The Effect of Traffic Lane Closures on the Highway Motorist

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The occupancy of roadways for maintenance and construction interferes with traffic. A computer program was developed to perform an economic analysis of the impact on the motorist created by lane closures associated with this roadway occupancy. The analysis accommodates hourly distributions of traffic by direction and generates motorist costs. Included are vehicle operational costs as a function of vehicle weight and speed and freeway alignment; time costs by trip purpose, income level, and time loss; and accident costs. Nomographs, derived from computer output, were developed to permit rapid determination of motorist costs for any given occupancy interval, traffic volume, and lane closure.

High traffic volumes on freeways frequently cause accelerated deterioration of the pavement surface. Consequently, early in its life, the pavement may need maintenance. Maintenance is difficult to perform in the presence of the high traffic volumes, and the time that the road can be occupied by such crews is limited. These constraints, together with hasty repairs, add to the costs of maintaining a freeway. Additionally, the occupancy of the roadway by maintenance crews creates conflicts with the motorist. These conflicts influence motorist operating costs and create motorist delays, increased opportunities for accidents, and increased levels of pollution. The Federal Highway Administration determined that one means of minimizing the cost associated with pavement maintenance is to produce a pavement requiring minimum maintenance or even no maintenance. The warrants for the design of this "premium pavement" would be the savings in maintenance and motorist costs realized by eliminating maintenance or severely limiting it.

The information presented in this paper is the result of a study made to develop traffic warrants for premium pavements. An economic analysis of roadway occupancy during maintenance was developed. This analysis encompassed, in addition to maintenance expenditures, the operating, time, and accident costs to the motorist caused by roadway occupancy. (The term roadway occupancy shall be used to mean occupancy of the roadway by maintenance crews.) The analysis is in the form of a computer program called EAROMAR, economic analysis of roadway occupancy for maintenance and rehabilitation. In general, the program (Fig. 1) performs three functions:

1. It establishes a data matrix of given and assumed information in an initialization routine;
2. It determines the specific hours that the roadway will be occupied by work crews

annually, together with the maintenance and rehabilitation costs associated with that occupancy; and

3. It determines the operation, time, and accident costs to the motorist caused by the roadway occupancy.

This paper is limited to those aspects of EAROMAR that relate to the impact of lane closures on the motorist.

FIELD DATA COLLECTION

Before the analysis and the relationships required to establish motorist speeds under different roadway closure conditions were developed, an extensive field study was made to develop quantitative data on speed profiles under different roadway occupancy conditions. Speed profiles were developed for both normal and roadway occupancy conditions so that the implications of the road closure could be quantified. The mechanics of the field data collection effort were automated as much as possible to improve the reliability of the data and to expedite data reduction efforts.

A simple frequency oscillator was built to be attached to the speedometer of the test vehicle. Oscillator output signals were monitored on small inexpensive portable cassette tape recorders. A midfrequency signal was used to indicate that the test was in progress. The oscillator was attached directly to the speedometer cable with a T-connector. The speedometer-excited frequency signal was a function of the speed of the vehicle (Fig. 2). A third signal was controlled by the vehicle driver and served as an event marker. In the development of speed profile data, the test vehicle was normally operated between interchanges. A test period was about 45 minutes, the length of the cassette tape.

In addition to the speed profile, two observers stationed at each end of the work zone collected volume, headway, and elapsed time data on vehicles passing through the work zone. Figure 3 shows a profile trace of a test vehicle passing through a work zone with observers located at each end.

DATA REDUCTION

The data from the cassette tapes were consolidated on 7-in. reels of ¼-in. magnetic tape. These reels were processed through an analog computer to create a digital readout of times for each frequency event on the tapes. This was accomplished in the following manner.

1. An analog computer board was designed to identify three frequency signals on the tape.
2. A time pulser was set to operate ¹⁄₁₀₀-second signals, which were counted by an accumulator and held.
3. As each signal was identified, it was assigned the value of the accumulated number residing in the pulse hold area.
4. The numbers for frequency signals above the test frequency were made negative to differentiate them from the frequency signals below the test frequency.
5. The resulting digital numbers were placed in a computer tape file.

Once the tapes were converted, programs were developed to convert the time information into speeds. These speeds were accurate to 1 percent. An example of the speed profiles developed is shown in Figure 4 for a two-lane closure on a six-lane divided facility. The period covered from 11 a.m. to 1 p.m. and the control zone was in the p.m. peak direction.

During the study no queues were observed in the presence of maintenance closures. This was not completely unexpected because as a general policy maintenance is scheduled during hours of low traffic volumes so as to minimize disruptions to traffic.

Figure 1. General flow of EAROMAR.

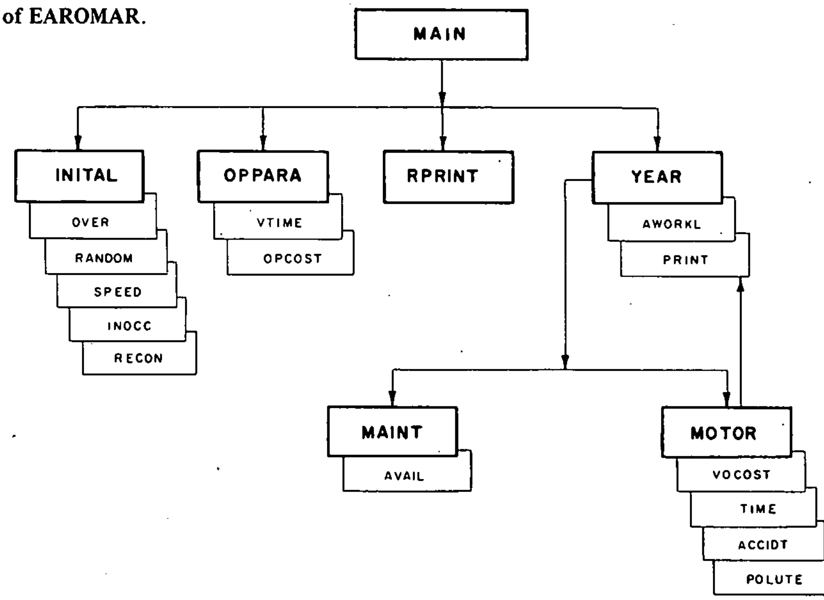


Figure 2. Schematic of speedometer (low-frequency) and event marker (high-frequency) signals.

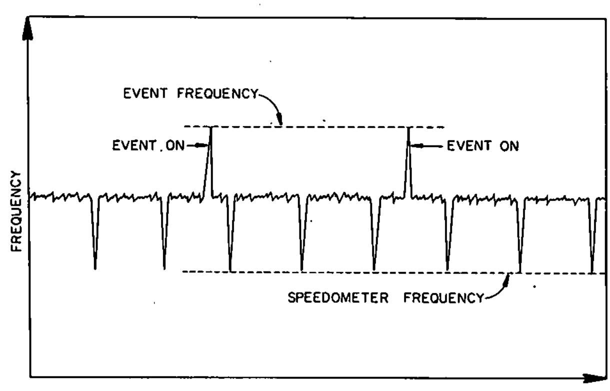
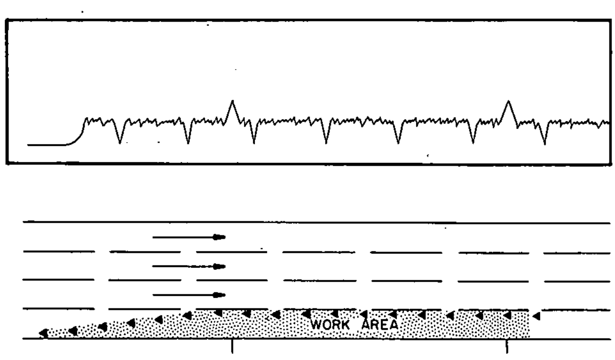


Figure 3. Schematic of signals generated during a typical test vehicle run through work zone.



Queue profiles were obtained from test runs made on Interstate 495 around Washington, D.C., during rush hour. A typical queue is created by traffic entering I-495 at the Va-123 interchange (Fig. 5).

SPEED MATRIX ALGORITHM

Based on the observations and data collected during the field studies and on established speed-volume relationships in the Highway Capacity Manual (8), an algorithm was developed to create a speed matrix as a function of freeway design speed, speed limit, and roadway capacity. Results of this algorithm are shown in Figure 6.

The user of the computer program EAROMAR provides a description of the freeway design speed and the speed limit and capacity for each feasible lane closure. The program generates a speed matrix for a range of volume-capacity ratios for each lane closure.

TRAFFIC

In the program a traffic matrix is initialized based on given hourly distributions of traffic by trip purpose. Each hourly distribution is for two directions, reflecting a.m. and p.m. distributions for the following trip purposes: work, social-recreation, personal business, vacation, school, and commercial. Figure 7 shows a typical hourly distribution for work trips in the peak a.m. direction.

VALUE OF TIME

The program generates a matrix in which the value of time is associated with each trip purpose, time loss in minutes, and income level. This is based on the work done at Stanford Research Institute by Thompson and Thomas (1).

OPERATION COST

The operation cost matrix created by the program is a function of roadway alignment, vehicle weight, speed and speed changes, and the consumption parameters—fuel, tire, oil, maintenance, and depreciation. The consumption parameter curves developed were based on the work of Winfrey (2), Claffey (3), and Sawhill (4).

Figure 8 shows typical fuel consumption curves. The consumption rate is a function of speed and grade. Figure 9 shows tire wear consumption in increments of 0.001 inch per speed change cycle as a function of speed change. Figure 10 shows the depreciation rate for a range of vehicle classes as a function of speed.

Unit costs are specified for fuel, tires, oil, maintenance, and depreciation as program input. The series of consumption models is used with inputs for vertical and horizontal alignment data, weight data on a range of vehicle weight classes, and the unit costs to generate two matrices of hourly operating costs, one for passenger cars and one for commercial vehicles. Operation costs are a function of speed in both matrices.

ECONOMIC ANALYSIS

EAROMAR performs an analysis annually by direction, work activity, and feasible lane closure. Once the actual hours of occupancy have been established, the impact of that occupancy on the motorist is computed in terms of changes in operation costs, value of time loss, increased accidents, and pollution effects.

Operation Costs

The operation costs are based on determining (a) the operating cost through the

Figure 4. Speed profiles when two of three directional lanes were closed to traffic.

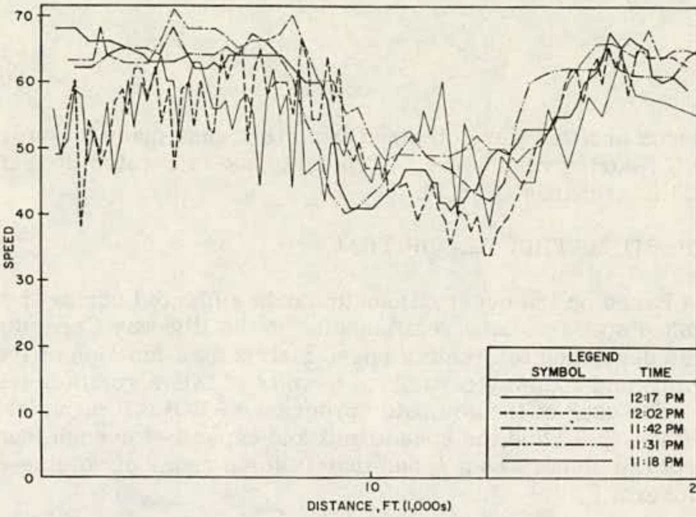


Figure 5. Example of queue on a four-lane freeway.

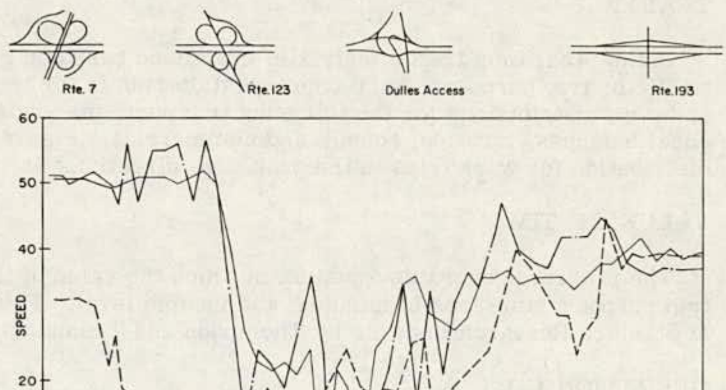


Figure 6. Speed curves for highway on which speed limit equals design speed.

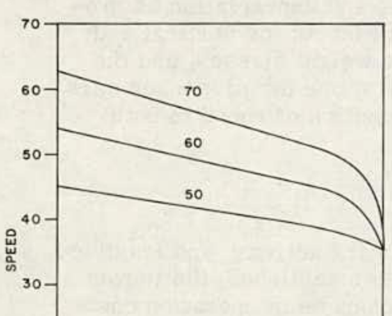


Figure 7. Distribution of all traffic in a.m. peak direction.

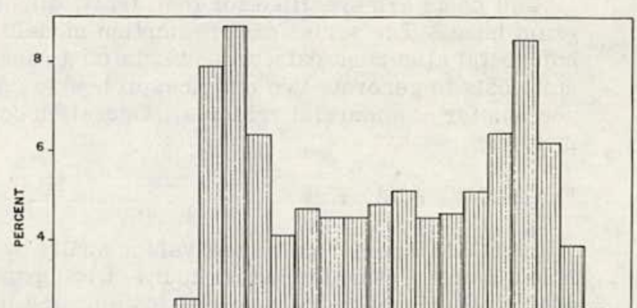


Figure 8. Gasoline consumption as a function of speed and grade.

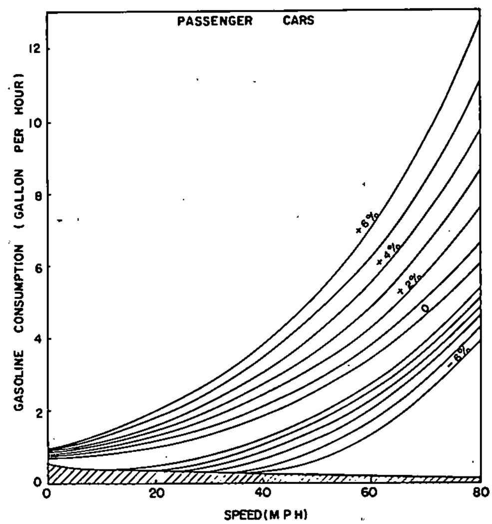


Figure 9. Excess tire wear as a function of speed change for passenger car.

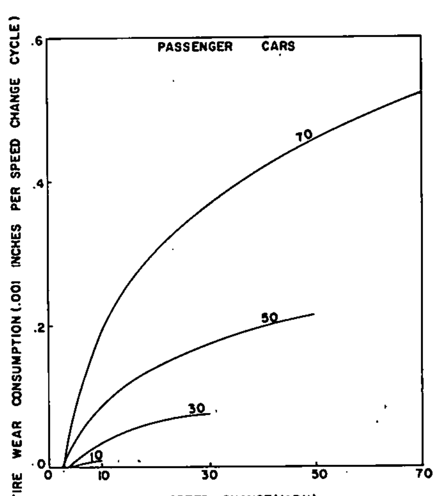
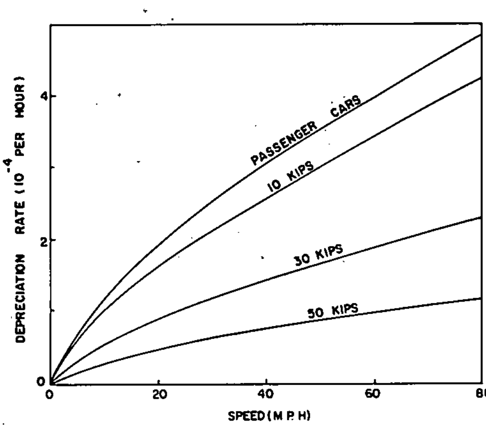


Figure 10. Depreciation rate for a range of vehicle weights as a function of speed.



influence zone of traffic under normal conditions, (b) the operating cost of traffic passing through the influence zone for the lane closure, and (c) the cost of the speed change cycle created when traffic slows from a normal freeway speed to a speed equal to 1.5 times the difference in freeway speed and influence zone speed. The costs for passenger cars and commercial traffic are separate, and adjustments are made to reflect a reduction in capacity as a function of the percentage of commercial traffic in the traffic stream. When a queue occurs, the operation costs for traffic operating normally over the distance queued and the operation costs in the queue are determined. The net operation costs associated with the occupancy are the occupancy costs less the normal costs.

Time

The value of time is a function of time lost and trip purpose (1). A distribution of traffic by trip purpose exists for each hour of the analysis. The lost time is the difference between the duration spent in the influence zone during normal operations and the duration spent during the closure. Additionally, any time spent in the queue is considered. The total time loss is used to compute a value of time for the traffic analyzed each hour.

Accidents

Changes in accident rates for normal and lane closure situations are determined two ways. An increased accident rate is associated with the deceleration process (5). Also, the accident rate is related to operating lanes (6).

Pollution Effects

The determination of pollution effects is based on emission factors for hydrocarbons and carbon monoxide. Slower speeds produce larger emission factors per unit of time. The pollution is presented as days of pollution, i.e., additional days of normal operation to create the additional emissions.

RESULTS

EAROMAR was used to generate motorist costs for a range of freeways and traffic volumes. The generated output was used to establish a series of nomographs. These nomographs are included in a manual developed to permit a noncomputer analysis (7).

Two sets of nomographs were developed. The first set, shown in Figures 11, 12, and 13, permits a determination of the motorist costs associated with road closures when there is no queuing. Illustrated is a roadway occupancy between 9 a.m. and 4 p.m. The motorist costs given in Table 1 were determined by using the three nomographs and an average directional annual traffic volume of 30,000.

Motorist costs increase substantially when a queue occurs. Figure 14 shows a nomograph used to determine motorist costs during hours of queuing when one lane is open to the motorist. The nomograph is used as follows:

1. A line is drawn from point A on the percentage scale to 30,000 on the directional traffic volume scale to create a point on the X-X line.
2. A line is drawn from point B through the point created on the X-X line to an intercepting point on the percentage scale.
3. A horizontal line is drawn through the interception point created on the percentage scale.

Every "hour of the day" bar that is crossed by the horizontal line is a queue hour for the 30,000 directional volume. The operation costs and value time losses must be

Figure 11. Nomograph for determination of increased vehicle operation costs.

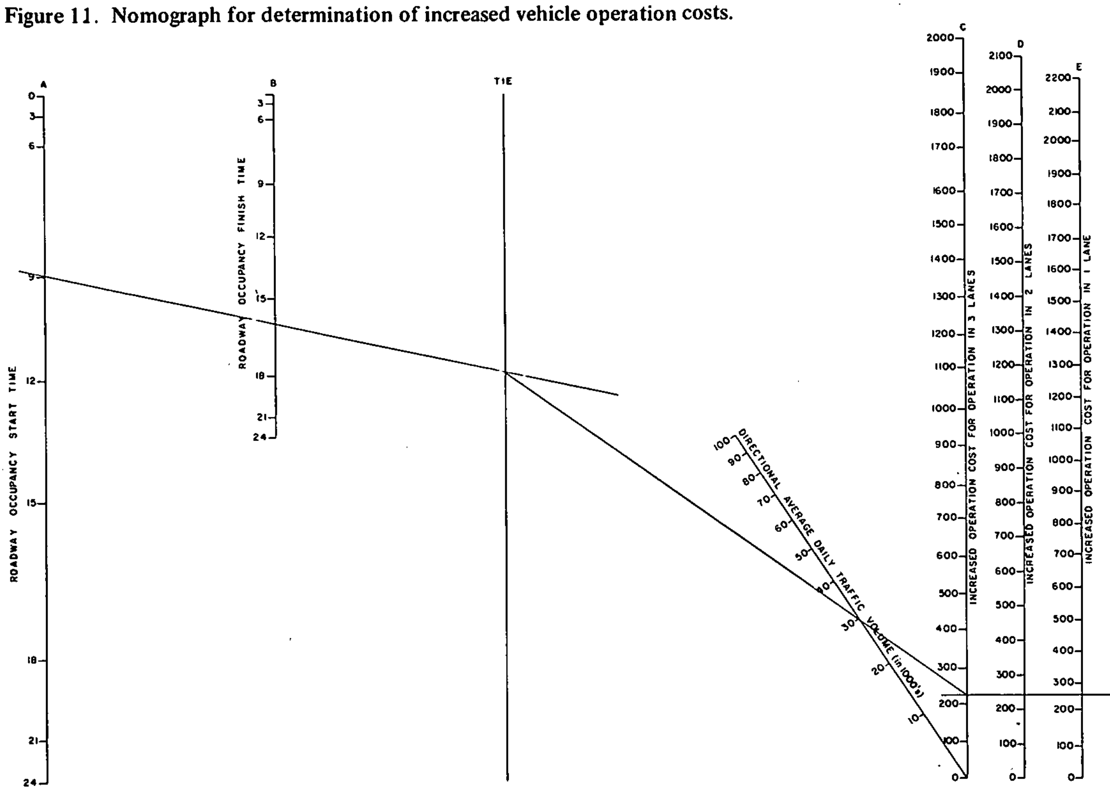


Figure 12. Nomograph for determination of time costs.

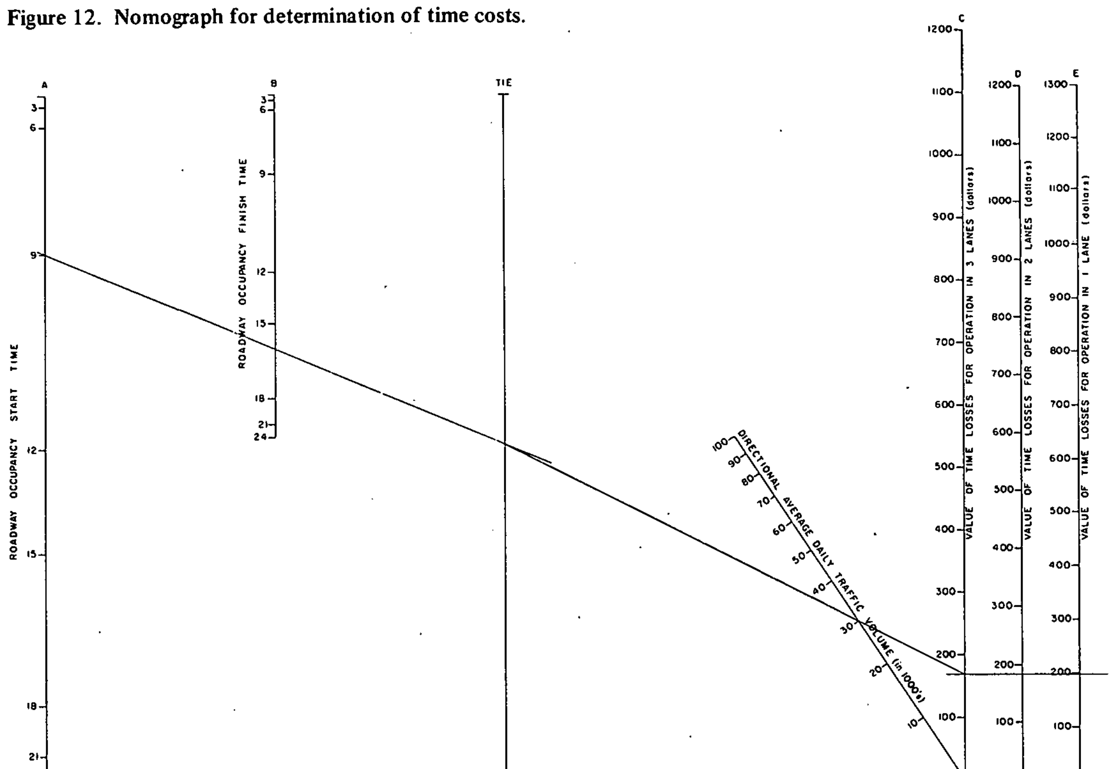


Figure 13. Nomograph for determination of accidents costs.

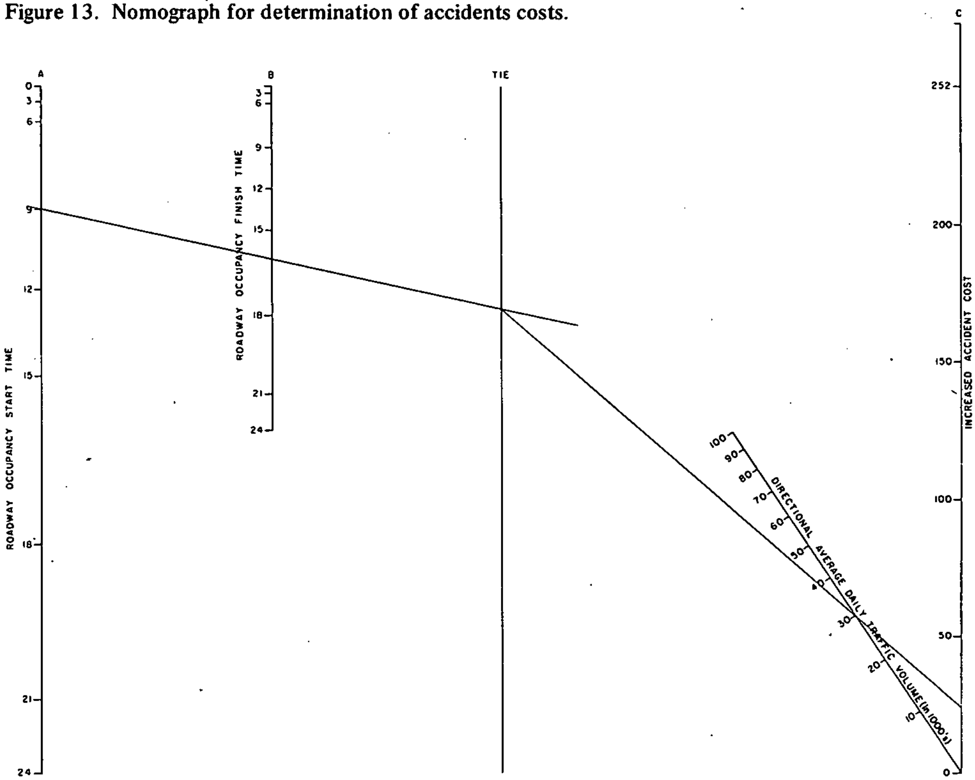


Figure 14. Nomograph for determination of increased operation and time costs during hours of queuing.

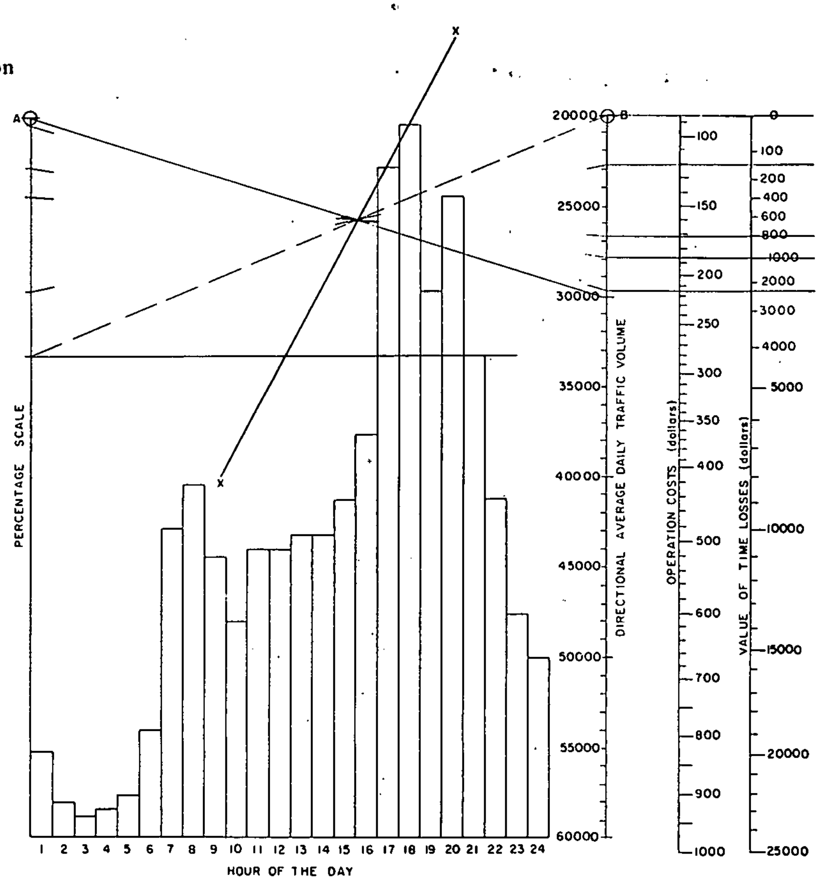


Table 1. Motorist operation costs during nonqueue conditions.

Lanes Open	Costs (dollars)		
	Operation	Tire	Accident
3	220	170	25
2	240	185	25
1	260	200	25

Table 2. Queuing costs for example conditions shown in Figure 14.

Hours	Operation Cost (dollars)	Value of Time Loss (dollars)
17	187	1,000
18	215	2,300
19	120	150
20	171	800
21	85	0
Total	778	4,250

determined separately for each queued hour. In the example shown in Figure 14, hours 17 through 21 are all queued. To determine the costs associated with the queued hours requires the following additional steps:

4. Draw a horizontal line from the top of each queued hourly bar to the percentage scale.
5. From each point created on the percentage scale for a queue bar, draw a line through the point created on the X-X line to an intercepting point on the directional traffic volume scale.
6. For each intercepting point on the directional traffic volume scale, draw a horizontal line through the operation costs and value of time losses scales.

The queue costs associated with queue hours 17 through 21 as taken from the nomograph are given in Table 2. Of course, these queued costs would only be determined if the actual roadway occupancy included the queue hours 17 through 21. The impact of the queuing in terms of increased costs to the motorist for operation costs is $778 and for loss time is $4,250; the total is $5,028. The cost to the motorist of having one lane open on a freeway between 9 a.m. and 4 p.m. is $485 because no queue hours are included in this interval.

CONCLUSION

An example of the motorist costs that are generated by the EAROMAR program when the roadway is occupied for maintenance and rehabilitation has been presented. The program permits an objective evaluation of the implications of roadway occupancy to the motorist. Although the program was designed to provide warrants for developing a premium pavement, it also has application in the development of general benefit-cost analyses, it can be used in development of closure strategies where roadways need to be occupied, and it can be used to forecast maintenance costs.

ACKNOWLEDGMENT

Contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented. Contents do not necessarily reflect the views or policies of the Federal Highway Administration.

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