratory, Champaign, Ill., 1977.
6. B. F. McCullough, W. Uddin, and J. P. Zaniewski. Design and Evaluation of Resurfacing Alternatives for Pavement Rehabilitation, *Proc., 6th International Conference on the Structural Design of Asphalt Pavements,* Ann Arbor, Mich., July 1987, Vol. 1, pp. 859–873.
7. W. Uddin, R. F. Carmichael III, and W. R. Hudson. A Methodology for Life-Cycle Cost Analysis of Pavements Using Microcomputer. *Proc., 6th International Conference on the Structural Design of Asphalt Pavements,* Ann Arbor, Mich., July 1987, Vol. 1, pp. 773–794.
8. H. Watanatada et al. *The Highway Design and Maintenance Standards Model.* Johns Hopkins University Press, Baltimore, Md, 1987.
9. W. D. Paterson and B. Attoh-Okine. Summary Models of Paved Road Deterioration Based on HDM-III. In *Transportation Research Record 1344,* TRB, National Research Council, Washington, D.C., 1992.
10. *NCHRP Report 277: Portland Cement Concrete Pavement Evaluation System.* TRB, National Research Council, Washington, D.C., 1985.
11. J. P. Zaniewski, B. C. Butler, G. Cunningham, G. E. Elkins, M. S. Paggi, and R. Machemehl. *Vehicle Operating Costs, Field Consumption and Pavement Type and Condition Factors.* Final Report. FHWA, U.S. Department of Transportation, June 1982.
12. *Highway Performance Monitoring System Analytical Process,* Vol. 1–4. Office of Highway Planning, FHWA, U.S. Department of Transportation, March 1983.
13. *Pavement Maintenance Management for Roads and Streets Using the PAVER System.* Technical Report M-90/05. U.S. Army Corps of Engineers, July 1990.
14. P. Bein, J. B. Cox, R. W. Chursinoff, G. H. Heiman, and G. A. Huber. Application of HDM3 Pavement Deterioration Model in Saskatchewan Pavement Management Information System. In *Transportation Research Record 1215,* TRB, National Research Council, Washington, D.C., 1989, pp. 60–69.

Publication of this paper sponsored by Committee on Transportation Economics.