USER DELAY COST MODEL FOR HIGHWAY REHABILITATION

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Recently, traffic volumes on many highway facilities have increased to the extent that rehabilitation operations can cause long delays and extra operating costs to the users. Consequently, in addition to the construction costs of rehabilitation, user cost has become an extremely important factor in the total economic evaluation of highway improvements. This paper describes a comprehensive methodology for calculating user costs caused by rehabilitation operations on highways. A model based on engineering and economics has been developed and is capable of predicting extra user costs associated with rehabilitation operations. A number of major variables are considered; they include highway type, geometric characteristics, construction factors such as time and length of job, and traffic handling method. The model has been computerized and can be used for either in-depth project evaluation or for large-scale network planning. The capability of the methodology is demonstrated with several typical example problems. The results emphasize that, for certain situations, user costs of rehabilitation operations may reach extremely high values. The neglect of user costs can result in major errors in the economic evaluation of alternative highway pavement rehabilitation strategies.

•REHABILITATION operations on highways have in the past been considered in terms of construction requirements. Vehicular traffic was considered only as something that needed to be accommodated. Therefore, in economic terms, highway engineers were only dealing with the pure construction cost portion of the problem. Since traffic volumes were often not too heavy, this approach was reasonable for many situations.

During the past decade, however, large traffic volumes on many highways have resulted in the need for extensive maintenance, resurfacing, and reconstruction of many portions of the highway network. Engineers have begun to realize that, in addition to construction costs, an additional factor of user delay costs, due to the interruption of traffic, is involved in the problem (1, 2, 3, 4). These user delay costs may be considered as extra vehicle operating costs plus actual time delay costs to the user.

Today, rehabilitation operations represent one of the major activities of many highway departments. In Ontario, for example, an average of 8,000 miles (12 875 km) of highways undergo rehabilitation (excluding user cost); in the United States the cost for rehabilitation has reached over $1 billion. In 1972, expenditure on major improvements in England amounted to approximately $140 million (7).

The magnitude of these numbers clearly indicates the importance of highway rehabilitation in transportation and suggests the need for considering user delay costs in economic evaluations.

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IMPORTANCE OF USER DELAY IN PAVEMENT MANAGEMENT SYSTEM

In a pavement management system, the problem of user delay costs may be considered in an overall manner in the planning phase and in a detailed sense in the design phase. Because of the many possible combinations of layer materials and thickness increments, the designer is able to generate a number of alternative strategies for the problem. To estimate the costs and benefits of each strategy, techniques that predict the outputs of that strategy are used first. Then, values are placed on these outputs so that all strategies may be compared and so that the designer may be suitably guided in selecting the optimal strategy (3, 4).

In practice, the main factor usually considered in this selection is the cost of each alternative. As a consequence, the importance of determining costs with reasonable accuracy over the chosen analysis period becomes very clear. Since user costs can reach very high values, their neglect may lead the designer to an unrealistic and uneconomical solution. Therefore, the cost of user delays that occur because of rehabilitation operations, such as maintenance and resurfacing, needs to be included in the overall cost of the strategy.

OBJECTIVES OF PAPER

The general purpose of this paper is to provide a methodology for calculating user delay costs caused by highway rehabilitation operations. More specifically, the objectives are to

1. Define the role of the user cost concept within the context of the pavement management system,
2. Define a user delay cost system and its subsystems,
3. Describe a computerized model for estimating user delay costs, and
4. Demonstrate the application of the model to individual projects and network priority programming studies.

DEVELOPMENT OF MODEL

Basic Structure

The model is basically composed of two main phases. In the first phase, the time delays caused by rehabilitation operations are calculated. In the second phase, costs of delays are determined through an economic evaluation procedure. Figure 1 shows the two main phases and their component activities.

The model first calculates capacities before and during the construction period (8). Hourly demand volumes are determined from the use of a submodel discussed later. These capacities and demand volumes are then analyzed to determine the difference in travel times before and during the construction period.

Evaluation of the outputs of the first phase is the next step so that the total cost of the extra time spent in the construction zone can be determined. In this evaluation phase, only the operating costs of vehicles and users' time costs are considered. Accidents and discomfort costs through the rehabilitation area are not considered.

Traffic Handling Methods Considered

The control of traffic during construction is one of the most important aspects of performing rehabilitation on highways. Protection of the rehabilitation crew from motor vehicles and safety of the traffic flow are required. This area is of sufficient importance that most highway departments, such as in Ontario (9), have their own traffic control and construction sign manual.

The type of traffic handling method used is also extremely important in the structure of the user delay cost model. Each type results in a different effect of construction on the traffic flow and varying delays to the user.

The method used for any particular situation depends mainly on the type of highway, its geometrics, and the presence or absence of shoulders, frontage roads, or other alternate routes.

The number of alternative methods that can be appropriate for a particular problem is usually limited by the geometrics and environmental characteristics of the highway. If a situation occurs in which alternate methods can be used, then the selection depends on the volume of traffic approaching the construction zone.

The following most common methods of handling traffic are considered in the model:

1. For two-lane highways without shoulders, two flagmen are generally posted at each end of the rehabilitation area to stop traffic in one direction while traffic from the other direction proceeds through (method 1, Figure 2). In the presence of shoulders, traffic in the nonrehabilitation direction can be diverted to the shoulder while the other traffic uses their lane (method 2, Figure 3).
2. For four-lane highways, if one lane is closed (method 3), traffic in the rehabilitation direction gets only one lane (Figure 4). It may sometimes be desirable to close all lanes in one direction (method 4). In this case, all rehabilitation traffic is usually diverted to the other direction and occupies the inner lane (Figure 5).
3. For six-lane highways with nontraversable medians, the three lanes in each direction are usually rehabilitated in three stages (method 5). In the first stage, the outer lane is closed and traffic uses the other two lanes. When this is finished, then both outside and median lanes are closed. In the last stage, two outside lanes are opened, and only the inside lane is closed (Figure 6).
4. For both four- and six-lane highways, where a detour can be used (method 6), all the traffic in the rehabilitation direction is channeled to the detour (Figure 7).

Determination of Capacities

Initial capacity (before construction) is an important factor in predicting speeds before construction. However, capacity during construction is also involved because of the changes in the geometric layout of the highway.

The initial capacity of the highway section can be directly determined for given initial geometric and traffic characteristics by using the Highway Capacity Manual (HCM) (8) approach. However, capacity calculations for the construction period involve the problem of determining new geometric layouts of the roadway. In this case, psychological effects should also be considered. Since there is no generally acceptable technique that combines subjective and objective factors, the assumptions given in appendixes A, B, and C[1] have been made in the development of the model.

As a result of these assumptions, determination of capacities during the construction period can be made in the same way by using the HCM procedures.

Estimation of Hourly Demand Volumes

Estimation of hourly demand volumes is extremely important in the overall structure of the user delay cost model because the accuracy of the model depends mainly on the capacity-demand analysis from which delays are determined.

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[1] The appendixes of this paper are available in Xerox form at the cost of reproduction and handling from the Transportation Research Board. When ordering, refer to XS-60, Transportation Research Record 554.

Figure 1. General structure of model.

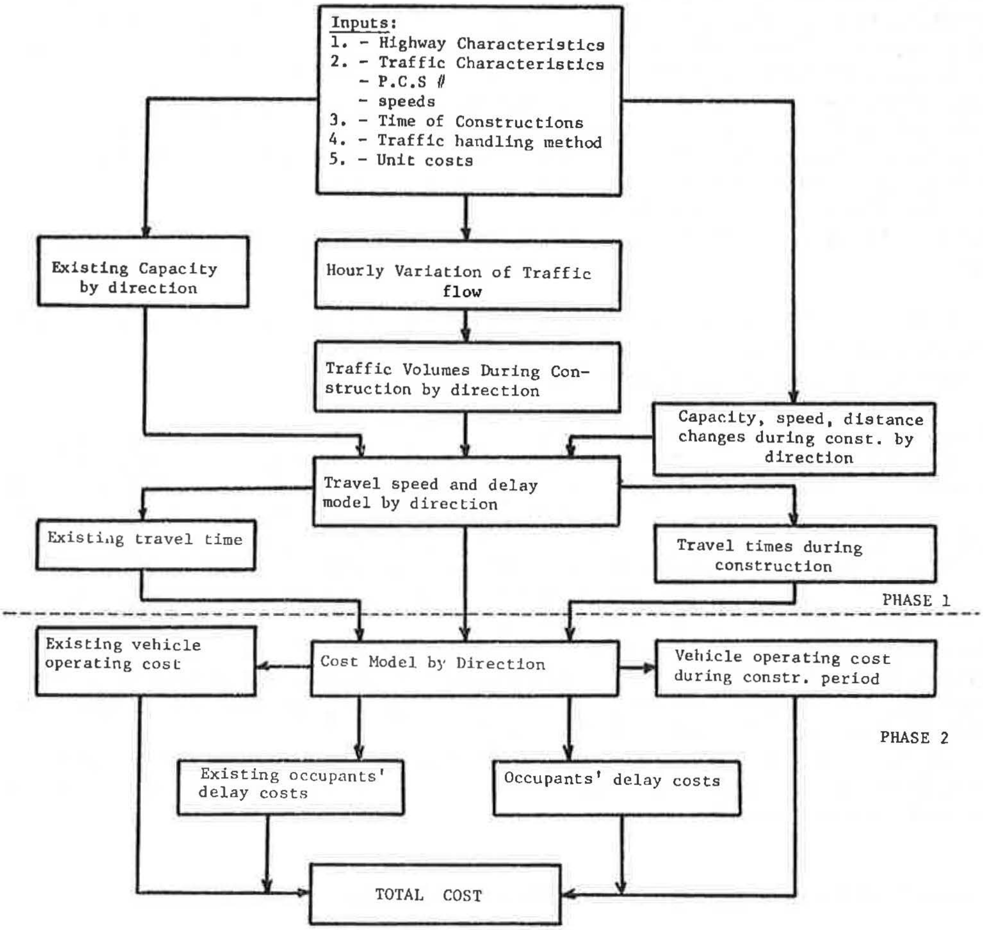


Figure 2. Method 1 for two-lane highways without shoulder.

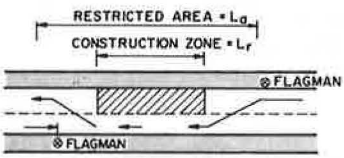


Figure 3. Method 2 for two-lane highways with shoulder.

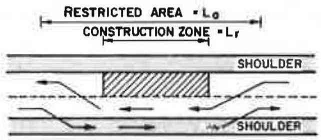


Figure 4. Method 3 for four-lane highways, one lane closed.

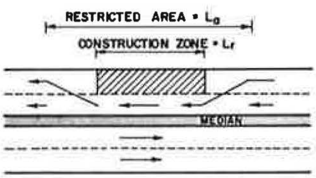
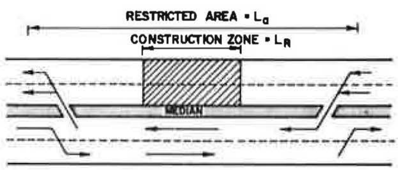


Figure 5. Method 4 for four-lane highways, two lanes closed.



There may be several ways, including sophisticated techniques of structuring a model, to predict hourly variation of traffic flows. In this investigation, however, a deterministic type of approach and permanent counting station (PCS) data were used.

The problem of developing a general traffic pattern that is applicable to every highway in an agency's network is difficult because of the large variety of factors that can affect the pattern on any particular link. However, if the highway network can be broken down into relatively homogeneous groups, then each group can be represented by one traffic pattern. Most agencies achieve this through a PCS system such as in Ontario. The PCS provides detailed traffic information and the opportunity of grouping highways that have similar traffic characteristics.

Based on this concept and the PCS in Ontario, the following relationships were developed:

1. Average annual daily traffic (AADT) versus monthly average daily traffic (ADT), i.e., monthly factors; and
2. Hourly volumes versus ADT, i.e., hourly factors.

These hourly factors should be developed for each month of a year. Because of practical considerations, however, 6 months (November to April) were excluded from the model (i.e., under the assumption that rehabilitation is not carried out in the winter). The rest were grouped as summer season (July and August) and off-season (May, June, September, and October) because of the similarities in traffic patterns. Two groups were tested against three groups (May and October, June and September, July and August), and there was no significant difference in the resulting factors. Therefore, the two-group method was used for simplicity.

Currently, few, if any, agencies perform rehabilitation on weekends. Nevertheless, assuming that in future this situation might change, the same relationships were developed separately for weekend days. A detailed documentation of these and previously described relationships is given elsewhere (10).

The following formula is then used to estimate hourly demand volumes (if AADT volumes, PCS number, and time of rehabilitation in terms of month, weekday, or weekend day and hour are known):

$$\text{hourly traffic demand volume} = \text{AADT} \times \text{monthly factor} \times \text{hourly factor} \quad (1)$$

Travel Speed and Delay Submodel

Three types of delays to motor vehicles can occur because of rehabilitation operations. These are due to low speeds, speed change cycles, and queues. Delays caused by low speed and speed change cycles are computed from the speeds before and during construction that are determined from the HCM speed-flow relationships.

Assuming that all vehicles approach the rehabilitation area at the same speed (speed before construction) and travel at the same restricted speed through the area of influence, the delay per vehicle is computed as the normal travel time through the area (i.e., without restrictions) minus the travel time at the reduced speed (due to rehabilitation).

Acceleration and deceleration delays are not calculated separately because they are taken into account in developing the cost tables of speed change cycles.

Queuing Models

It has been assumed in this investigation that traffic flow is not stopped by any cause external to the traffic stream in all traffic handling methods, except in method 1. In method 1, vehicles in one direction are from time to time forced to stop to give way to the traffic in the other direction. These two flow situations correspond to uninterrupted and interrupted flows, respectively, as designated in the HCM.

Since operational characteristics in these two flow situations are completely different, two different techniques are used for calculating delays in each situation, as described in the following sections.

Queuing Model for Uninterrupted Flow

The model used for uninterrupted flow conditions requires that a record be kept of cumulative arrivals and departures on an hourly basis. Cumulative arrivals are calculated from the hourly demand volumes, and total vehicles served are determined on the basis of capacities.

The graphs in Figure 8 are obtained from hourly cumulative arrivals and departures. If cumulative arrival and departure graphs are denoted by A(t) and D(t) respectively, the area between A(t) and D(t) gives the total delay due to the rehabilitation operation. In the user delay cost model, however, the average delay per vehicle and average queue length in each hour are used rather than the total delay and total vehicles affected.

The vertical distances between A(t) and D(t) at half hours give the average hourly queue lengths AQL. Similarly, horizontal distances at half hours give the average hourly queuing time AQT for vehicles.

Queuing Model for Interrupted Flow

It is assumed that the rehabilitation area in method 1 basically works as a simple signalized intersection with two signal phases and no turning movements. This is because of the similarity in vehicle movements and other operational characteristics.

In view of this assumption, the following techniques, which are mainly applicable for signalized intersections, have been used for determining signal and queuing delays in method 1.

Degree of Saturation Less Than One

For the case in which degree of saturation is less than one (this represents the situation where intersection discharge capacity is greater than the arrival rate; when the arrival rate exceeds the discharge capacity, the degree of saturation is greater than one), Webster's method (11) is used to calculate average delay per vehicle due to red and green phases during a signal cycle. The assumption is made that cycle characteristics remain constant (fixed time cycle) through the construction period. The number of vehicles affected in each hour is equal to the hourly demand volumes.

Degree of Saturation Equal to or Greater Than One

When the degree of saturation is equal to or greater than one, Webster's method gives an unrealistic solution of infinite delay. This might be correct if demand volumes were always greater than the discharge capacity; however, in reality, after a certain period of congestion flow, demand volumes begin to decrease, and then capacity exceeds the input rate. Therefore, infinite delays cannot occur.

The following deterministic model is developed for determining delays when the degree of saturation is equal to or greater than one. This model, like the queuing model for uninterrupted flow, also requires a record of cumulative arrivals and departures, but on a cyclic basis.

Cumulative arrivals and departures for each cycle are calculated based on Figure 9. Then, graphs A(t) and D(t) are obtained. For each hour, the area between the graphs A(t) and D(t) gives the total hourly delay. These total hourly delays are then divided by hourly demand volumes to determine the average delay per vehicle in each hour.

Figure 6. Method 5 for six-lane divided highways.

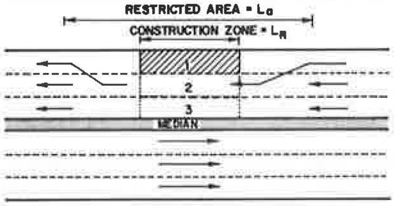


Figure 7. Method 6 for four- and six-lane highways, detour.

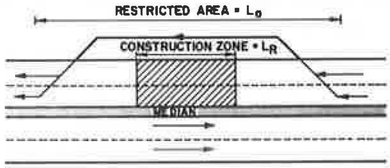


Figure 8. Queuing model.

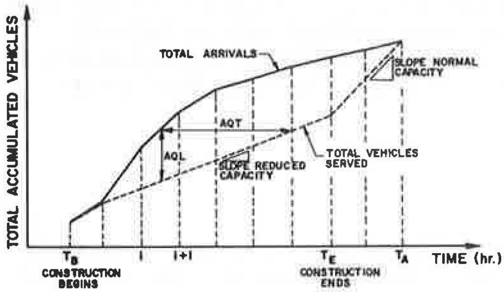


Figure 9. Deterministic queuing model for interrupted flow.

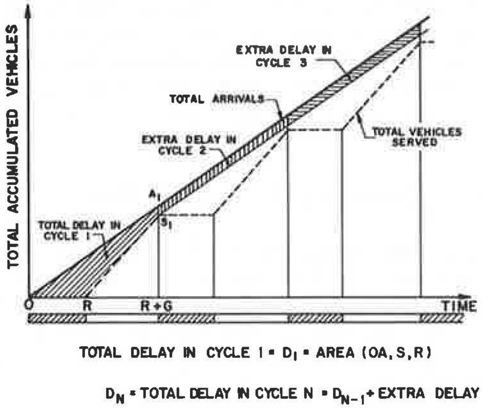
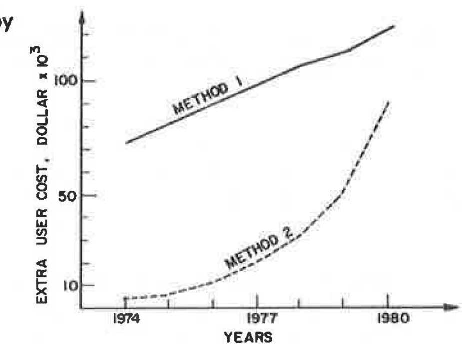


Table 1. Method 1 and 2 costs for two-lane highways.

	Method 1		Method 2	
Construction Year i	User Cost in Year i (dollars)	Present Value in 1974 (dollars)	User Cost in Year i (dollars)	Present Value in 1974 (dollars)
1974	72,743	72,743	3,066	3,066
1975	80,057	74,127	5,841	5,409
1976	87,516	75,031	11,191	9,594
1977	94,911	75,343	18,738	14,875
1978	102,737	75,515	32,075	23,576
1979	110,446	75,167	53,755	36,585
1980	118,165	74,464	88,638	55,857

Figure 10. Variation of user cost by years for methods 1 and 2.



User Delay Cost Equations

The total daily user delay cost (TUDC) is calculated from the following formula:

$$TUDC = \sum_{1}^{n} (CARCST + SUTCST + TRACST) \tag{2}$$

where

n = number of hours in construction period,
CARCST = total hourly delay cost for passenger cars in dollars per hour,
SUTCST = total hourly delay cost for single-unit trucks in dollars per hour, and
TRACST = total hourly delay cost for transport trucks in dollars per hour.

$$CARCST = CARCS1 + CARCS2 \tag{3}$$

$$SUTCST = SUTCS1 + SUTCS2 \tag{4}$$

$$TRACST = TRACS1 + TRACS2 \tag{5}$$

where

CARCS1 = hourly user cost for passenger cars in rehabilitation direction,
SUTCS1 = hourly user cost for single-unit trucks in rehabilitation direction,
TRACS1 = hourly user cost for transport trucks in rehabilitation direction,
CARCS2 = hourly user cost for passenger cars in nonrehabilitation direction,
SUTCS2 = hourly user cost for single-unit trucks in nonrehabilitation direction,
TRACS2 = hourly user cost for transport trucks in nonrehabilitation direction.

Each of these directional costs is composed of cost of stopping or slowing down, cost of traveling at low speed, and cost of delay. The following equation is given for passenger cars in the rehabilitation direction, but the same idea is used for all other vehicle types and directions.

$$\begin{aligned} CARCS1 = {} & CARSTP \times STPCST + CARSLOW \times SLOWCST \\ & + CARSLOW \times (OPCSTC - OPCSTB) \times MILE \\ & + IDLECST \times (CARSTP \times QUEDEL + CARSLOW \times SPDDEL) \\ & + TIMECST \times (CARSTP \times QUEDEL + CARSLOW \times SPDDEL) \end{aligned} \tag{6}$$

where

CARSTP = number of cars stopped in rehabilitation direction because of congestion;
STPCST = cost of stopping from the speed before construction, per passenger car;
CARSLOW = number of cars slowed down in rehabilitation direction because of rehabilitation;

SLOWCST = cost of slowing from the speed before construction to reduced speed, per passenger car;
OPCSTC = operating cost during construction period, per passenger car;
OPCSTB = operating cost before construction period, per passenger car;
IDLECST = idling cost per passenger car;
QUEDEL = average hourly queuing delay in rehabilitation direction;
SPDDEL = speed delay in rehabilitation direction due to low speed, per passenger car;
TIMECST = cost of time for passenger cars; and
MILE = length of influenced area.

The first component in equation 6 gives the cost of stopping and slowing down. Nevertheless, in this investigation, it is assumed that, if demand volumes exceed capacity, all vehicles stop, otherwise all vehicles slow down. Therefore, in equation 6, either the first or second item in the first component is always ignored according to the presence or absence of a queuing situation.

The second component concerns the cost of traveling at low speeds through the rehabilitation area. The third component gives the operating cost of idling, and the last component gives the time cost of delays.

All unit costs needed in equation 6 can be taken from cost tables developed by type of vehicle (passenger car, single-unit truck, and transport truck). An example, for Ontario conditions, is shown in appendix A. Because these unit costs can change rapidly, an updating process is required. Detailed documentation of a computerized method for such an updating process is provided elsewhere (10) and uses, as base year information, the type of data in appendix A.

MODEL APPLICATION

Necessity of Computerization

The model in the previous section could be used in the form of a procedural manual in which the methodology is presented in tables and graphs to keep the calculations simple. Because of the nature of the problem, however, a computer program is preferable. This is because of the solution time involved and because the large number of mathematical calculations would make a manual solution quite inefficient. Therefore, the whole methodology has been computerized for easy application by using a main program and 14 subroutines (10).

The following sections provide several examples of application.

Example Problem for Two-Lane Highways

A section of two-lane highway with 7,000 AADT of equal directional split, 12-ft (3.7-m) lanes, and obstruction on one side at 5 ft (1.5 m) is considered for methods 1 and 2 for a forthcoming resurfacing. The section has been assigned to the relevant PCS for the area. It is assumed that rehabilitation begins on a weekday in August 1974 at 7 a.m. and, including 2 weekend days, continues for 10 days. The road is rehabilitated for 5 hours each day and has a 1-mile (1.6-km) area of influence.

It is further assumed that 60- and 40-sec green phases, with a total cycle length of 140 sec, are used in method 1 for rehabilitation and nonrehabilitation directions respectively. This means that the capacity of the roadway section will be reduced significantly. Because of these reduced capacities and high-demand volumes, oversaturated flow conditions occur for almost every hour for both weekday and weekends. Consequently, each vehicle approaching the rehabilitation area stops and waits in a queue. Average hourly delay per vehicle goes up as high as 0.98 hours on weekdays and 1.13 hours on weekends (as determined by the queuing submodel).

In addition, because of the congested flow within the influenced area of one line (1.6 km), average operating speeds drop down to 28 mph (45 km/h). The total (extra) user cost for the 10 working days, based on the computerized model (10) and the unit cost tables in appendix C, can be calculated as $72.743. Table 1 gives this cost and the costs for future years up to 1980 (i.e., if resurfacing were delayed). These future costs increase because of increasing traffic volumes, which are assumed for the example to compound at 5 percent per year.

If method 2 were used to handle the traffic instead of method 1, then the resulting reduction in capacity would still exceed the demand. Therefore, no queuing situation occurs. Because of the changes in volume/capacity ratios, speeds are reduced. However, in the rehabilitation area, vehicles travel much faster than they do in method 1. As a result, the total user cost of rehabilitation for the 10 days is calculated as $3,066, as given in Table 1. Future costs for method 2 for this situation are also given in Table 1 and are based on the same annual traffic growth rate of 5 percent.

Figure 10 compares the extra user costs for methods 1 and 2. It is quite apparent that method 1 results in very high user costs for all years although, relatively, user costs would be incurred with method 2 up to about 1977.

Example Problems for Four-Lane Highways

A four-lane expressway with 1,500 AADT, 12-ft (3.7-m) lanes, adequate shoulders on one side, and 5-ft (1.52-m) shoulders on the other is considered for methods 3, 4, and 6. The time characteristics of the rehabilitation are assumed to be the same as used in the previous example for methods 1 and 2.

In method 3, when one lane in one direction is closed to the traffic, the normal directional capacity of 2,506 is reduced to 1,146 vehicles/hour. However, hourly traffic demand volumes do not exceed the reduced capacity either on a weekday or on a weekend day. Therefore, no queuing delays are caused by the traffic. The reduction in speeds due to reduced capacity is also not very large. Consequently, in this method the user cost due to 10 days of rehabilitation operation has the low value of $1,266 in 1974 (Table 2).

Suppose, for the same rehabilitation operation, method 4 is used to handle the traffic during construction. In this case, the reduction in capacity becomes so great that demand volumes on weekend days exceed the capacity. This means that vehicles are delayed in queues in addition to the low-speed delays. These extra queuing delays constitute the major part of the user cost on weekends. For this reason, on each weekend day $3,377 of high user cost occurs; however, rehabilitation on each weekday causes only $535 of extra user cost. In this method, the total user cost of the entire operation is $11,036 for 1974, as given in Table 2.

If traffic in the rehabilitation direction is diverted to the frontage road (method 6), which has two 10-ft (3-m) lanes and 4-ft (1.2-m) shoulders on both sides, no queuing situation occurs. Reductions in speed are also minimal because of the large discharge capacity. As a result, negligible total user costs of $231 occur because of the 10 days of work, as given in Table 2.

Time of the rehabilitation, in terms of month of the year and hours of the day, has an extreme importance in the user cost concept, mainly because of the changes in traffic characteristics. Tables 3 and 4 give these effects for month and hours of the construction for method 3. Night and early morning paving operations could result in very substantial user cost savings for the given example (Table 4). There would be, however, extra construction costs associated with such policies and possibly increased safety hazards.

Example Problems for Six-Lane Highways

A six-lane freeway with 12-ft (3.7-m) lanes and obstruction on one side at 5 ft (1.5 m) is to be rehabilitated. Suppose the highway section has an AADT of 25,000 vehicles and

Table 2. Method 3, 4, and 6 costs for four-lane highways.

Construction Year i	Method 3 User Cost in Year i (dollars)	Method 3 Present Value in 1974 (dollars)	Method 4 User Cost in Year i (dollars)	Method 4 Present Value in 1974 (dollars)	Method 6 User Cost in Year i (dollars)	Method 6 Present Value in 1974 (dollars)
1974	1,266	1,266	11,036	11,036	231	231
1975	1,461	1,353	15,072	13,956	251	232
1976	1,690	1,449	22,295	19,114	286	245
1977	2,335	1,853	35,273	28,001	334	265
1978	2,843	2,090	46,030	33,833	384	282
1979	3,427	2,332	60,375	41,090	463	315
1980	4,369	2,750	80,521	50,742	543	342
1981	5,678	3,313	109,942	64,150	617	360
1982	7,356	3,974	150,021	81,051	696	376
1983	9,541	4,773	196,446	98,272	771	385

Table 3. Effect of month of construction on user cost for method 3.

Construction Year i	June User Cost in Year i (dollars)	June Present Value in 1974 (dollars)	August User Cost in Year i (dollars)	August Present Value in 1974 (dollars)	October User Cost in Year i (dollars)	October Present Value in 1974 (dollars)
1974	316	316	1,266	1,266	229	229
1975	387	358	1,461	1,353	254	235
1976	462	396	1,690	1,449	286	245
1977	550	437	2,335	1,853	338	269
1978	644	474	2,843	2,098	401	295
1979	743	506	3,427	2,332	471	320
1980	846	533	4,364	2,750	549	346
1981	954	556	5,678	3,313	632	369
1982	1,065	575	7,356	3,974	717	387
1983	1,181	590	9,541	4,773	809	404

Table 4. Effect of time of day on user cost for method 3.

Construction Year i	August: 7 a.m. to 12 noon[a] User Cost in Year i (dollars)	August: 7 a.m. to 12 noon[a] Present Value in 1974 (dollars)	August: 1 to 6 p.m.[a] User Cost in Year i (dollars)	August: 1 to 6 p.m.[a] Present Value in 1974 (dollars)	August: 1 to 6 a.m.[a] User Cost in Year i (dollars)	August: 1 to 6 a.m.[a] Present Value in 1974 (dollars)
1974	1,266	1,266	2,177	2,177	25	25
1975	1,461	1,353	2,554	2,272	27	25
1976	1,690	1,447	2,742	2,351	30	25
1977	2,335	1,453	3,100	2,461	32	25
1978	2,843	2,090	3,914	2,876	35	25
1979	3,427	2,332	5,780	3,933	37	25
1980	4,314	2,750	12,034	9,589	39	25
1981	5,678	3,313	26,656	15,553	42	24
1982	7,356	3,974	47,351	25,582	45	24
1983	9,541	4,773	74,598	37,318	47	23

[a]Construction period.

a traffic composition of 80 percent passenger cars, 15 percent transport trucks, and 5 percent single-unit trucks. The section has been assigned to the relevant PCS. The total length of the section is 10 miles (16 km). Because of the available personnel and equipment, only 2 miles (3.2 km) of a lane can be rehabilitated each day between 7 a.m. and 12 noon. Rehabilitation begins on a Tuesday in August 1974 on the outer lane. According to method 5, on the first Tuesday, the outer lane will be closed to traffic; on Wednesday, the two outside lanes will be closed to traffic; and on Thursday, only the inside lane will be closed. The same situation is then repeated four times for the next consecutive 3-day groups.

During the 10 days on which rehabilitation is on outer and inner lanes, the reduced capacity of the section can handle the traffic volumes approaching the construction zone. Therefore, no queuing situation occurs. Total user costs of $1,326 occur mainly because of the fluctuations in speeds and low speed delays.

During the 5 days on which both the middle and outer lanes are closed, vehicles wait in long queues. Consequently, very long delays occur. As a result of these long delays, the user cost of this period has the large value of $16,317. Thus, the total user cost of the 15-day rehabilitation operation becomes $17,644.

Summary Tables for Network Priority Programming Application

The model developed and computerized in this study can be used by transportation agencies and individuals for both research and practical purposes. At the network planning level, however, where the user cost subroutine may need to be run many times, the model could be uneconomical to use in its detailed, present form because of the total solution time required. Therefore, for planning purposes, the model can be used to generate summary user cost tables for different traffic handling methods, demand volumes, and average conditions. These approximated tables can then be used at the planning level instead of the model itself.

Tables in appendix B give these average user delay costs per day for the six traffic handling methods considered in this investigation. They incorporate the most up-to-date unit prices available (i.e., as given in appendix C). An updating process that considers changes in these unit prices in the form of price elasticities has also been developed in the study and forms the basis of this paper.

CONCLUSIONS

1. User costs associated with rehabilitation operations may reach such high values that their neglect can result in major errors in the economic evaluation of alternative pavement rehabilitation strategies.
2. The major variables that affect these extra user costs are time of construction (hour, day, month), traffic volume, traffic handling method, and type and geometric characteristics of the facility.
3. A computerized model for calculating user delay costs (including extra vehicle operating costs) has been developed. The model may be applied, in a detailed sense, to individual project situations or, in an overall way, to network evaluation of a number of projects.

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