A SYSTEM TO MONITOR THE ROAD-USER COST OF URBAN TRAFFIC CONGESTION

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In any congested traffic stream, the road-user cost of time plus vehicle operation includes a component "cost of congestion" that is additional to the cost associated with flow at a minimum acceptable level of service of C. This project performed speed-and-delay runs using a tachograph-equipped car on Atlanta arterials and freeways. The resulting speed-time graphs were converted to dollar costs of congestion. The conversion was based on the tables of vehicle operating cost published in 1969 by Winfrey and on recent research on the value of time to automobile drivers and operators of commercial vehicles. The calculations were expedited by the computer program RUNCOST, written for this project by the Federal Highway Administration. Computer calculations of time cost plus operating cost were plotted against observed travel speeds. These plots yielded the congestion components of road-user costs. One hour of field data collection was found to require an expenditure of $15 for office processing. It was concluded that the monitoring system is both technically feasible and economical. Recommendations for congestion-monitoring programs and further research are presented.

•THIS PAPER is an abridged version of the final report of a recent research project on the road-user cost of urban traffic congestion. It was postulated, and demonstrated as part of the project, that congested flow is more costly to the driver than is flow at an acceptable level of service. There is an incremental "cost of congestion" that includes the dollar value of lost time plus any extra cost of operating a vehicle at an unacceptably low level of service. If it could be measured, the incremental cost of accidents would be another component of congestion cost. This project was directed toward techniques for measuring the total cost of time and vehicle operation in various traffic streams and for determining the component of that cost attributable to traffic congestion. Separating the congestion cost component from the portion that can be considered reasonable and acceptable makes it possible to obtain a true indication of the magnitude of the congestion problem.

NEED FOR CONGESTION-COST STUDIES

An economical method for measuring the dollar cost of congestion would be valuable for several reasons. One important use would be for mobilizing public and legislative support for proposed transportation improvements. These improvements need not be highway construction projects but could be proposals for public transit, traffic-signal improvements, or any other project aimed at reducing congestion.

If dollar costs of congestion were measured city-wide, and in several cities throughout a state, they would provide a basis for comparing the relative needs of these cities for transportation improvements. Congestion costs could be a basis for setting priorities

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and would be of assistance in the difficult task of allocating state or federal transportation funds to the various urban areas on the basis of demonstrated relative costs of congestion. If city-wide measurements were carefully tabulated by travel corridor, the relative needs within a city would become apparent. The relative priority of a certain corridor project in one city versus a proposed corridor project in another city could be determined rationally.

It is emphasized that priorities would be determined by relative congestion cost, as defined earlier, rather than by relative total cost. The congestion cost reflects needs or deficiencies, whereas the total cost includes the portion considered reasonable and acceptable.

A third reason for congestion-cost studies pertains to the current Traffic Operations Programs to Increase Capacity and Safety (TOPICS). These programs involve operational improvements in signals, signs, markings, channelization, and the like to facilitate traffic flow without major new construction or right-of-way acquisition. In view of increased public resistance to new highway construction in urban areas, TOPICS projects are becoming increasingly important. Before-and-after studies of their effectiveness need to be sufficiently precise to reveal benefits on the order of 5 or 10 percent in some instances. TOPICS points up the need for a sensitive tool for precise before-and-after measurements of congestion costs.

Here again it is emphasized that attention should be directed to the congestion component of total road-user cost. The measure of effectiveness of a TOPICS project, for example, should not be the reduction in total road-user cost but rather the reduction in the congestion component. An improved signal system that has reduced total road-user cost by 12 percent may have reduced the congestion component by 90 percent!

REVIEW OF LITERATURE

There is no evidence in the literature of a technique for measuring the road-user cost of urban traffic congestion either for a selected roadway length or for an entire city. Consideration has been given to the road-user cost of stops, delays, and accidents in studies of traffic-signal systems, but typically these calculations are quite generalized, depend on average values, and do not take a microscopic look at the motion of an individual vehicle in the traffic stream. Moreover, they are concerned with the total cost rather than with the component attributable to congestion.

Past Practices

Measurements of urban traffic congestion have been made for many years by the well-documented methods of the speed-and-delay study or the travel-time study [National Committee on Urban Transportation (10), for example]. Although these procedures are based on a test vehicle "floated" in the traffic stream, they do not yield dollar costs, much less the congestion cost component. Instead, these procedures measure congestion as a delay rate, defined as the difference between the observed rate of motion and a rather arbitrary standard rate for that particular type of street.

Ten years ago there were insufficient data on vehicle operating costs. The major publication on the subject at that time (2) dealt primarily with passenger vehicles on rural roads. Data on the operating costs of trucks and buses were quite generalized. Operation at typical urban speeds, under stop-and-go conditions, was not well documented.

Until recently there was insufficient research on the value of lost time to automobile drivers and operators of commercial vehicles; many engineers felt that computations of monetary loss due to delay were controversial at best.

Some Recent Advances

Several recent developments have pointed the way to substantial improvements over past practices. A number of recording devices have been devised to aid in the gathering of data by a "floating" test car. Montroll and Potts (9) described and Argo-Kienzle tachograph that attaches to the speedometer cable of a test vehicle and furnishes a graph of vehicle speed. They used this device successfully in their research on acceleration noise.

Greissman (7) described his Traffic Data Compiler (available from Marbelite) of similar installation; it provides a speed graph and several digital readouts of speed-and-delay data.

Information on vehicle operating cost was greatly expanded and improved by Winfrey (12). Winfrey's comprehensive tabulations of vehicle operating costs for a wide range of uniform speeds and speed changes are appropriate for urban traffic composed of both cars and trucks. The time-speed charts furnished by the Argo or Marbelite devices give a complete account of a test vehicle's motion as it is floated through traffic. Therefore, they are ideally matched to the Winfrey tables for the calculation of operating costs.

Recent research has shed much light on the value of lost time to automobile drivers and operators of commercial vehicles. Thomas and Thompson (11) documented the value of time for commuting motorists as a function of their income level and amount of time saved. Adkins et al. (1) developed the values of time savings of commercial vehicles in various U.S. locations.

Sufficient research has also been performed on level-of-service criteria to allow the total road-user cost of operation and time to be divided into a component of cost associated with reasonable and acceptable traffic flow and a cost component attributable to congestion. The Highway Capacity Manual (8) set forth quantitative guidelines for acceptable flow in terms of minimum speed for freeways, signalized major arterials, and other types of roadways.

PURPOSE AND SCOPE OF PROJECT

This project has brought together these recent advances and has added computerized data processing for the purpose of producing an economical new system for measuring urban traffic congestion. The project tested the technical feasibility and the economy of routinely performing speed-and-delay runs with a tachograph-equipped car and then of converting the resulting speed graph to a dollar cost of congestion with the aid of a computerized version of Winfrey's tables of operating cost.

The testing program took place on selected sections of Atlanta freeways and arterials. Multiple speed-and-delay runs were performed using two types of commercially available tachographs. Manual classification counts were obtained concurrently to give the composition of the traffic by type of vehicle. These field data were then processed to yield road-user costs of congestion.

The final report for the project describes additional field data and office calculations that are not within the scope of this paper. These include supplementary machine volume counts, data on factors influencing capacity, and calculations of volume-capacity ratios. The final report also includes travel-speed contour maps prepared for typical sections of freeway and arterial roadways.

METHOD

Field Data Collection

Speed-and-delay runs were performed in 1970-71 on 13 selected sections of the Atlanta network with a total length of 85 miles. Six of these were Interstate freeway sections, each including several interchanges, and several were major arterial sections, each including a number of signalized, at-grade intersections. Two commercially available tachographs were tested; most of the runs were made with a Marbelite Traffic Data Compiler, but an Argo-Kienzle tachograph was used toward the end of the project.

The lengths of the sections varied from 3.7 to 10.4 miles, averaging 6.5 miles. The lengths were selected to be short enough to allow at least three speed-and-delay runs in each direction during the morning commuter rush and again during the afternoon peak. Three runs were also made during off-peak hours. All runs were made on a typical weekday, and complete data were recorded for both directions of the runs.

The Marbelite tachograph used for most of the speed-and-delay runs is a typewriter-sized device that rides on the front seat of the car alongside the driver. Priced at about $3,000, it is driven by a connection to the vehicle's speedometer cable and is powered by the vehicle's battery. It produces a continuous graph of the speed of the vehicle as it is driven through traffic. Unlike most commercial tachographs, however, the device includes several digital readouts of total trip time, total stopped time, and so forth. Photographs, sample speed charts, and field sheets were published by Greissman in 1967 (7).

Although it is possible for the driver alone to operate the Marbelite tachograph, especially in low-speed, stop-and-go traffic, an observer accompanied the driver on this project so that more detailed data could be recorded without compromising safety. During each run the observer made marks on the speed graph at a number of checkpoints. The marks were numbered consecutively, and the observer entered on a field sheet an identification of the location of each numbered checkpoint. The vehicle's odometer reading at each checkpoint was also entered and later became the basis for determining the length of each subsection.

Manual classification counts were taken concurrent with the runs in order to classify the composition of the traffic stream into the five typical vehicles for which Winfrey published data on operating costs. These counts were taken by a team of two observers stationed at a selected location in the section. One observer counted the passenger cars and the four-tired (light) trucks, while the other counted the three types of heavy trucks corresponding to Winfrey's cost tables. The team counted only one direction at a time. The counts were taken in one direction for a 5-min period, followed by a 1-min break for recording the tallies. Then counts resumed for 5 min in the other direction, followed by a 1-min break. In this way, the volumes in each direction were counted for 5 min in every 12-min period.

During the field work it was noted that the traffic conditions tended to vary widely within a section. Inasmuch as the sections are radials, the degree of congestion tended to decrease substantially with distance from the city center. Therefore, it was decided to divide the speed graphs from each section into subsections at intermediate checkpoints so that congested locations could be properly identified. The subsections were selected after consideration was given to the available volume-count records and the desirability of avoiding subsections so short that speed-and-delay results might be unstable. Figure 1, a sketch of an example freeway section, shows the five subsections into which the data from each run were subdivided and includes the ADT of each subsection as an indication of relative traffic use.

The Argo tachograph was also field tested. This compact unit mounts conveniently beneath the dash, is driven by a speedometer cable, and is powered by the vehicle's battery. The model used by Montroll and Potts (9) for traffic research purposes, model TCO-11/7G1K1, has two features vital for traffic engineering work. One is that the circular speed graph rotates once in 24 min (rather than 24 hours) and therefore can easily be read to the nearest 2 sec. A pack of seven 24-min charts permits continuous operation for up to 168 min. Also, this model includes an "event recorder," similar to the one on the Marbelite device, that records a mark on the graph at the push of a button. Inasmuch as the speed chart is inaccessible during the runs, the event recorder is quite necessary for locating checkpoints on the chart. The Argo unit is priced at approximately $300, including an "analyzer stand" that magnifies the small charts for easier reading in the office.

It is desirable to use an inexpensive dash-mounted clock and a battery-operated tape recorder with the Argo tachograph. At the beginning of the run and at each checkpoint the driver should actuate the event recorder momentarily, turn on the tape recorder, and record the time, the odometer reading, and a description of the event, such as "start of southbound run number two." The tape recorder is then turned off until the next checkpoint. The driver will have no difficulty in performing these functions, even on a high-speed facility. The final report of the project includes detailed instructions for the use of the Argo tachograph and its accessories.

Office Processing of Data

Computer Determination of Vehicle Operating Cost—After the speed graphs of the runs were divided into subsections, they were coded for computer calculation of vehicle cost.

These calculations were performed by the computer program RUNCOST (14), which was written in 1970 for this project by Bloom and later modified by Radics, both of the Federal Highway Administration. The purpose of the program is to eliminate the tedious process of translating a graph of speed versus time into a vehicle operating cost by means of Winfrey's tables.

The Winfrey tables give the costs per vehicle-mile of operating a passenger car and four types of trucks at uniform speeds ranging from 0 to 80 mph and also indicate the additional costs of accelerating or decelerating these vehicles. The tables take into account the profile gradients of the roadway and the horizontal curvature as well. Operating costs, more precisely termed running costs by Winfrey, include costs of fuel, tires, engine oil, maintenance, and depreciation. The cost of the fuel component does not include the state or federal road-user tax.

Briefly, RUNCOST uses the following six program control cards:

1. Title, which provides a heading that is printed at the top of each page of output, plus an adjustment factor (to correct for known tachograph error in recording speed) and a cost inflation factor (to update Winfrey's costs to the present);
2. GRAD, which provides information on the grade distribution;
3. CURV, which provides information on the horizontal curvature;
4. PAR, which provides the length of run in miles, the tachograph time scale calibration, the cost in dollars of an hour of vehicle time, and the total number of vehicles using the roadway during the time for which the speed-and-delay run is considered representative of traffic conditions;
5. VEH, which describes the distribution of the five vehicle types using the roadway; and
6. GO, which marks the end of a set of control cards and the beginning of the input data.

The input data cards describe the graphs of speed versus time as a series of coordinates. The coding of the graphs requires that they be digitized, that is, approximated by a series of points connected by straight lines. Each point has digital coordinates of time and speed that are coded on the input data cards.

The RUNCOST program prints out the following calculations of operating cost: cost per vehicle, tabulated by the five types of vehicles; cost per average (composite) vehicle; cost component due to speed changes and stops; cost component due to uniform speeds (on prevailing profile grades and horizontal curves); and cost per vehicle-mile of travel (VMT) for each vehicle type and for the composite vehicle. Additional printout includes stopped time, total travel time, the overall travel speed, and the length of the run as computed by the series of coordinates of time and speed. Computer printout of the cost of time is described next.

Computer Determination of Time Cost—Apart from Winfrey's tables, the RUNCOST program also computes the dollar value of the time of the run for each of the five vehicle types and for the composite vehicle based on dollar values of time specified by the user on the PAR card. The sum of operating cost and time cost for each type of vehicle is reported as well.

Thomas and Thompson (11) reported the value of time for commuting motorists as a function of their income level and the amount of time saved. In this project, therefore, a study was made of Atlanta income levels and travel characteristics so that the approximate value of time could be specified for passenger cars.

The average family income level for the five-county Atlanta metropolitan area was found to be in the $10,000 to $12,000 range as of 1968. The "amount of time saved" was more difficult to deal with inasmuch as speed-and-delay runs report a total time rather than a time saved by taking an improved or alternate route. Nevertheless, a hypothetical or typical amount of time saved was developed for Atlanta as follows. First, it was determined from the Atlanta Area Transportation Study (3) that the modal work trip length is 24 min. Next, Carter (13) found in his Wisconsin Avenue study that improvements on a signalized arterial can increase travel speeds from 20 to 30 mph. Such an increase in speed would mean a saving of 8 min in the modal work trip length in Atlanta. An 8-min saving was considered to be representative of other types of improvements also, for the purpose of this project.

Figure 1. Example freeway.

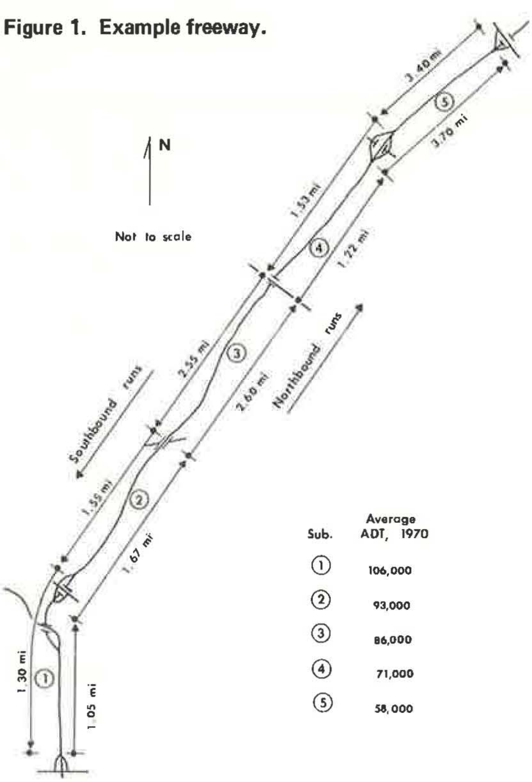


Figure 2. Cost versus speed for afternoon peak on example freeway.

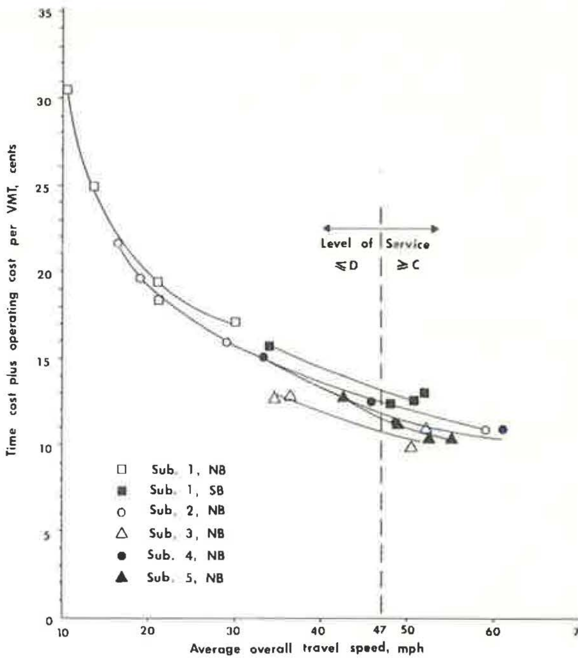


Table 1. Congestion costs for run 4, subsection 1, during peak period.

Cost Item	Cents
Operating cost/VMT	7.28
Time cost/VMT	23.15
Subtotal	30.43
Less estimated cost at 47 mph	12.0
Total	18.4

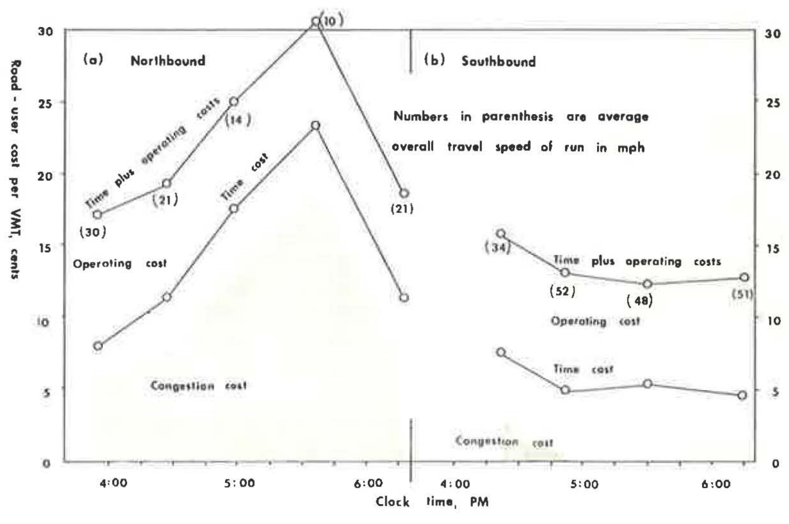
Note: Time of run was 5:36 p.m., and the average speed was 10.3 mph.

Table 2. Time and cost for office processing data.

Item	Time Expended (hour)	Cost per Hour (dollar)	Total (dollar)
Tape recorder playback	0.15	3.00	0.45
Processing of manual counts	0.15	3.00	0.45
Coding of control cards	0.15	3.00	0.45
Coding of data cards	2.0	3.00	6.00
Computer card punching	1.34	3.00	4.03
Computer cost (IBM 360/65)			1.20[a]
Portion of road-user cost due to congestion	1.0	3.0	3.00
Total			15.58

[a]See text for assumptions affecting this cost.

Figure 3. Congestion costs for subsection 1 of example freeway.



Thomas and Thompson indicate a value of time of $1.44 per person per hour for these levels of income and time saved (11, Table 5). With an average car occupancy of 1.5 persons, the value of time was calculated to be $2.16 per hour.

The values of time for Winfrey's four classes of commercial vehicles were obtained from Adkins et al. (1) and were updated from 1965 to 1970 on the basis of data from the U.S. Bureau of Labor Statistics and Dodge Trucks, Inc. The results were $4.23, $5.36, $6.26, and $7.06 per hour for trucks weighing 2.5, 6, 20, and 25 tons respectively (including driver's wages).

Obtaining Congestion Costs From Computer Output—The speed graphs and the computerized Winfrey tables were used to calculate road-user costs by subsection for all runs, whether or not congestion was present. The road-user cost attributable to congestion was determined by considering that congestion costs are accrued whenever the level of service falls below C, as defined by the Highway Capacity Manual (8).

In the case of freeways, the Manual considers the level of service to fall below C whenever the average speed is less than approximately 47 mph (corresponding to an operating speed of 50 mph) or the volume-capacity ratio exceeds 0.75. For urban and suburban arterials, the lower limit of level of service C is an average overall travel speed of 20 mph or a volume-capacity ratio of 0.80 to 0.90 (depending on the degree of signal progression).

To determine for each section the road-user costs attributable to congestion required that the level of service be determined on the basis of speed alone. The omission of the volume-capacity criterion simplified the determination of level of service and kept requirements for field data collection and office processing to a tolerable level for routine monitoring of congestion cost.

A graph was made of time cost plus operating cost per VMT versus average overall travel speed of each run. These data were obtained from the RUNCOST computer output. Figure 2 shows an example of this type of plot. The time cost plus operating cost corresponding to the lower limit of level of service C was then obtained from the graph. This lower limit is at 47 mph for freeways and 20 mph for arterials. Then, for any run, the portion of the time cost plus operating cost that is in excess of this graphical value was taken to be the congestion cost of the run. An example of this calculation is given in Table 1. Both Figure 2 and Table 1 are considered in greater detail later.

FINDINGS

Office Procedures

Table 2 gives the steps in office procedure that normally would be followed in routine measurements of congestion cost. The time and expense estimated for each step are also shown. Table 2 indicates that 1 hour of field speed-and-delay data will require office processing costing approximately $15. The largest single item of expense is seen to be the coding of data cards. The cost of computer processing per hour of field run will vary within wide limits, depending on such factors as size of batch processed, number of other users sharing the cost of the execution time, and the installation's policy on per-hour charges. In this project it was found that execution time ranged from 1 to 4 min per hour of field run; a time of 2.5 min is representative. Also, 46,000 bytes of storage are required for the execution of this program; therefore, nine other users could share the capacity and cost of the IBM 360/65. Assuming computer time to be valued at $280 per hour, the cost of computer processing was calculated as 2.5/60 × $280 × 1/10 = $1.17 (rounded to $1.20).

Example Highway Subsection

The findings for subsection 1 of an example freeway (Fig. 1) during a single period of the day are presented herein. The manual counts taken during the afternoon peak indicated that, in the northbound (outbound) direction, the vehicle distribution was 90.4 percent passenger cars, 7.4 percent commercial delivery (2.5-ton) trucks, 1.4 percent six-tired, single-unit (6-ton) trucks, 0.5 percent semi-trailer, 20-ton trucks, and 0.3 percent semi-trailer, 25-ton trucks. In the southbound (inbound) direction, only 86.2

percent of the vehicles were passenger cars, and the truck percentages were correspondingly higher. For the vehicle distribution in the northbound direction, the weighted value of time was found to be $2.39 per hour and, for the southbound direction, $2.53.

Figure 2 shows the findings from the speed-and-delay runs on all five subsections with regard to average overall travel speed and road-user cost. The figure indicates that speed varied over a wide range, from 10 to 60 mph. The highest speeds tended to be associated with the lowest road-user cost—approximately 10 cents per VMT—whereas the lowest speed of 10.3 mph was associated with a road-user cost of over 30 cents per VMT. At a speed of 47 mph, which is the lower limit of level of service C, the road-user cost varied from approximately 10 to 13 cents per VMT. This variation is due to the fact that any particular average speed, such as 47 mph, can be associated with a wide range of road-user costs, depending on whether the vehicle maintains a uniform speed or experiences considerable speed changes ("acceleration noise"). A value of 12 cents, close to the average for all subsections, was taken as an estimate of the cost at 47 mph for subsection 1. This estimate of 12 cents was used in Table 1 to calculate the cost of congestion. Data given in Table 1 show that for an example run over subsection 1 the total road-user cost of operation and time was 30.4 cents. With the cost at 47 mph estimated to be 12.0 cents, the congestion cost for the run was found to be 18.4 cents.

The data from the calculations given in Table 1 are shown graphically in Figure 3. The figure shows for subsection 1 the average speed, operating cost, time cost, and congestion cost for each of the five northbound and four southbound runs by time of run. For example, at 5:36 p.m. in the northbound direction, Figure 3 shows plotted from Table 1 the values of time plus operating cost, time cost alone, and congestion cost. The figure indicates much greater congestion cost in the northbound (outbound) direction than in the southbound (inbound) direction, as might be expected during the afternoon commuter rush.

CONCLUSIONS

The specific objective of this project was to develop and evaluate a practical, economical, and rational system for monitoring urban traffic congestion and the associated road-user cost.

Based on the findings, it is concluded that the project was successful in demonstrating the feasibility of monitoring congestion and its cost. It was shown that the engineering profession now has available to it a new, precise tool for expressing the results of speed-and-delay runs in dollars-and-cents terms.

It is further concluded that the office procedure, based on the RUNCOST computer solution of Winfrey's cost tables, was found to be sufficiently economical in time and money to recommend itself for widespread use.

RECOMMENDATIONS

Program for Monitoring an Entire Urban Area

The following recommendations are offered for the development of a congestion-monitoring program in an urban area:

1. Travel corridors in the urban area should be identified.
2. Speed-and-delay runs with a suitably equipped test vehicle should be performed for each corridor annually during morning and afternoon peaks of a typical weekday and during any other important peaks caused by recreation, shopping, and so forth. The lengths of these runs should be selected so that consecutive runs will not be more than about 20 min apart.
3. If possible, these runs should be performed on the same day that the routine annual machine volume counts are scheduled, preferably recorded by hour and direction. Manual classification counts should be performed only if the existing file of such data is inadequate.
4. These runs may require supplemental delay studies at certain intersections. Speed-and-delay studies usually record through movements only and may not adequately reflect serious left-turn delays.

5. The office procedures of coding and computer processing should next be performed, as given in Table 2. This step includes the processing of the computer printouts to give the dollar cost of congestion per VMT, as in Table 1.

6. The next step should be a comparison of congestion costs per VMT with those measured in previous years to indicate trends with time.

7. Plots of congestion cost similar to those shown in Figure 3 should be prepared for selected sections, as needed for visual aids in describing a particular congestion problem.

8. Congestion costs per VMT should then be converted to congestion costs per mile by multiplying by the number of vehicles using the section.

9. Step 7 should be repeated, using congestion costs per mile, to indicate trends with time. Are these changes in line with the advance-planning forecasts of trends in traffic demand?

10. Again using congestion costs per mile, the sections should be ranked in order of congestion. Comparisons of corridor congestion can be made among the corridors within an urban area and among corridors in different cities. As relative needs become apparent, decisions concerning priorities and programming can be considered.

Further Research

1. The most urgent need for further research is in the area of accident costs of congestion. Accident costs per VMT could have been estimated satisfactorily for the 13 highway sections of this project. However, when the portion of road-user costs attributable to congestion are calculated, accident costs can be taken into account only if they are known as a function of level of service. Specifically, the relationship between accident cost per VMT and average travel speed, for various types of facilities, is needed.

2. A less expensive procedure is needed for digitizing the speed graphs for computer processing. A state-of-the-art review of this area is needed, followed by a determination of the most economical way to obtain access to the appropriate equipment.

3. It is to be expected that a large volume of road-user cost data will be generated by this monitoring system. These data should stimulate research along the lines of NCHRP Project 2-7 (6). The purpose of this project by Claffey (6; see also 5) was "to provide data on road-user costs as classified by arterial type, operating speed, traffic composition and delay factors." It is to be expected that the road-user cost data obtained by the monitoring system described herein will complement Claffey's work. In particular, these data will aid the development of basic tables applicable for planning and for selecting arterial street and expressway systems from the various alternates in urban areas. The Chicago Area Transportation Study (4) made use of such tables.

4. Many other research-oriented analyses of these road-user cost data suggest themselves immediately, such as the determination of the relationship between volume-capacity ratio and road-user cost (or congestion cost). Also, graphs of road-user cost versus average speed (such as Fig. 2) prepared for various types of roadways and traffic conditions need to be analyzed in order to determine a rationale for curve shape and location.

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REFERENCES

1. Adkins, W. G., Ward, A. W., and McFarland, W. F. Values of Time Savings of Commercial Vehicles. NCHRP Rept. 33, 1967.
2. Road-User Benefit Analyses for Highway Improvements. AASHO, 1960.
3. Atlanta Area Transportation Study. A Report on the Development of a Trip Distribution Model. Div. of Highway Planning, Georgia State Highway Dept., 1968.
4. Chicago Area Transportation Study, Vol. 3, Transportation Plan. Chaps. II and III, 1962.
5. Claffey, P. J. Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report. NCHRP Rept. 13, 1965.
6. Claffey, P. J. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP Rept. 111, 1971.
7. Greissman, J. The Traffic Data Compiler. Public Safety Systems, May/June 1967.
8. Highway Capacity Manual—1965. HRB Spec. Rept. 87, 1965.
9. Montroll, E. W., and Potts, R. B. Car Following and Acceleration Noise. HRB Spec. Rept. 79, 1964, pp. 37-48.
10. Determining Travel Time. National Committee on Urban Transportation, Public Administration Service, Chicago, Procedure Manual 3B, 1958.
11. Thomas, T. C., and Thompson, G. I. The Value of Time for Commuting Motorists as a Function of Their Income Level and Amount of Time Saved. Highway Research Record 314, 1970, pp. 1-15.
12. Winfrey, R. Economic Analysis for Highways. Internat. Textbook Co., Scranton, Penn., 1969.
13. Carter, A. A., Jr. Increasing the Traffic-Carrying Capability of Urban Arterial Streets—The Wisconsin Avenue Study. Div. of Traffic Operations Research, Office of Research, Bureau of Public Roads, U.S. Dept. of Commerce, 1962.
14. User's Guide to RUNCOST. Traffic Eng. and Parking Branch, Urban Planning Div., Federal Highway Administration.