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CONTENTS

FOREWORD

This RECORD contains 5 papers dealing with motorist and transit-user services. The papers should be of value not only to those who operate highway and transit systems but also to planners and designers. They also should be of interest to the users of highway and transit systems.

Ludwick discusses how an urban network traffic model had been modified to simulate an unconditional preemption bus priority technique that automatically grants a green signal to buses approaching an intersection. An improvement of 15 to 20 percent in bus travel time is possible, but there would be some adverse effect on cross-street traffic. For headways that are greater than 2 min far-side bus stops appear to be best.

Huchingson and Dudek have completed development work on a dial-in telephone system by using interviews with local residents and reviewing previous work. They recommend that the system incorporate the 6 major traffic descriptors preferred by motorists into messages of less than 60-s duration. The messages should be updated frequently by field information.

Salter and Jadaan reveal in their study of English motorways that the characteristics of disabled vehicles in England are similar to those in the United States. Little difference was found between commuter and recreational motorway disablements. Climatic conditions also appear to have little effect on rate of disablement.

Lord, in a study of the role of roadside rest areas in motorist services, identified the following research needs: (a) determination of the proportion of various classes of motorists, (b) determination of the needs of each class, and (c) how rest areas can most effectively fulfill motorist needs. An important role of rest areas can be in providing motorist information, but much work is needed to determine exactly how this can be accomplished.

Nadan and Wiener explain a responsive electronic vehicular instrumentation system (REVIS). Using low-cost, highly reliable integrated circuits, they have designed a system that detects highway incidents independent of traffic-flow rate. A benefit-cost analysis indicated that, for controlled-access rural highways, REVIS is superior to the highway patrol in detecting incidents or disablements.

—Everett C. Carter

SIMULATION OF AN UNCONDITIONAL PREEMPTION BUS PRIORITY SYSTEM

John S. Ludwick, Jr., Mitre Corporation

An urban network traffic model has been modified to simulate a bus priority technique that automatically grants a green signal to buses as they approach an intersection. Such a technique could be implemented at individual intersections. Bus routes along 18th and 19th Streets in downtown Washington, D.C., were simulated, and traffic data representing the morning peak were used as model input. Repeated simulation runs tested the effect that the bus priority system had on bus and nonbus traffic for combinations of bus headways (from 0.5 to 4 min) and near-side and far-side bus stop locations. The technique substantially improved many aspects of bus operations, including reduction of the mean number of unnecessary stops, and the mean, 90th percentile, and standard deviation of travel time. An improvement of 15 to 20 percent in bus travel time was supported by statistical test. Other vehicles on bus streets also benefited from this type of system. Cross-street traffic was adversely affected by shorter headways, but far-side stops were far superior to near-side stops under those conditions. Under the conditions simulated, the bus priority system would have the least impact on other vehicles in applications with far-side bus stops when headways were 2 min and greater. However, a consideration of passenger movement rather than vehicle movement may indicate that the system should be operated at shorter than optimum headways.

•TODAY'S urban commuters spend up to 25 percent of their weekday free time traveling to and from work. The natural pattern of urban growth has resulted in an almost perfect negative correlation between the traffic attraction of the central business district and the traffic handling capability of the central business district's street network. Future technologies will provide unique solutions to the problem; in the meantime, however, the existing corridors must be used most efficiently to enable movement of as many people as possible. This can be accomplished by increasing the bus-to-car ratio. During peak travel hours, the average occupancy of a bus is equivalent to that of 35 cars, but its size is equivalent to merely 3 cars. Even after one allows for reasonable bus headways, 1 lane of bus traffic can carry the equivalent of 3 lanes of automobile traffic on city streets. However, to increase the bus-to-car ratio, commuters must be attracted to the bus from their cars. One way to accomplish this would be to ensure that transit service provides origin-to-destination travel time that is comparable with, or better than, that for automobiles.

Overall bus travel time begins with a built-in time handicap that results from the walk from trip origin to bus stop, the wait for the bus, stops for loading along the route, and the walk to the destination from the bus stop. If, in addition, the bus encounters the same traffic conditions as the car does, trip time cannot improve. This implies that some type of bus priority system (BPS) is necessary. Bus priority systems can use completely new roads, reserved lanes during peak periods, or expressway exits and bypasses for congested areas. Another bus priority technique, which is the one

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this paper will discuss, depends on recognizing buses in the traffic stream and changing traffic signals to benefit them. This can be done by automatically granting green lights or weighing supplementary data before making such a decision.

Such a system, from a people-moving viewpoint, could be justified even if it caused large delays to other traffic. In fact, this might even be seen as desirable, as it would favor the bus in the bus-to-car travel-time ratio. But a BPS should not unduly affect other traffic, and the tolerable value of inconvenience varies among communities. Implementing a BPS scheme is not a minor undertaking, and system effectiveness is difficult to predict for other than simple applications.

Although various bus priority techniques have been tested, the effectiveness of a given system depends as much on characteristics of the bus routes as it does on BPS technique. It may be necessary to relocate bus routes or bus stops to take best advantage of different BPS strategies.

An existing urban traffic model has been modified to simulate various bus preemption techniques involving traffic signals. The effects of various operating conditions were separated in simulations of local-service bus routes that had a range of headways and different bus-stop locations. The results help to identify conditions particularly favorable to BPS application.

Some terminology that will be used throughout the paper is defined as follows:

1. A near-side bus stop is located on the near side of the downstream intersection.
2. A far-side bus stop is located on the far side of the downstream intersection.
3. Preemption of a traffic signal overrides the existing signal pattern and substitutes a new signal pattern to benefit buses.
4. Unconditional preemption results if preemption is granted whenever a bus "requests" it.
5. Conditional preemption results if other factors (such as side street queues, time since last preemption, or expected bus travel and dwell time) are considered in determining whether a preemption will be granted.
6. A green extension preemption holds a green phase in the bus direction at the end of the normal green phase.
7. A red truncation preemption terminates a red phase in the bus direction and replaces it with a green phase.

SUMMARY

Computer simulation runs tested a number of unconditional preemption BPS cases, including combinations of various bus headways that ranged from 0.5 to 4 min, near-side and far-side bus stops, and 1 route per street and multiple routes. The following, subject to the constraints of the simulation, were found:

1. The BPS algorithm provided substantial benefits to buses regardless of headways or bus stop location;
2. When BPS was operative, other vehicles on bus streets benefited;
3. BPS use resulted in a penalty to cross-street traffic; and
4. The greatest penalty occurred with short headways and near-side bus stops.

The simulation results show that a BPS with medium and long headways and using far-side bus stops holds most promise. However, stable network operation results at headways as short as 0.5 min.

BPS ALGORITHM

The unconditional signal preemption strategy discussed here provides a green extension or red truncation. [A conditional 10-s green-extension strategy was simulated and was found to provide little benefit (4).] The algorithm guarantees a green signal to a bus approaching an instrumented intersection. If the signal is green at the time, it is held green until the bus clears the intersection; if it is not green, it is changed to green. The technique requires an indication of when a bus is in a detection zone, which extends upstream from an intersection. If no priority is in effect when a bus enters the zone, the signal facing the proper approach is checked. If the signal is not green, the sequence of phases at the intersection is scanned until 1 is found that will provide a green signal. This is the priority phase. A 4-s yellow signal is then provided for all green-signal faces that would not be green in the priority phase. This is the standard caution signal and is adequate to safely stop a vehicle. If a bus is still in the zone at the end of this time, the priority phase is initiated and remains in effect until all buses leave the zone. The phase that would have been in effect at that time, if no priority had been granted, is then determined, and a 4-s yellow signal is provided for all green-signal faces that would not be green in the normal phase. If, at the end of this time, no more buses have entered the zone, the normal phase is restored. Any signal synchronization in the network is thus maintained after the departure of all buses. This type of preemption technique could be used at individual intersections.

The preceding description illustrates typical operation during long-headway bus operations. During short-headway operations, other buses may enter or leave the zone during the 4-s yellow periods, and a different sequence of control will result.

MODEL

The Urban Traffic Control System-1 (UTCS-1) program is an urban network traffic simulation model that can be used for testing and evaluating traffic control techniques; it was specifically sized to be able to simulate the area of the UTCS-BPS in Washington, D.C. The model is discussed in detail by Bruggeman, Lieberman, and Worrall (5). Only an overview is presented here. Development of the UTCS-1 program has been evolutionary. It was based on the DYNET model, which had been based on the TRANS model developed for the Bureau of Public Roads. Later versions have revised and expanded the original UTCS-1 model (6, 7). The model flexibility allows simulation of virtually any geometric configuration and many forms of traffic control. The model has been extended to provide the capability of simulating and evaluating a wide variety of control systems that give buses preferential treatment at traffic signals.

Model Operation

The UTCS-1 model microscopically simulates the action of vehicle traffic in an urban network. Vehicles move through the network, change lanes, accelerate, and decelerate based on car-following and queuing logic to satisfy specified traffic-signal timing and network topology. Each vehicle is given an identification number, and its position is updated once every time period, which is usually 1 s. Vehicles enter the network at locations and times selected by random number to satisfy given input flow rates. Random numbers also are used to determine the type of vehicle entering the network according to specified entry link proportions and assigned driver characteristics related to reaction time and desired cruising speed. Acceleration characteristics of vehicles differ according to type of vehicle. When a vehicle enters a link, stochastic distributions are used to determine the turning movement that it will make at the downstream node and the pedestrian blockage that it will cause when it turns. The dwell times of buses at bus stops also fit predetermined distributions. However, location and time of entry of buses, as well as the sequence of links traversed, is set when bus route and headway are provided.

During the course of the simulation statistics are collected by type of vehicle and link; they may be printed out at various intervals during simulation. The statistics include moving, delay, and total time, which are measured in vehicle minutes and seconds/vehicle mile (seconds/vehicle kilometer); average speed; stops per vehicle;

and volume, occupancy, and number of cycle failures. Obviously, a large amount of input data is required to simulate a desired network accurately.

Modifications for BPS Simulation

Modifications were made to the model to add BPS logic to the traffic-signal timing and to provide additional output data for analysis of BPS operation. The BPS logic gives the choice of a conditional, fixed-time, green-extension preemption or an unconditional green-extension and red-truncation preemption. In either case, signal patterns remain coordinated after buses leave the network. Output summaries now put together vehicle data by bus street and cross street and include equivalent statistics for buses. For example, travel time/vehicle mile (travel time/vehicle kilometer) is given for all vehicle traffic on bus streets, for all vehicle traffic on cross streets, and for buses on bus streets to allow rapid determination of significant changes in traffic flow resulting from different combinations of scheduling conditions. (Bus streets and cross streets are selected by input data cards.) Queue-length data on selected links are output regularly, and moving and delay times of individual buses and the number of bus priorities requested and used are totaled. A bus-trace feature that stores the position of all buses in a time period and prints out the progress of each bus through the network at the end of the simulation helps one to visualize the dynamics of BPS operation.

Other modifications were made to provide greater statistical validity for the analysis of bus behavior. For example, the model originally used the current value of the random number generator to choose the dwell time of a bus at a bus stop. To determine the difference in travel time, later analysis paired each bus run not using BPS with a run using BPS; the initial random number was the same in each case. As soon as BPS influences the signal timing on any link, the situations will diverge, and the random number used to assign dwell time to a given bus at a given bus stop will not be the same in both cases. The resultant large variations in dwell time can mask the effects of bus priority operations. Of course, with a large enough number of runs, the effects will average out, but, for greater resource efficiency, the random number now used to choose the dwell time is formed by combining the initial random number, the entry time of the bus into the network, and the bus stop served. (The resulting sequence of numbers meets statistical criteria for randomness.) This process ensures that the sequence of bus dwell times occurring when BPS is operative will be the same as when no bus priority is simulated.

In the UTCS-1 model, it was noted that buses entered the network at the same times during every run. Of course, random events caused by changing the initial random number will cause the position of the bus at a given time to vary from run to run. However, a bus entering a given route at a given time has a good chance of encountering the same sequence of traffic signals on each run, which could unduly influence the BPS statistics. Again, a large number of runs would alleviate the problem, but another model change will randomize the initial signal timing based on the input random number and ensure that a given bus will encounter a variety of signal sequences for different runs.

NETWORK CHARACTERISTICS

The network used for the analysis is shown in Figure 1. It is the central grid portion of the Washington, D.C., UTCS-BPS network, which runs from G to K Streets and 17th to 20th Streets. Traffic-flow and signal-timing data are typical of the morning peak. A bus priority system with a large number of crossing bus routes will only reallocate delays among the routes in inverse ratio to the bus traffic intensity on those routes. Therefore, the routes selected were on parallel 3- and 4-lane 1-way streets: northbound 18th Street and southbound 19th Street. These streets have approximately equal signal splits (40 s green and 40 s red). Average traffic volume is approximately the same for 19th Street and its cross streets (200 vehicles/hour/lane). The average

Figure 1. Simulation network.

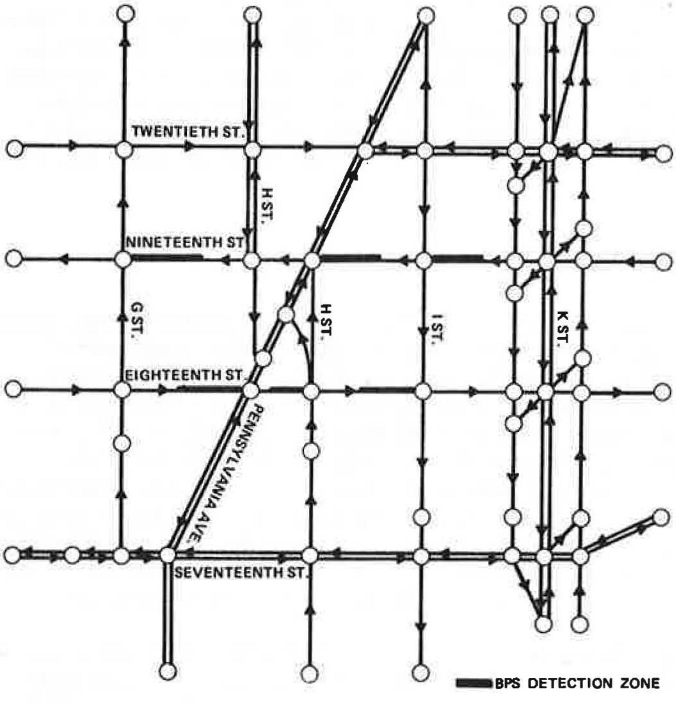


Figure 2. Bus-street travel time, buses only.

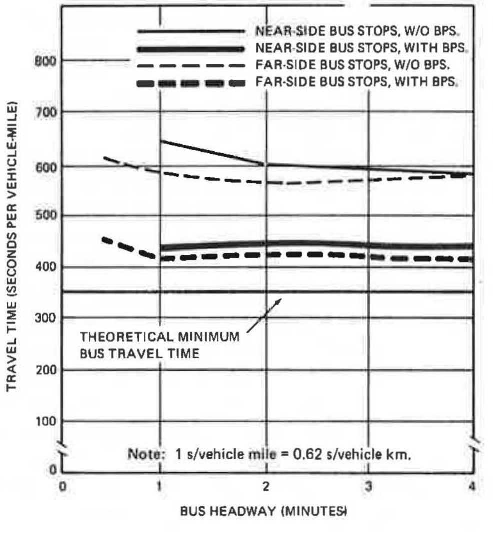
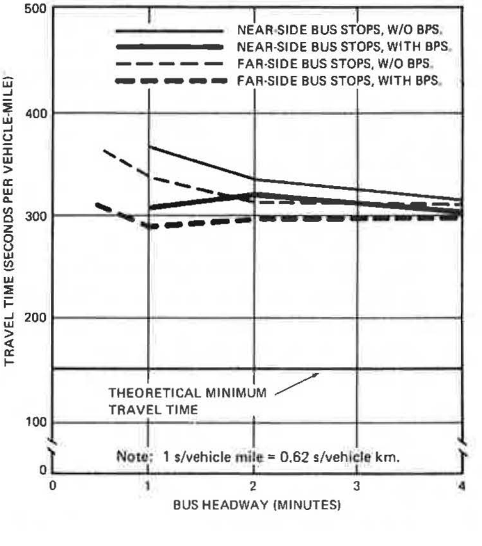


Figure 3. Bus-street travel time, all vehicles.



traffic volume for 18th Street is approximately twice as heavy as that for its cross streets. Eighteenth Street serves 2 bus stops and 19th Street serves 3.

Each bus street has 3 intersections instrumented for bus priority. Because K Street is itself a major east-west bus street, its intersection with 18th Street northbound is not instrumented. All other signalized intersections are instrumented. Bus detection zones begin 210 ft (64 m) upstream from the instrumented intersection and extend to within 5 ft (1.5 m) of the intersection. Therefore, near-side bus stops are completely within the zones and, for the streets chosen, no part of the far side bus stops are within a zone.

MEASURES OF EFFECTIVENESS

A large number of statistics are now available from the model that permit comparisons to be made of different runs. However, as the number of cases to be examined increases, it becomes more difficult to assess the overall effects of these comparisons. Although all of the measures of effectiveness resulting from each run were examined for possible inconsistencies, travel time/vehicle mile (travel time/vehicle kilometer) and stops/vehicle mile (stops/vehicle kilometer) were selected initially for close scrutiny. It should be noted that, although these measures are easily determined from the model, they are not easily measured in the field. Consequently, measures such as volume and occupancy, which are more closely related to measuring instrumentation, are often used. A major reason for stressing travel times and stops is that these measures can be directly related to system benefits, and many other measures are related only indirectly.

Travel time and delay time are important measures in determining the efficiency of vehicle traffic flow. Analyses of traffic control systems often assign monetary value to an individual's time and determine system benefit by multiplying that value by the total time saved when the system is used. The number of stops is a measure that can be related to air pollution and accidents. In fact, the Washington, D.C., and San Jose, California, traffic control systems use a weighted function of stops and delays as an indication of the efficiency of the signal-timing plan chosen. Also both measures can be related to vehicle operating efficiency and, thus, energy consumption. At first glance, it may seem that these 2 measures of effectiveness are the same, but this is not the case. For example, a vehicle in stop-and-go traffic may have a shorter travel time than does a vehicle stopping only a few times for longer periods of time.

For bus operations, travel-time statistics probably provide the most important measures of a system's effectiveness. In addition to the mean value, the 90th percentile of travel time is of interest because one method of specifying schedule time is based on the travel time that is not exceeded in 90 percent of the cases; sufficient improvement in this time could result in fewer buses being required for the same level of service. Although travel-time improvement is most important, BPS also could be of use if the variance of travel times from run to run were decreased. Failure to adhere closely to a schedule compounds inefficiencies. Buses that arrive early tend to gain time because of the decreased loading time required for fewer waiting passengers; late buses tend to lose time picking up more passengers at each stop. The result is a dynamic instability that causes buses to pair up. The magnitude of this statistic is also important to the bus commuters' satisfaction; if travel time varies greatly from day to day, they may return to their cars for a more consistent trip time. The considerations previously cited concerning stops and reduction of pollution and accidents also apply to buses.

ANALYSIS OF RESULTS

Figures 2, 3, and 4 summarize mean travel-time data resulting from the simulation runs. Data are presented separately for buses, all vehicles on bus streets, and all vehicles on cross streets. Bus headways of approximately 0.5, 1, 2, and 4 min were used. Headways were offset slightly from these values to prevent multiples of a head-

Figure 4. Cross-street travel time, all vehicles.

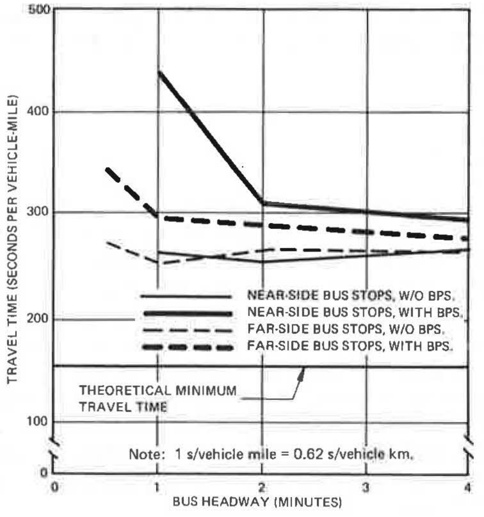


Table 1. Bus statistics.

		Travel Time									Stops, Mean		
		Mean			90th Percentile			Standard Deviation					
Headway (min)	Bus Stop Location	Without BPS (s/ vehicle mile)	With BPS (s/ vehicle mile)	Change (percent)	Without BPS (s/ vehicle mile)	With BPS (s/ vehicle mile)	Change (percent)	Without BPS (s/ vehicle mile)	With BPS (s/ vehicle mile)	Change (percent)	Without BPS (stops/ vehicle mile)	With BPS (stops/ vehicle mile)	Change (percent)
0.5	Near side	—	—	—	—	—	—	—	—	—	—	—	—
	Far side	606	471	-22	690	570	-17	95	67	-29	13.0	17.7	-25
1	Near side	657	450	-32	774	506	-35	113	67	-40	19.5	14.5	-26
	Far side	594	438	-26	658	500	-24	99	50	-49	16.0	11.0	-31
2	Near side	606	474	-22	665	517	-22	113	60	-47	17.9	14.5	-19
	Far side	546	438	-20	665	514	-23	113	74	-35	13.5	11.0	-19
4	Near side	588	447	-24	711	535	-25	92	64	-30	19.5	15.5	-21
	Far side	585	417	-29	672	503	-25	77	60	-22	16.0	10.2	-37

Note: 1 s/vehicle mile = 0.62 s/vehicle km. 1 stop/vehicle mile = 0.62 stop/vehicle km.

Table 2. Statistics for all vehicles.

			Travel Time			Stops		
Bus Headway (min)	Street	Bus Stop Location	Without BPS (s/vehicle mile)	With BPS (s/vehicle mile)	Change (percent)	Without BPS (stops/vehicle mile)	With BPS (stops/vehicle mile)	Change (percent)
0.5	Bus	Near side	—	—	—	—	—	—
		Far side	345	315	-9	8.5	7.5	-12
0.5	Cross	Near side	—	—	—	—	—	—
		Far side	270	350	+30	4.5	7.3	+62
1	Bus	Near side	365	310	-15	8.5	7.6	-11
		Far side	335	290	-13	7.3	7.0	-4
1	Cross	Near side	265	440	+66	4.6	7.3	+59
		Far side	250	295	+18	4.5	5.5	+22
2	Bus	Near side	340	325	-4	8.1	7.5	-7
		Far side	315	295	-6	7.5	6.4	-15
2	Cross	Near side	250	310	+24	4.7	5.7	+21
		Far side	270	310	+15	4.4	5.4	+23
4	Bus	Near side	320	300	-6	7.3	6.9	-5
		Far side	315	290	-8	6.8	6.2	-9
4	Cross	Near side	265	290	+9	4.6	5.5	+20
		Far side	260	275	+6	4.4	4.8	+9

Note: 1 s/vehicle mile = 0.62 s/vehicle km. 1 stop/vehicle mile = 0.62 stop/vehicle km.

way from coinciding with multiples of a signal cycle. Each data point represents the output of 4 model runs; each run has a different random number and different initial signal timing.

Mean Travel Time

As shown in Figure 2, bus travel time is improved substantially when BPS is used, and the location of bus stops has little effect on travel time. In fact, individual bus travel times with and without BPS were compared by using the Wilcoxon matched-pairs test. At least 15 percent improvement (more than 20 percent for some combinations of headway and bus stops) was shown at the 0.05 level of significance. The same test comparing travel times for near- and far-side bus stops showed no statistically significant difference. Figure 3 shows the adverse effect of short-headway bus operation on other vehicles on the bus streets under normal conditions (without BPS). When BPS is used, other vehicles also benefit. Figure 4 shows the corresponding travel-time penalty for cross-street traffic when BPS is used. When headways are shorter than 2 min, far-side bus stops are far superior to near-side bus stops although 0.5-min headways result in substantial delays.

The lowest line on each graph indicates the shortest average travel time attainable for the given vehicles on the given streets. For all vehicles, this is 150 s/vehicle mile (83 s/vehicle km); it is derived from the free-flow speed of the appropriate links although an individual vehicle's speed may range from 0.75 to 1.27 times this value. For the bus-only case, the additional time required to decelerate to a halt at a bus stop, to pick up and drop off passengers, and to accelerate to free-flow speed was also considered. A minimum travel time of 365 s/vehicle mile (226 s/vehicle km) resulted. When BPS is operative, mean bus travel time improves to within 15 percent of the minimum.

The near-side, 0.5-min headway case is not shown because the runs encountered severe traffic congestion. Without BPS, buses at bus stops accumulate queues of right-turning vehicles and other buses behind them. If buses enter the network infrequently enough, queues have time to dissipate before additional buses arrive. At 0.5-min headways, however, queues do not have time to dissipate, and eventually the storage capacity of the right lane of short links is exceeded. This causes spillovers (vehicles entering intersections that are not clear). Spillovers, in turn, block cross streets and prevent bus-street vehicles from entering the bus links. When BPS is operative, congestion on bus links is minimized, but cross-street congestion at controlled intersections is increased because the signal remains red for cross streets while a bus is in the detection zone. Cross-street queues eventually cause spillovers at their upstream intersections, some of which are, in turn, bus streets. It is obvious that near-side bus stops will cause this during some short headway conditions; the simulation gives an indication of the critical headway value. For far-side bus stops, 0.5-min headways result in a stable operation without BPS because vehicles approaching a bus dwelling at a far-side bus stop can pass it if there is space ahead of the bus. Although vehicles on cross streets are delayed by 30 percent, conditions will remain stable at 0.5-min headways with BPS because instrumented intersections are held green for only that amount of time required for the bus to travel through the detection zone, not for the dwell time.

Other Statistics

Additional travel-time and stop data are given in Tables 1 and 2. As the model records individual bus travel times, not only standard deviations and 90th percentiles of bus travel times but also the percentage differences in each statistic are presented when BPS is used. Only the mean travel time is available for other vehicles because the paths followed by them are randomly chosen during a simulation run and only link totals are available. Similarly, only link and bus-stop data are available from the model, so no measure of vehicle variation can be derived.

In summary, buses receive substantial benefits over the entire range of headways tested when BPS is used (20 to 30 percent improvement in mean and 90th percentile travel times, 25 to 50 percent improvement in travel-time standard deviation, and 15 to 20 percent improvement in stops). Data on other-vehicle traffic show headway differences that can be separated into 3 regions:

1. A long-headway range (4 min or more) that shows almost no difference whether BPS is or is not used,
2. A short-headway range (1 min or less), in which extreme effects occur when BPS is used, and
3. A medium-headway range in which effects decrease with increasing headways.

For short headways, far-side bus stops caused much less disruption to cross-street traffic than did near-side bus stops (travel time and stops were at least 30 percent better). However, even with far-side bus stops, BPS operation with short headways caused significant degradation to cross-street traffic. For medium headways, far-side bus stops were slightly superior to near-side bus stops (10 percent or less improvement in bus travel time and stops) and caused less degradation to cross-street traffic. At long headways, BPS had little effect on other-vehicle traffic.

Multiple Routes per Street

Cases with multiple routes per street that were tested indicated that the previously mentioned headway definitions also would apply when average bus headway, not route headway, is used. Thus, even though long headways may seem relatively short, equivalent route headways are not unreasonable if they are viewed as bus headways multiplied by the number of routes operating on a street.

Short Headways

Two points concerning the results of the short-headway case require discussion. First, the assumption that a street with 4-min headways would have the same amount of other vehicles as it would if it had 0.5-min headways may be questioned. There would be some trade-off between modes of passenger travel, so that a passenger demand requiring 0.5-min headways would result in fewer other vehicles being required than when 4-min headways would be used. Another factor stems from the commuter's choice of routes to minimize travel time (or perceived travel time). That is, if bus streets result in great congestion for right-turning vehicles, the commuter who wishes to make a right turn will choose a nonbus street that has less congestion.

Second, the realism of the model's handling of right-turning traffic at near-side bus stops is pertinent. The objection may be made that a link of car traffic may not queue up behind a bus at a bus stop if the drivers realize that the signal will remain green until the bus has left the zone, but the model modifications required to realistically simulate what would actually happen are considerable.

The net result of these 2 points is to simulate a kind of worst-case condition. That is, very short headway bus traffic would probably result in (or be a result of) fewer other vehicles being on the bus streets; therefore, congestion would not be as bad as simulated. Also actual right-turning traffic would not increasingly queue up behind buses at a near-side bus stop. Some vehicles would change lanes and turn in front of the bus and cause shorter queues than those measured.

CONCLUSION

Simulation results have indicated that an unconditional preemption bus priority system can provide substantial benefits to buses in an environment representative of many cities. However, successful application of the technique requires more than just modifications to traffic-signal hardware; relocation of bus stops and bus routes may also be necessary. In some applications, BPS will have little effect on other vehicles. In other applications, BPS may cause substantial delay to cross-street traffic. The urban planner must determine the acceptable trade-off between overall passenger movement and inconvenience to automobile passengers.

ACKNOWLEDGMENTS

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DEVELOPMENT OF A DIAL-IN TELEPHONE SYSTEM BASED ON OPINIONS OF URBAN FREEWAY MOTORISTS

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A dial-in telephone system is being installed in Dallas, Texas, to inform motorists of traffic conditions on a major expressway leading to the central business district. This paper summarizes the findings of a questionnaire administered to over 300 motorists in 7 central business firms. The questionnaire was designed to establish the degree of interest in the service and to help develop design and operational criteria for the phone messages. The results of the survey indicate that 75 percent of the respondents stated that they would use the service. Their greatest interest was in information regarding location and degree of congestion, alternate routes, the reason for congestion, and whether a lane was blocked. Messages based on the survey results were recommended for various situations, and other design and operational criteria were specified. A follow-up study is planned to be conducted after the system is in use to determine motorists' evaluation and use of the system.

•PREVIOUS research (1, 2) has indicated that an effective, real-time, freeway-driver information system should include, in addition to visual communication, various modes of audio communication. Dudek and Carvell (1) explored 3 proposed methods: commercial radio, low-powered radio, and dial-in telephone. They concluded that all 3 modes may be necessary to satisfy the preferences of motorists.

This paper is about a dial-in telephone system, which, as a part of an integrated system, appears to be useful in trip planning. The telephone, like a low-powered radio system, has several advantages.

1. Freeway traffic information is presented in real time and can be specific to local interest.
2. The message can be varied easily as conditions change.
3. The cost of implementation is nominal compared with that for visual modes of information.

In addition, telephones are usually available to office workers.

The present conceptual design for the telephone system is that each origin zone would have a separate call number to provide local rather than wide-area coverage. Separate records would provide taped broadcasts of the local area freeway traffic conditions based on data from the traffic control center. The telephone answering service would be equipped with enough extensions to handle the anticipated volume of calls during peak periods.

The area to which this paper is directed relates to quantitative and qualitative aspects of the message that is to be reported over the telephone. The message can be most effective if it presents the traffic information that motorists can most readily interpret in terms of their particular needs. It should provide the necessary information for the driver to voluntarily make the appropriate traffic planning decision that will

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be compatible with redistribution of demand and will ameliorate traffic congestion. This paper deals with motorists' preferences with regard to the message and their acceptance of the dial-in telephone system.

OBJECTIVES

The objectives of the research reported in this paper were as follows:

1. To determine the types of messages that should be transmitted to freeway motorists over a dial-in telephone system. Traffic information may be described in different ways, but the criterion of driver opinion or preference was the primary consideration in message selection.
2. To determine from motorists' responses their interest in the telephone dial-in system and, more specifically, when they would most likely use it.

The results of this survey were to be used in the development of a set of message packages for common traffic situations. A follow-up study is planned to assess motorist acceptance and use of the dial-in system after it has been in operation for a period of time.

PREVIOUS WORK

Three studies have been reported in recent literature that deal specifically with driver preferences for certain types of traffic descriptor messages. Heathington, Worrall, and Hoff (4) investigated driver preferences for descriptors of heavy, moderate, and no congestion. Descriptors were presented as overhead sign messages followed by the message NEXT 3 MILES (4.8 km). They found for heavy congestion the most preferred descriptor was ACCIDENT—HEAVY CONGESTION; second choice was SPEED—5 to 15 MPH (8 to 24 km/h); third and fourth choices were HEAVY CONGESTION and STOP AND GO TRAFFIC. Least preferred were EXTRA DELAY—10 to 20 MINUTES, TRAVEL TIME—15 to 25 MINUTES, and a blank sign. Similar results were found for moderate congestion except that the ACCIDENT and STOP AND GO TRAFFIC descriptors were not used.

Dudek and Jones (3) conducted a questionnaire survey of 505 drivers from Houston and Dallas. When they were asked to select the information that was most helpful in determining freeway traffic conditions, 70 percent preferred information on either location and length of a congested area or degree of congestion.

Case, Hulbert, and Beers (5) conducted an extensive study of changeable messages for freeway signing. They found a different order of priority. Most drivers preferred knowing which lanes were blocked. Knowing the distance from the problem ranked second.

The following indicates the ranking given to the descriptors in the 3 studies:

Heathington, Worrall, and Hoff	Dudek and Jones	Case, Hulbert, and Beers
1. Cause and congestion level	1. Location of congestion	1. Lane blockage
2. Speed	2. Congestion level	2. Distance to problem
3. Congestion level only	3. Cause of congestion	3. Delay time
4. Stop and go	4. Speed	4. Cause for delay
5. Delay time	5. Travel time	5. Location
6. Travel time		
7. Blank sign		

Heathington, Worrall, and Hoff did not investigate preferences for location or length of a congested area because this was indicated in all messages by NEXT 3 MILES. Dudek and Jones did not investigate delay and stop and go. Only Case, Hulbert, and Beers investigated lane blockage. The first 2 studies suggest that motorists have a strong preference for information on level of congestion; information on travel time was less preferred. The results are contradictory on the importance of speed information as well as on several other areas. The 2 studies are principally relevant to visual modes of presentation, and a different ranking sequence may apply to audio modes. Therefore, one of the major questions in our survey related to freeway driver preferences when the mode of presentation was a dial-in telephone system.

METHOD

Motorist Sample

The sample was selected from the central business district because all of the employees in it worked a day shift and typically faced a daily trip planning problem. They would be involved in traffic congestion and, hence, might have occasion to use the service.

A sample of 303 employees was selected from 7 different businesses: 3 life and health insurance companies, 2 banks, and 2 oil companies. These businesses were selected because they hired a large number of employees. The number of participants from each organization ranged from 33 to 62.

Instructions on general criteria for participant selection were given to the personnel departments of the various companies. Only those employees who drove or rode in a privately owned vehicle to or from work were included. Passengers in car pools could be respondents.

Questionnaire Description

A questionnaire was developed that had 4 major parts:

1. Instructions to the respondents and a brief description of the proposed system;
2. Request for general information on age, sex, education, and use of a freeway for commuting;
3. Request for information on availability of a telephone, expected frequency and times of use, and strength of interest measured by willingness to call back if the line is busy; and
4. Request for preferred 5 out of 12 messages.

The 20-question form that was administered to those in the sample is presented in an appendix.[1]

RESULTS AND DISCUSSION

Informational Descriptors

The most important question was that on preferred descriptors. Table 1 gives a summary of the results.

[1] The original manuscript of this paper included an appendix, Dial-In Telephone Questionnaire. The appendix is available in Xerox form at cost of reproduction and handling from the Transportation Research Board. When ordering, refer to XS-57, Transportation Research Record 536.

Table 1. Rank order of descriptors.

Rank	Descriptor Subject	Number Selecting	Percent Selecting
1	Location of congestion	217	75.1
2	Degree of congestion	206	71.3
3	Recommended alternate routes	176	60.9
4	Lane blockage	142	49.1
5	Reason for congestion	137	47.4
6	Delay expected by congestion	101	34.9
7	Delay at ramp and alternate ramps	99	34.3
8	Time saved by alternate routes	87	30.1
9	Recommended safe speed	79	27.3
10	Travel time to exit ramp	74	25.6
11	Average freeway speed	54	18.7
12	Average speed on parts of freeway	45	15.6
13	Other	10	3.5

Over 70 percent of the respondents preferred messages on location of congestion and degree of congestion, which is consistent with the findings of Dudek and Jones (3).

Sixty percent of the respondents wanted to know recommended alternate routes. This alternative was not investigated in the visual mode studies of Dudek and Jones (3) or Heathington, Worrall, and Hoff (4), but Case, Hulbert, and Beers (5) found that 78.5 percent wanted advice on alternate routes.

Slightly over a third of the respondents were interested in the delay to be expected on the freeway compared to the normal traffic speed. The relatively low importance associated with time delay was also found by Dudek and Jones (3), and Heathington, Worrall, and Hoff (4).

Less than 20 percent were interested in the average speed of traffic on either the freeway or parts of the freeway. This finding came even though these alternatives were placed in the first and second positions in the sequence of alternatives. Dudek and Jones (3) also found speed ranked fourth out of 5 descriptors.

Telephone Service Information

All respondents had access to a telephone where they worked, and all but 2 percent had access to a private telephone. Approximately 75 percent of the respondents indicated that they would use the service often or occasionally; only 25 percent would have little or no use for it. Over 90 percent of the respondents said that they would use the service 1 to 10 times per week. Infrequent users often left the remainder of the questions on dial-in service unanswered.

Slightly over 50 percent of the respondents were interested in the service both before they went to work and before they went home; slightly less than 25 percent of the respondents were interested in it only before going to work or only before they went home. As expected, about 75 percent of the respondents would dial in either between 6 and 9 a.m. or 4 and 7 p.m. Only 12 percent would use it on weekends, and only nominal interest was expressed in using it during other times of the day.

Of considerable note was the finding that almost 50 percent of the respondents would not dial again if the line was busy, which suggests that they viewed their time as being at a premium. Therefore, the service should not delay the user.

Although a great majority of the respondents now listen to traffic reports on radio, only a few believed that the reports were always timely and accurate. Fifty-eight percent said the reports were sometimes timely and accurate, but 25 percent of the respondents stated that they were not. This would suggest a need for an additional service such as a dial-in telephone system.

Driver Information

In response to the questions regarding driving habits, 89.4 percent of the respondents indicated that they normally drove or rode in a vehicle to and from work. The remainder of the respondents stated that they drove or rode sometimes. Approximately 89 percent stated that they always traveled on a freeway; the remainder responded that they sometimes traveled on a freeway.

The results indicate that 55.8 percent of the respondents took the North Central Expressway to and from work in the central business district.

The frequency of freeway trips each week was as follows:

Trips/Week	Respondents (percent)
1 to 5	14.8
6 to 10	50.2
11 to 20	32.7
More than 20	2.3

A final question related to the time that freeway users took to go from their places of work to their vehicles. Responses indicated how old the telephone message would be by the time the motorists started on their homeward trip. These results were as follows:

Work to Vehicle (min)	Respondents (percent)
1 to 3	8.4
3 to 5	26.4
5 to 10	38.1
More than 10	27.1

These findings suggest that even the most timely telephone system may need to be supplemented with radio advisories or changeable message signs because the telephone information will in many cases be more than 10 min old when drivers reach their vehicles.

General Information

Three hundred and twenty-seven persons from 7 downtown Dallas businesses responded. Twenty-four persons were deleted because they did not meet the criterion of using a Dallas freeway. Thirteen respondents indicated that they would never use the service, and they omitted several questions that presumed use of the service. Their responses were included in the results. Table 2 gives a breakdown of the number of respondents in each of the 7 groups.

Table 3 gives a summary of the respondent sex, age, and education characteristics. The sample consisted of an approximately equal male-female division; the age range of 25 to 44 years had the most subjects. As expected, the respondents were well educated.

RECOMMENDATIONS

The following design and operational recommendations will be evaluated in phase 2 of this study:

Table 2. Number of respondents.

Group	Number Used	Deleted	Incomplete
1	36	3	1
2	49	5	3
3	33	3	1
4	62	3	0
5	35	5	2
6	45	6	3
7	43	1	3
Total	303	24	13

Table 3. Sex, age, and education of respondents.

Item	Number	Percent
Sex		
Male	167	55.1
Female	136	44.9
Age		
24 or younger	46	15.2
25 to 44	199	65.7
45 or older	58	19.1
Education completed		
Grade school	0	0.0
High school	86	28.4
Business college or trade school	23	7.6
Two years of college	49	16.2
Senior year of college	101	33.3
Graduate or professional school	44	14.5

1. Telephone messages should include the 6 major traffic descriptors preferred by the urban motorists.
2. When there is no incident, construction, or maintenance, the first information should be on the level of congestion (heavy, moderate, light), and the location of the heaviest congestion should be expressed in terms of 2 cross-street names.
3. Both inbound and outbound conditions should be given, but the information of greater demand should be given first, that is, inbound in the mornings and outbound in the afternoons. Busy listeners then can decide whether to continue listening after their informational needs are satisfied. Those times when there are no incidents on the freeway should be mentioned also.
4. When an incident has occurred, this information takes priority. Its general nature (stalled car, accident, unidentified blockage) should be identified. Its exact location, whether it is inbound or outbound, and the lanes blocked should be mentioned. Locations should refer to the nearest cross streets. Lanes blocked should be referred to as right, middle, or left (inside or outside are ambiguous terms).
5. The message should indicate how far the traffic is backed up and the estimated duration of the blockage in minutes. The latter information should be updated whenever there is any change in status, such as when a wrecker appears on the scene. Both information on the onset of the stoppage and delay information should be updated as often as possible.
6. When an incident occurs, the message should also indicate recommended alternative routes and entrance ramps. Motorists should be told where they should leave the freeway to avoid an incident. If the freeway is quicker than other alternatives, this advisory should be given.
7. The traffic advisory should indicate when an incident has been removed and traffic congestion begins to subside. It should also state how far traffic is backed up and level of congestion. Repeating which lane was blocked is desirable because the backup may still be greater in this lane.
8. Messages for morning and afternoon advisories during peak periods should be similar in format.
9. The message for off-peak periods will be similar to peak periods with no incidents.
10. Although the greatest demand from commuters on Monday through Friday will be between 6 and 9 a.m. and 4 and 7 p.m., the system should operate during off-peak periods throughout the day. When the system is not in operation, a taped message should provide this information.
11. The success of the operation depends on the brevity of the messages because demand on the telephone system will come primarily during 2 short periods each day. Messages should never exceed 60 s and normally should be held to 15 to 20 s. There should be enough extensions that a caller does not receive a busy signal during peak periods.
12. The messages should be delivered by trained speakers with easily understood voice qualities and diction. They should emphasize the key words in the messages.

13. A brief introductory statement is recommended to inform the listener about 4 key pieces of information: (a) the traffic advisory itself, (b) the expressway to which it applies, (c) that the information is based on traffic control center data, and (d) the time the data were last updated. An example would be: This traffic advisory for the North Central Expressway is based on traffic control information received at 7:25 a.m. The time of update assures the listener that the message is current and can be relied on. The listener should not be delayed by lengthy acknowledgments on who provides the public service.

SUMMARY

The city of Dallas at present is installing a dial-in telephone system to provide motorists with real-time information on North Central Expressway traffic conditions. The objective of this study was to determine from a large sample of urban freeway motorists the types of messages that they felt should be transmitted and other requirements for system design. The major findings of the questionnaire are as follows:

1. The types of traffic descriptor information ranked most important were location and degree of congestion, recommended alternate routes, whether a lane was blocked, and reason for congestion. Fifty percent or more of the respondents stated that they preferred this form of information. Expected delays (minutes of time lost) and time saved by taking other routes were next in importance. Little interest was shown in estimated travel time to destination, recommended safe speeds, or expected average speeds.
2. Seventy-five percent of the sample stated that they would use the service often or occasionally. About 93 percent stated that they would use it 1 to 10 times per week. Fifty percent of these would use it both mornings and afternoons. Twenty-five percent would use the service only in the mornings; the other 25 percent would use it only in the afternoons.
3. Peak demand for the service was from 6 to 9 a.m. and 4 to 7 p.m. Little interest was reported in weekend and evening service.
4. Half of the respondents stated that they would not dial again if the service line was busy. This underscores the importance of the user's time and the need for multiple extensions and brief call times.
5. Over 70 percent of the sample listen to radio traffic reports at present, but 25 percent stated that the reports were not timely or accurate. This finding supports the need for real-time information.
6. A telephone system needs to be supplemented with radio advisories and changeable message signs because the telephone information often will be more than 10 min old when the motorist reaches his or her vehicle.
7. The respondents consisted almost entirely of freeway drivers, 55 percent of whom take the North Central Expressway and 85 percent take the freeway more than 5 times a week.
8. The sample contained an approximately equal number of men and women. Ages of most respondents ranged from 25 to 44 years. Their educational level was well above the high school level, and almost half claimed a college education.

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The contents of this paper reflect the views of the authors who are responsible for

the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration.

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CHARACTERISTICS OF DISABLED VEHICLES ON ENGLAND'S YORKSHIRE AND LANCASHIRE MOTORWAYS

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An analysis of the records of calls reporting breakdowns received from the emergency telephone system on 2 sections of the British motorway system has been carried out to determine the factors that influence the rate of vehicle disablement on British limited-access highways.

EMERGENCY telephone calls received during a 7-month period on Yorkshire motorways and during summer weekends for a 3-month period on Lancashire motorways have been examined, and the hourly, weekly, and monthly patterns of reported disablements have been determined. The basic relationships between reported disablements and traffic flow for the mainly business and commercial flows in Yorkshire and the mainly recreational flows in Lancashire were determined. Similar rates were found for both situations. Hourly, daily, and monthly patterns of traffic flow and reported disablements were observed and compared. Distribution of age based on first registration for disabled vehicles has been investigated together with the suspected cause of the disablement. The proportion of disablements due to faults that could be corrected at the roadside was found.

An attempt has been made to correlate breakdown rate with climatic variation by using mean ambient temperature as an independent variable. Membership in the Automobile Association (AA) and the Royal Automobile Club (RAC), both of which give help to disabled vehicles, of occupants of disabled passenger cars was also noted to be a significant factor in the operation of the emergency telephone system.

The need for facilities to enable users of the British limited-access motorway system to summon aid in the event of accident or vehicle disablement has long been recognized. The British motorway system consists of 2 carriageways separated by a central reservation. Each carriageway is normally composed of 3 traffic lanes together with a hard shoulder or emergency lane. Emergency telephones are located in pairs on opposite sides of the motorway at 1-mile (1.6-km) intervals. Communication with the driver in the event of an emergency on the British motorway system is handled by the police. Information is received at the police traffic control room primarily from the emergency telephones and, less frequently, from police patrols. The objective of the emergency telephone system is to provide motorists with a communication link that reduces the time required to obtain aid. The telephone system also is believed to be effective in reducing hazards and congestion caused by disabled vehicles, which thus increases the safety of motorists and maximizes highway capacity.

Research is currently being carried out at the University of Bradford into the cost effectiveness of this system and into the likely benefits of other disabled vehicle location-and-aid systems that could be introduced as alternatives to emergency telephones.

As an initial step in evaluating any disabled vehicle location-and-aid system it is necessary to determine the nature and frequency of vehicle stoppages on the highway system that are caused by breakdowns. To obtain this information we have analyzed the motorway emergency telephone records on disabled vehicles on the West York-

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shire and Lancashire motorways. In West Yorkshire attention was focused on vehicle disablements throughout the whole week. In the analysis of the Lancashire records, however, Saturday and Sunday were studied because this is when most vehicles travel for leisure purposes. By selecting 2 differing study periods we hoped to determine the difference between the characteristics of vehicle disablements on a motorway carrying mainly commercial and business traffic and those on a motorway carrying recreational or holiday traffic.

The motorways selected for study, which are shown in Figure 1, are as follows:

1. M1 between junctions 30 and 43 [41 miles (66 km)],
2. M62 between junctions 27 and 42 [6 miles (9.6 km)] and junctions 13 and 22 [21 miles (33.8 km)],
3. M6 between junctions 21 and 35 [60 miles (96.6 km)],
4. M18 between junctions 32 and 2 on A1(M) [9 miles (14.5 km)], and
5. A1(M) in the West Riding of Yorkshire [14 miles (22.5 km)].

In West Yorkshire the study was from October 1971 to May 1972; in Lancashire the study period was from July to September 1971. Average daily traffic flows during 1971 are shown in Figure 1 (1).

TOTAL DISABLEMENTS

Because of the large volume of data available for the West Yorkshire motorways a sampling procedure was used and the data for the first 7 days of each month were analyzed. In Lancashire all records for each Saturday and Sunday between July 17 and September 26 were analyzed. The number of reports of disabled vehicles received during these periods is given in Table 1 for West Yorkshire motorways and Table 2 for Lancashire motorways.

DAILY AND HOURLY VARIATIONS IN DISABLEMENTS

Table 2 also gives the effect of the day of the week on disablements on Lancashire motorways. In the early part of the summer-vacation period more disablements occurred on Saturdays than on Sundays mainly because of higher traffic volumes on Saturdays. For the West Yorkshire motorways, where leisure traffic is a very small portion of total flow, the average proportion of disablements occurring on any given day is as follows:

Day	Percentage
Sunday	11.48
Monday	14.83
Tuesday	15.38
Wednesday	14.31
Thursday	14.20
Friday	17.77
Saturday	12.03

In evaluating any disabled vehicle location-and-aid system, one must know the distribution of vehicle disablements throughout the day, and Table 3 gives this distribution for weekday traffic on M1 in West Yorkshire and for Saturday and Sunday traffic on Lancashire motorways. These hourly variations in reported disablements are shown in Figures 2, 3, and 4. It is interesting to note the dual peaks in the M1 weekday pattern (Fig. 2), which is characteristic of a highway where flow is influenced by commuting. For Saturday and Sunday flow (Figs. 3 and 4), the peaks are those that would be expected on a highway carrying a large proportion of weekend holiday traffic.

Figure 1. Motorway sections studied.

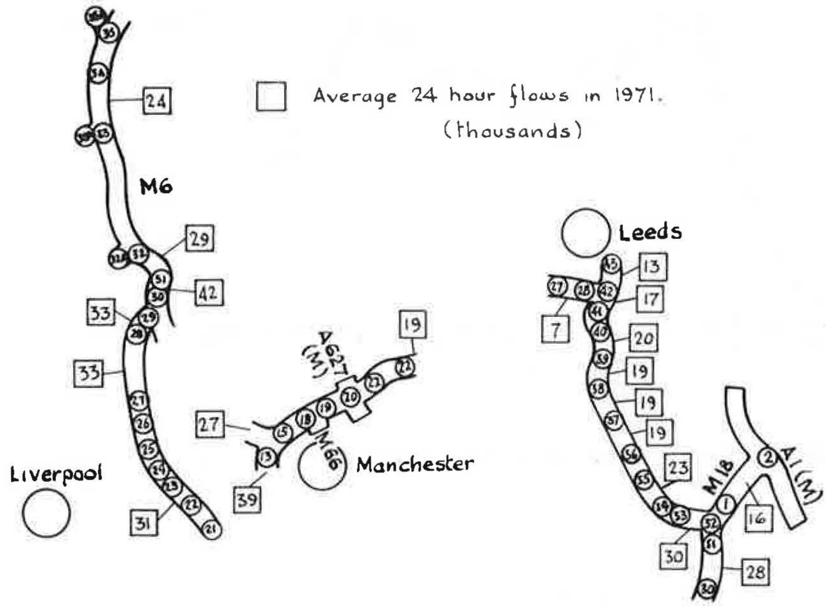


Table 1. Reported disabled vehicles on West Yorkshire motorways.

Time	M1	M18	M62	A1(M)
1971				
October	1,071	264	193	242
November	1,138	198	203	167
December	1,034	164	198	170
1972				
January	1,135	195	210	198
February	1,059	175	205	193
March	1,135	198	217	216
April	1,018	197	223	198

Table 2. Reported disabled vehicles on Lancashire motorways, 1971.

Date	Disablements	Date	Disablements
July 17[a]	177	August 22[b]	144
July 18[b]	147	August 28[a]	179
July 24[a]	183	August 29[b]	152
July 25[b]	147	September 4[a]	178
July 31[a]	174	September 5[b]	167
August 1[b]	142	September 11[a]	150
August 7[a]	178	September 12[b]	169
August 8[b]	171	September 18[a]	142
August 14[a]	150	September 19[b]	151
August 15[b]	142	September 25[a]	133
August 21[a]	158	September 26[b]	114

[a]Saturday. [b]Sunday.

Table 3. Hourly distribution of disablements for the entire study period.

Hour of Day	Disablement Percentage: M1 Weekdays	Lancashire Motorways: Saturdays	Lancashire Motorways: Sundays	Hour of Day	Disablement Percentage: M1 Weekdays	Lancashire Motorways: Saturdays	Lancashire Motorways: Sundays
1	1.14	2.50	2.23	13	5.23	8.02	6.42
2	1.21	1.86	1.35	14	6.06	7.12	6.49
3	0.53	1.03	1.01	15	6.52	7.76	6.35
4	0.61	0.58	0.74	16	6.67	7.76	8.18
5	0.53	0.90	0.47	17	7.42	7.18	7.03
6	0.68	0.71	0.47	18	8.41	7.12	7.23
7	1.67	1.60	0.95	19	6.59	5.58	6.76
8	3.94	1.54	0.95	20	4.47	4.68	7.64
9	7.80	3.40	1.55	21	3.26	4.11	5.81
10	8.41	3.85	2.36	22	2.27	3.34	6.22
11	7.05	7.31	5.00	23	2.50	2.68	4.19
12	5.53	7.25	6.89	24	1.52	2.12	3.72

Figure 2. Distribution of vehicle disablements and traffic flow on M1 on weekdays.

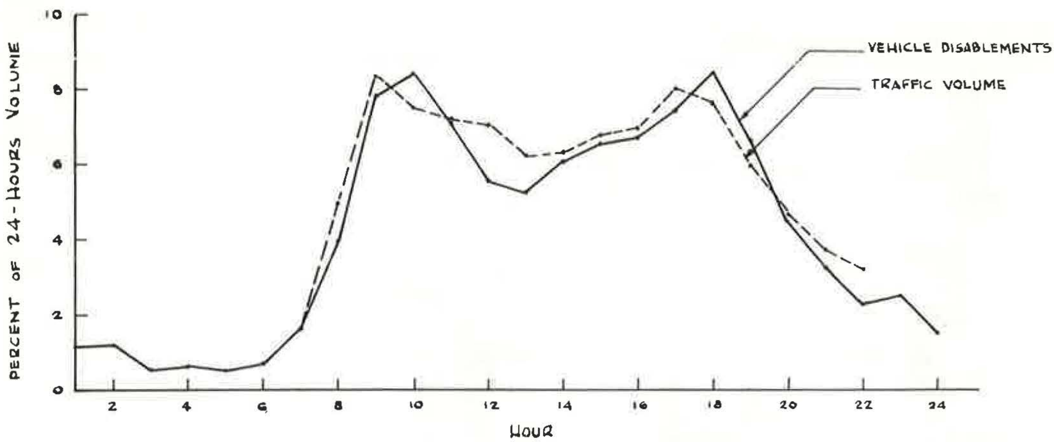


Figure 3. Comparison of disablements and traffic volume on M6 on Saturdays.

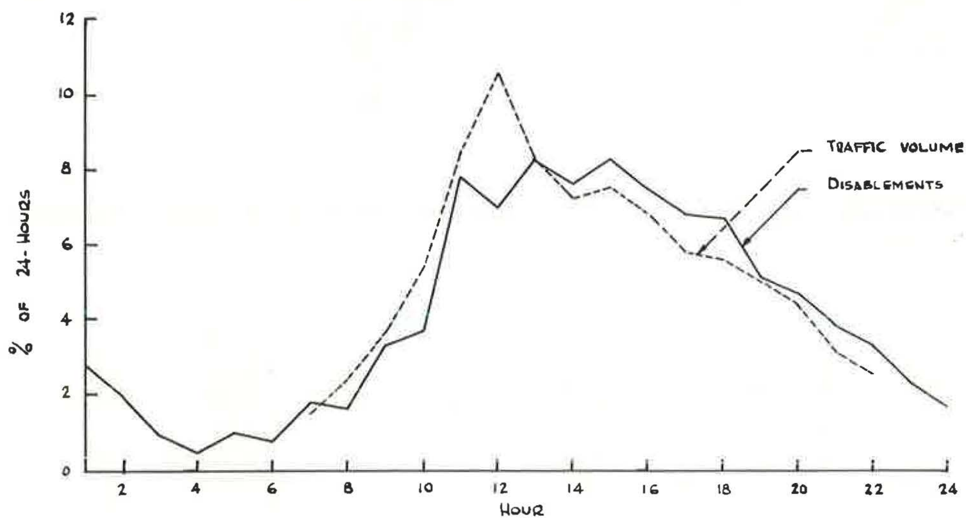
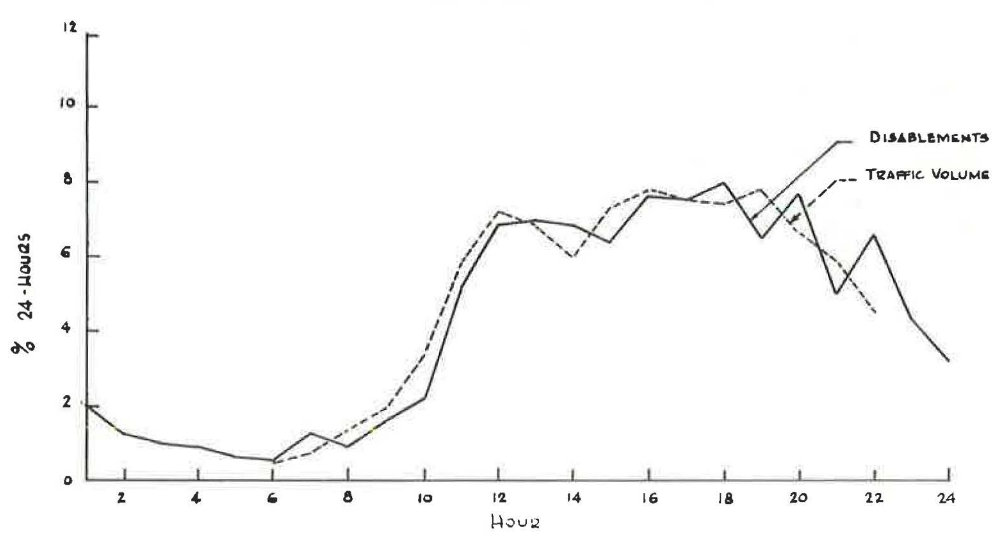


Figure 4. Comparison of disablements and traffic volume on M6 on Sundays.



DISABLEMENTS AND TRAFFIC VOLUME

The number of reported disablements is a function of the number of vehicles on the road. The factor of interest is the disablement rate expressed as disablements per vehicle unit of length. It was thus necessary to relate the reported disablements to traffic flow by using expanded 16-hour traffic counts. Variations in mean hourly traffic flow for the 2 motorway networks selected for study are shown in Figures 2, 3, and 4, and the close correlation between disablements and flow is apparent.

DISABLEMENT RATE

Disablement rate, expressed as reported disablements per million vehicle miles (vehicle kilometers), is an important factor in the design or evaluation of any disabled vehicle location-and-aid system for limited-access highways. Using data from M1 in Yorkshire for weekdays and Lancashire motorways for weekends, we found the following:

Time	Rate	r
Weekday	0.00005	0.78
Saturday	0.00004	0.73
Sunday	0.00004	0.85

The slightly lower values for recreational flows can be explained by the better climatic conditions that prevailed from July through September 1971. Kuprijanow (2) reported comparable rates.

AGE OF DISABLED VEHICLES

Disabled vehicle age was extracted from the emergency telephone call records. The age of the vehicle was assumed to be the date of first registration of the vehicle. The percentages of disabled passenger cars and commercial vehicles in each age group are given in Table 4. Although no conclusions can be drawn about the relative disablement rates of vehicles of different ages because age distribution of vehicles on motorways is not known, it can be seen that vehicles reported as being disabled during the weekend period in Lancashire are older than those reported disabled in Yorkshire. For commercial vehicles the difference is approximately 1 year. This difference in age can be expected when one motorway system carries mainly business and commercial traffic and the other carries mainly recreational traffic. It is interesting to note that commercial vehicles also had an older age distribution because of the number of vans and light trucks that are used for private purposes.

CAUSES OF VEHICLE DISABLEMENT

Callers on the emergency telephone system are asked to try to identify the cause of the disablement, and, although it has not proved possible to check either the accuracy of the diagnosis or whether repairs on the emergency lane were possible, these initial reports are an indication of the faults that do occur. Table 5 gives the suspected causes of disablement and their distribution. The relative similarity between suspected faults on both Yorkshire and Lancashire motorways is clearly shown.

A further investigation was made into the relationship between reported type of fault and the vehicle age for the Lancashire motorway. The resulting percentage of reported faults and disabled vehicle age are given in Table 6.

Although it is not possible to comment on how liable vehicles of certain ages are to become disabled with certain faults (because the age distribution of all vehicles on the

Table 4. Percentage distribution of ages of disabled vehicles.

	Yorkshire Motorways		Lancashire Motorways	
Years Since First Registration	Passenger Cars	Commercial Vehicles	Passenger Cars	Commercial Vehicles
0 to 1	6.8	6.2	1.0	0.7
1 to 2	13.9	15.3	6.0	8.3
2 to 3	12.7	16.7	7.3	15.4
3 to 4	12.2	14.4	9.4	10.5
4 to 5	7.6	9.6	12.5	14.7
5 to 6	9.9	13.6	9.9	11.5
6 to 7	9.2	9.0	9.6	6.6
7 to 8	5.2	4.1	10.4	7.6
8 to 9	8.9	6.3	7.4	5.4
9 or more	13.6	4.8	26.5	19.3

Table 5. Distribution of suspected causes of disablements.

	Yorkshire, All Vehicles		Lancashire Cars		Lancashire Goods	
Suspected Fault	Number	Percent	Number	Percent	Number	Percent
Lack of fuel	383	14.08	304	11.56	57	13.94
Flat tire or wheel trouble	289	10.63	263	10.00	56	13.69
Water required	81	2.98	38	1.44	5	1.23
Mechanical failure	1,079	39.70	1,232	46.88	181	44.01
Mechanical-electrical failure	444	16.34	416	15.82	43	10.51
Electrical failure	213	7.84	186	7.07	23	5.62
Fuel-mechanical or fuel-electrical problems	171	6.29	119	4.53	35	8.56
Brake failure	17	0.63	22	0.84	3	0.73
Lack of oil	40	1.47	47	1.78	7	1.71
Driver illness	1	0.04	2	0.08	0	0

Table 6. Percentage distribution of causes of disablements on Lancashire motorways by vehicle age.

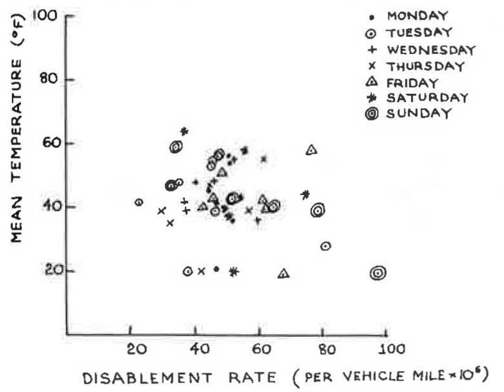
Vehicle Age (years)	Lack of Fuel	Flat Tire	Water Required	Mechanical Failure	Mechanical-Electrical Failure	Electrical Failure	Fuel-Mechanical or Fuel-Electrical Problems	Brake Failure	Lack of Oil	Driver Illness
0 to 1	10.0	6.7	0	23.3	23.3	13.3	20.0	0	0	3.4
1 to 2	20.9	8.4	0.5	41.4	13.1	4.7	7.9	1.0	2.1	0
2 to 3	18.4	10.2	0.8	37.9	18.4	5.5	7.4	0.8	0.6	0
3 to 4	8.2	11.7	2.1	52.9	12.7	6.9	3.4	0.7	1.4	0
4 to 5	17.7	11.0	1.5	41.0	15.4	7.2	4.6	0.3	1.0	0.3
5 to 6	15.7	9.5	1.3	48.0	13.4	4.9	4.2	0.7	2.0	0.3
6 to 7	7.2	8.6	2.5	51.4	15.8	7.2	5.0	1.1	1.2	0
7 to 8	8.9	10.6	1.0	48.2	14.5	8.3	4.0	1.3	3.2	0
8 to 9	6.5	9.7	1.4	52.2	13.0	7.9	4.6	0.5	4.2	0
9 or more	8.9	11.8	1.4	47.1	16.3	7.3	4.7	1.0	1.5	0

Table 7. Ranking of reported disablement causes on the Lancashire motorways.

Vehicle Age (years)	Lack of Fuel	Flat Tire	Water Required	Mechanical Failure	Mechanical-Electrical Failure	Electrical Failure	Fuel-Mechanical or Fuel-Electrical Problems	Brake Failure	Lack of Oil	Driver Illness
0 to 1	5	6		1	1	4	3			7
1 to 2	2	4	9	1	3	6	5	8	7	
2 to 3	2	4	7	1	2	6	5	7	9	
3 to 4	4	3	8	1	2	5	6	7	9	
4 to 5	2	4	7	1	3	5	6	9	8	9
5 to 6	2	4	8	1	3	5	6	9	7	10
6 to 7	4	3	7	1	2	4	6	9	8	
7 to 8	3	2	8	1	2	4	5	7	6	
8 to 9	5	3	8	1	2	4	6	9	7	
9 or more	4	3	8	1	2	5	6	9	7	

Note: More than 1 cause can share the same ranking.

Figure 5. Comparison of mean temperature and breakdown rate on M1.



Note: 1 breakdown/vehicle mile = 0.62 breakdown/vehicle km.

motorways is not known), it is possible to comment on how liable vehicles of certain ages are to develop certain suspected disabling faults. To illustrate the relative importance of the various causes of disablements, we have prepared the rankings given in Table 7. It is interesting to note that vehicle age has little effect on the distribution of disabling faults. As expected, for vehicles of any given age, the primary suspected cause of disablement is mechanical failure. Mechanical-electrical failure and lack of fuel are the second most frequent causes.

MEMBERSHIP IN MOTORING ORGANIZATIONS

In Great Britain, membership in the AA and the RAC has many advantages when vehicle disablement occurs. These organizations will provide on-the-spot assistance to disabled vehicles and if necessary will tow the disabled vehicle from the motorway. When a disabled vehicle report is received by the police control room the disabled driver is asked if he or she is a member of either of these organizations. In this study, 42.57 percent of the drivers of disabled cars in Yorkshire were club members, and 62.9 percent in Lancashire were members. As expected, the percentage was found to be higher in the Lancashire motorway study because of the largely recreational nature of the traffic.

EFFECT OF WEATHER ON BREAKDOWN RATE

Climatic conditions can be expected to influence breakdown rate, but, in a temperate climate such as Great Britain's, climatic extremes rarely occur. Expected extreme conditions would most likely be heavy rainfall and snowfall, icing of the road surface, and high temperatures.

When precipitation rates are high, the area of rainfall usually is localized. Heavy snowfall and severe icing are infrequent problems on the motorways considered in this study, and under these conditions the incidence of disabled vehicles is a function of the highway maintenance operations of salting, sanding, and clearing. For these reasons vehicle disablements due to precipitation and severe icing are not considered in this paper. Temperature variations remain to be considered, and, because temperature records were available for the region of the Yorkshire motorway, an attempt was made to determine the correlation between temperature and breakdown rate. The results of the analysis are shown in Figure 5 where it can be seen that there is little relationship between ambient temperatures and the rate of disabled vehicle reports. This is not an unexpected result for the generally temperate climate of Great Britain.

CONCLUSIONS

This paper investigated some of the fundamental aspects of the disabled vehicle problem on limited-access highways. It was found that only a small difference existed between the rate of vehicles becoming disabled on Yorkshire motorways where a high proportion of the flow consisted of business and commercial traffic and the rate of those becoming disabled on Lancashire motorways where a high proportion of the flow was recreational.

Suspected causes of a vehicle becoming disabled were investigated. Mechanical-electrical problems and lack of fuel were found to be significant problems in causing disablement. Climatic conditions as measured by ambient temperature were found not to have any significant effect on vehicle disablement.

This study is the first stage in the assessment of the benefits of disabled vehicle location-and-aid systems on limited-access highways.

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OPPORTUNITIES FOR RESEARCH ON ROADSIDE REST AREAS AND THEIR ROLE IN MOTORIST SERVICE

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Today's traveler has begun to look to rest areas as far more than a "wide spot in the road" on which to pull off and relax. Particularly on Interstate highways, today's rest areas must be equipped to satisfy more than the need for rest. They must provide clean, well-lighted sanitary facilities, picnic and parking areas, safe drinking water, telephones, motorist information, and an ever growing list of support services. Other needs of motorists will have to be defined, and all needs will have to be quantified. Various classes of motorists, such as long distance truckers, casual travelers, tourists, or families on vacation, may have differing needs. Methods of best satisfying their needs will have to be provided. Another facet of the problem is the rest area and how it can be most effectively used to meet motorists' needs. Operation and maintenance problems are becoming increasingly complicated and costly. The need to clean and service the rest area, prevent vandalism, and operate sophisticated sewage-treatment and drinking-water purification equipment has created additional problems. An information gap has developed that motorist information systems at rest areas may help to fill. Research can play an important role in furnishing solutions to these problems.

•THE UNITED STATES has the most extensive highway system in the world. There are over 36,000 miles (58 000 km) of completed Interstate highways alone. Although some look disparagingly upon the highway system, it has brought to the country wealth and opportunity, and its social impact has been equally as great. The natural and historic scenic wonders of our country are now available to everyone. Because of the highway network and the diversity of relatively inexpensive transportation, the average family can vacation almost anywhere in the country.

The limited-access Interstate system has shortened travel time and distance. In 1950, it took 70 h at 40 miles/h (64 km/h) to cross the country. Today, even at 55 miles/h (89 km/h), the same trip can be made in 50 h. The Interstate system has simplified cross-country navigation and has made travel safer. The Interstate system was estimated to have prevented 7,500 fatalities and 347,000 injuries in 1975 (1, p. I-2). The aim to get travelers to their destinations more quickly, more easily, and more safely has been accomplished. But much work remains.

REST AREA PROGRESS

One of the greatest advances associated with highway travel is the development of the rest area. Thirty years ago a picnic table, a trash can, and a bush constituted a rest area. For the harried family or weary driver, there was little opportunity to escape from the highway environment. In most instances the picnic lunch was eaten 10 ft (3 m) from passing vehicles.

The early roadside parks have considerably evolved from little more than wide spots in the road to today's modern tourist information centers that have many of the

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comforts of home. The impetus for rest area development began with a provision of the Federal-Aid Highway Act of 1938. This act stated that "the States, with the aid of Federal funds, may include... such sanitary and other facilities as may be deemed necessary to provide for the suitable accommodations of the public." The objective of this legislation was to provide for increased motorist safety and comfort through the provision of occasional facilities for stopping and resting. With it was born the safety rest area (2, p. 38). Although the basic premise of the rest area is safety, motorist comfort and service are essential ingredients. Subsequent Federal-Aid Highway Acts, including one that established the Highway Trust Fund and the Highway Beautification Act of 1965, fostered the advancement and improvement of rest areas through funding and stimulus of rest area development concurrent with highway development (3, pp. 1-2).

In the early stages of rest area development, some states limited facilities to picnic tables and trash barrels at widened shoulder turnouts along the roadside. Others developed reasonably complete facilities with pit or vault privies, parking, picnic areas, and landscaping. The original purpose for rest areas was to provide safety and service to motorists, and that is still basically the purpose today. Expanded travel and increased rest area use have demonstrated a favorable response to rest areas. That response and the expressed desires of motorists for services guide the development of rest today (4). According to the FHWA's Office of Highway Planning there are today over 7,700 rest areas, 1,300 of which are on the Interstate system.

Growth in safety rest areas began with the Interstate Highway Act of 1956. As an extensive network of rest areas on Interstate highways developed, the limitations of existing facilities became apparent. These deficiencies created the need for research to

1. Determine the capacity of a rest area,
2. Formulate techniques to predict the number of people who would use a given facility during different times of the year, and
3. Evolve more representative criteria for the selection of rest area locations.

With the decision by the federal government in the fall of 1965 to participate in the cost of constructing sanitary facilities in rest areas, research in neighboring fields became absolutely necessary to properly select, design, construct, and maintain complete rest areas. One of the first steps in a rest area research program is to obtain a good knowledge of the highway user. Regrettably some rest area facilities do not reflect the broad range of motorist needs. We have opened the door to travelers; now we must determine who they are, what they need, and how they can be served.

USE OF TODAY'S REST AREAS

Motorists look for more than an opportunity to rest in the safety rest areas. They expect clean and well-lighted sanitary facilities, ample shaded picnic areas, scenic landscaping, sufficient parking facilities, telephones, litter receptacles, and informational displays (4). So that rest areas will be able to adequately serve motorists' needs, the Federally Coordinated Program for Research and Development in Highway Transportation (FCP) has under way a research project concerning rest areas. Currently, research studies are being conducted on rest area water supply and waste disposal requirements and sewage treatment technology that are aimed at improving these essential motorist services.

Nearly 95 percent of all persons stopping at rest areas make use of the sanitary facilities. According to the Federal Highway Administration's Office of Highway Planning nearly 60 percent of Interstate rest areas provide toilet facilities. To provide adequate rest room facilities, one must have basic information to determine what portion of those people traveling stop at a rest area and what the relationships are among distance from adjacent areas, towns, and types of travelers. These data are essential for the physical layout and design of rest rooms and facilities and are basic for providing adequate water supplies and sewage treatment facilities. Information shows that the bases of past design are not always adequate for today's use (5). Research into the technology of rest area sewage treatment is needed to respond to the requirements of the Water Pollution Control Act (Public Law 92-500) and to ensure adequate protection of public health and safety.

Providing safe and sufficient drinking water for rest areas is another problem where research is needed. With the increased mobility of the American public, there has developed a potential public health hazard. An estimated 1 million people per day use water supply systems at rest areas along the Interstate Highway System. Thirty-five percent of Interstate rest areas provide drinking water. Treatment for this water supply ranges from none at all to extensive treatment fully capable of ensuring the health and safety of travelers (6). Legislation has passed Congress recently that will require the treatment of all public water supplies. Numerous rest areas are located in areas where available water is unfit for human consumption because of contamination. Research to study techniques that will ensure the quantity and quality of public drinking water supplies at rest areas is contemplated as a part of this year's FCP.

A rest area is more than parking spaces and rest rooms. The components that make up a rest area vary from one area to another, and there is a need for research into component serviceability, ability to function, and cost effectiveness (7). Because of rising construction, operation, and maintenance costs, rest area designers and operators must be provided with information on the extent to which components provide the intended services with minimum maintenance requirements.

The objective of a recent FHWA contract, Cost-Effective Rest Area Components, will be development of a compendium of information on the ability to function and cost effectiveness of rest area components. It will provide component alternatives for use in the design, renovation, operation, and maintenance of rest areas.

Vandalism is a problem at some rest areas. Research into what motivates vandals and how to reduce and prevent vandalism is needed not just for rest areas or highway facilities, but for all public facilities.

INFORMATION PROBLEMS

As specified under parts 655 and 705, title 23 of the U.S. Code, severe limitations have been placed on outdoor advertising and specific "information" in the interest of the traveling public. In essence, information is limited to signs at interchanges to indicate gas, food, lodging, and camping. However, in creating an uncluttered, aesthetically pleasing view for travelers, we have isolated them on the Interstate highway. Although it is difficult to argue with increasing capacity, speeds, and safety and beautifying the highway environment, the isolation of the Interstate highway creates serious problems for the motorist in obtaining information on both public and commercial facilities.

The blue and white food and lodging signs call for quick decisions by motorists. The signs fail to inform the driver how far away restaurants are and when they are open. So drivers sometimes take a 20-min ride in the country and return to the Interstate.

A new approach now being evaluated in Virginia and Oregon provides signs at exits with logos for gas stations, restaurants, motels, and camping grounds (8). To facilitate reading, each sign can carry logos for no more than 6 gas stations or 4 motels, restaurants, and campgrounds. Firms must meet certain highway department criteria, and sign priority is based on distance from the exit. This solution still does not offer motorists an opportunity to plan their trips, and decisions still must be made in a matter of seconds. Interstate highway travelers need information on road conditions and the location of hospitals and emergency centers; police stations; hotels that accept pets; and scenic, historic, and amusement areas. These information gaps are the areas we need to address in our research. The most difficult aspect of the problem is ascertaining the method by which travel information is transmitted to the motorist. Although a number of methods might come to mind, not all are economically feasible or practical for motorists to use.

Roadside rest areas have potential for communicating with the motorist. Many states have taken advantage of this to provide a variety of information to the motorist through tourist information centers. Much remains to be done in this area, however.

RESEARCH

To accomplish the goals set in rest area research and development, research should focus on establishing and maintaining high standards of water quality and development of sewage treatment facilities that not only will meet government standards but also will be cost effective and easy to maintain. Research should be directed to those areas dictated by the evolutionary development of rest area facilities. A genuine need exists to improve motorist information services on the Interstate system; therefore, a concerted effort should be made in this area.

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AID TO DISABLED MOTORISTS: RESPONSIVE ELECTRONIC VEHICULAR INSTRUMENTATION SYSTEM

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The advent of low-cost, highly reliable, integrated circuits has made feasible the design and implementation of an electronic system to aid disabled motorists. A responsive electronic vehicular instrumentation system (REVIS) is presented that detects all highway incidents independent of traffic-flow rate. A cost-benefit analysis reveals that REVIS is superior to the highway patrol on limited-access rural highways.

•ONE of the greatest losses of efficiency experienced on urban highways results from disabled vehicles that either are on the shoulder of the road or block a moving traffic lane. The congestion and accompanying delay for other vehicles that result from a reduction in highway service volume are frequently more significant than the incident that causes the congestion. A 2-year study of highway incidents on the Gulf Freeway in Houston, Texas, showed that a 1-lane blockage by a minor accident or stall reduced flow by 50 percent even though only 33 percent of the road was blocked (1). An incident that blocked 2 lanes reduced flow by 79 percent. So freeway incidents create a reduction in service volume that is disproportionate to the physical reduction of the facility. The effect of a 1-lane blockage on a heavily traveled highway is shown in Figure 1. From this example, a reduction of 15 min in the time required for incident detection or police response results in significant savings of vehicle hours.

In recent years there has been growing interest and research activity among state and federal highway agencies to find cost-effective methods to quickly detect, identify, and respond to highway incidents (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24). Motorist-initiated and automatic systems of detection have been developed to complement the police patrol (22, 23). The most advanced system of automatic electronic detection of highway incidents has been placed in operation on the 42-mile (67.6-km) triangle of the San Diego, Santa Monica, and Harbor Freeways in Los Angeles (2). This system detects the flow disruption produced by a highway incident by electronically monitoring the volume and occupancy in each traffic lane every 0.5 mile (0.81 km); time averages are updated every 30 s. Occupancy is defined as the percentage of time that any vehicle is over an induction-loop detector buried in the road. When gradients in occupancy and volume between adjacent highway sections are calculated in real time and are found to exceed predetermined threshold values, a light on the panel map display board located in the control center is activated. A dispatcher may then call a helicopter to make an on-site inspection of the area and transmit a television signal back to the control center. After evaluating the incident, the dispatcher calls an appropriate aid vehicle into action. A similar system is being designed for the northern corridor of the New Jersey Turnpike.

An essential feature of the Los Angeles system is that some macroscopic disruption in the traffic flow must occur for an incident to be detected. On the Los Angeles triangle, which sustains 700,000 vehicles daily, this strategy for incident detection works excellently because the traffic model is valid. The primary beneficiary of this system is the driver upstream of the incident whose delay has been reduced greatly.

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Approximately 85 percent of the planned 42,500-mile (68 425-km) Interstate Highway System lies in rural areas where the strategy of detecting macroscopic changes in the traffic flow cannot work because the flow may be as small as 1 vehicle/h. In the event of a vehicle failure, an accident, or motorist illness, the motorist is dependent on assistance from other passing motorists or police aid. Such incidents on a rural highway may have hazardous consequences because both the detection time and distance to the nearest aid vehicle are significantly greater than they are on an urban highway. Call-box systems have been put into operation on many rural highways to lower incident-detection time (5, 6, 8, 20); the success of such systems is unclear. Goolsby and McCasland (5) reported that 38 percent of stopped motorists who were interviewed were unaware of the call-box system in operation on the Gulf Freeway. When call-box systems become more common, greater public awareness will exist. However, their effectiveness is still greatly dependent on prevailing weather conditions. Most rural highways therefore today still use police patrols to detect incidents.

Ability of the highway patrol to supply emergency service is inversely proportional to the population density of the area (15). For example there are currently more than 3,000 miles (4 830 km) of Interstate highway in operation in Texas. Assuming that patrol vehicles cruise the highways at 60 miles/h (96.6 km/h) and that patrols are designed ideally to have no overlap, the resultant patrol frequency past a given random point on a road is less than 1 per hour. The actual patrol frequency on an arbitrarily chosen section of Interstate highway is less than 1 pass every 4 hours (15). On I-15 between the California-Nevada border and Barstow, the highway patrol has 1 vehicle patrolling the eastern 65 miles (104.6 km) of the highway 16 hours per day. The adjacent patrol covers 45 miles (72.4 km) using 1 car 12 hours per day. Improved methods of incident detection and means for identifying the character of an incident are necessary (31).

The deficiencies in incident-detection systems are overcome in a responsive electronic vehicular instrumentation system (REVIS). The advent of low-cost and reliable, medium-scale, integrated circuits has made it possible to design an incident-detection system that operates on both rural and urban limited-access highways and is more cost effective than police patrols on rural limited-access highways.

REVIS DESCRIPTION AND OPERATION

The operation of REVIS is predicated on the assumption that each vehicle on an instrumented road is equipped with a data transponder capable of transceiving data between the vehicle and in-road detectors. The transponders consist of a mass-produced integrated circuit, planar power source, and an antenna that may be assembled on a Hollerith card. The transponder system, shown in Figure 2, is designed to last at least 1 year and is intended to operate in the 450 to 470 MHz band allocated for motorist-aid systems. Recently, Klensch et al. (30) constructed and tested a microwave, automatic, vehicular-identification system demonstrating the feasibility of this concept.

If a different class of transponder is issued to passenger vehicles, trucks, buses, vehicles with dangerous cargo, and emergency or patrol vehicles, the system can identify the type of vehicle involved in an incident, thereby allowing the operating agency to respond in an appropriate manner.

REVIS uses spatial multiplexing to separate one vehicle's signal from another's, thereby overcoming the major objection to in-car radio techniques previously studied by Cranston and Kell (23). A typical detector site, shown in Figure 3, consists of in-road induction-loop detectors immediately upstream from an ultra high frequency (UHF) antenna. The presence of a vehicle over the induction loop initiates a sequence leading to the exchange of data between the vehicle's data register and the roadside transceiver. In other words, when a vehicle's presence is sensed by a loop detector, the UHF antenna starts broadcasting an enabling code that triggers the vehicle's transponder to empty the contents of its data register and receive new data from the roadside transceiver. Should a vehicle transponder totally malfunction, the change in loop inductance would not be accompanied by the UHF data. This would indicate the

Figure 1. Effect of increased response time on delay produced by 1-lane blockage.

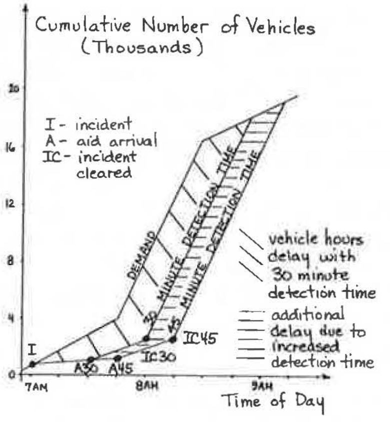


Figure 2. Vehicle transceiver on a toll card or inspection sticker.

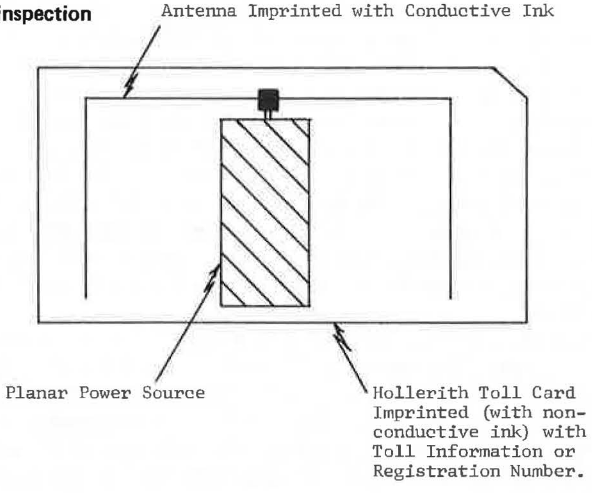
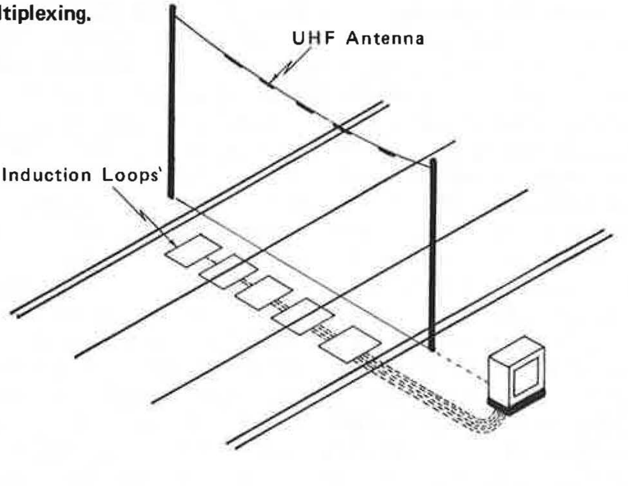


Figure 3. Typical detector site with spatial multiplexing.



nature of the error. One such error per interdetector space is self-correcting because the presence of a detected vehicle with no data is sufficient to identify the malfunctioning vehicle. Increasing the number of malfunctioning transceivers in interdetector space decreases the effectiveness of the system to the level of a pure occupancy system. The presence of detectors between lanes permits a valid data interchange should a vehicle be straddling 2 lanes when passing the detector site.

The operation of a type-0 REVIS is shown in Figure 4. Each detector has an induction loop and a UHF antenna in each of the m lanes, an environmental detector connected to the detector electronics, a buffer, and a communications modem. Communication to the central processing unit (cpu) from an ith-detector lane is accomplished over 1 full duplex line; each lane is independently addressable as a single drop line in the detector electronics. By using this technique one is able to reduce the effective number of digital input lines by a factor of m while requiring a corresponding decrease in the cpu-cycle time.

The operation of REVIS under normal conditions (no disabled vehicles and no unsafe speeding) is shown in Figure 5 for a single vehicle, α. On entering the highway, α encounters detector i_0, which loads an identification code into the vehicle's data register. (The same bit stream may be used simultaneously to identify another vehicle within a different interdetector space along the highway.) Because computer memories commonly use 8-bit bytes, we propose the use of a 16-bit code to permit 16,384 vehicles and 4 vehicle classes to be uniquely encoded in each interdetector space. On a 4-lane, limited-access, rural Interstate highway an interdetector spacing approaching 20 miles (32.2 km) would guarantee unique identification.

Real-time priority coding of 2 vehicles by REVIS is shown in Figure 6. The algorithm used assigns the lowest available number in an interdetector space to the vehicle entering the space. A vehicle's number becomes available for reuse when the vehicle exits from the interdetector space. Because the numbers being processed by the computer cannot identify the vehicle after it exits the highway, invasion of privacy is not possible.

The information received from the vehicle's data register is processed by the REVIS algorithm shown in Figure 7. The 16-bit identification code is transmitted to the cpu, which computes a safe arrival interval for α at the next detector site. This calculation is performed in real time and is based on current data from the traffic stream. The results, a minimum and maximum time of safe arrival at the next downstream detector site, are loaded into byte 3 and byte 4 memory locations respectively.

A single byte (8 bits) is able to represent time with a precision of 1 part in 256. The selection of the time unit corresponding to the least significant bit is dependent on interdetector spacing. For example, when the least significant bit represents 5 s, the maximum possible content of the byte would be 1,280 s (21 min and 20 s). On the distance-time diagram (Fig. 5) the calculation result appears as the safe arrival interval (SAI), α_{i+1}, which allows the construction of 2 broken lines whose slopes can be interpreted as the maximum safe speed and the minimum anticipated speed for current traffic conditions. After arriving at D_{i+1} within the safe arrival interval, the vehicle is no longer monitored within the i - (i + 1) interdetector space, and the SAI at D_{i+2} is generated. Under the conditions shown in Figure 5, the vehicle is completely monitored while on the highway without any required external action. When α properly leaves the highway at either an exit or rest stop, its presence at the $(i + n)_0$ detector indicates that it no longer requires surveillance; its identification code no longer resides anywhere within the computer and becomes available for reuse.

The operation of REVIS under action-required conditions such as severe speeding or a vehicle incident is shown in Figure 8 for a single vehicle, β. On entering the highway, β encounters detector i_0, which enters an identification code into the vehicle's data register and begins its surveillance. Because the time of arrival of β at D_{i+1} is significantly less than the minimum for safe arrival, which indicates that β has committed a serious speeding violation, REVIS lists this event at the control console. The console operator may dispatch corrective enforcement if desirable or may warn the driver to reduce his or her speed by roadside light-matrix signs. β, if it had been warnedtwice, would adjust its speed at time $t_{\beta_{i+2}}$ to be within the speed limit. At t_{β_x},

Figure 4. Type-0 REVIS.

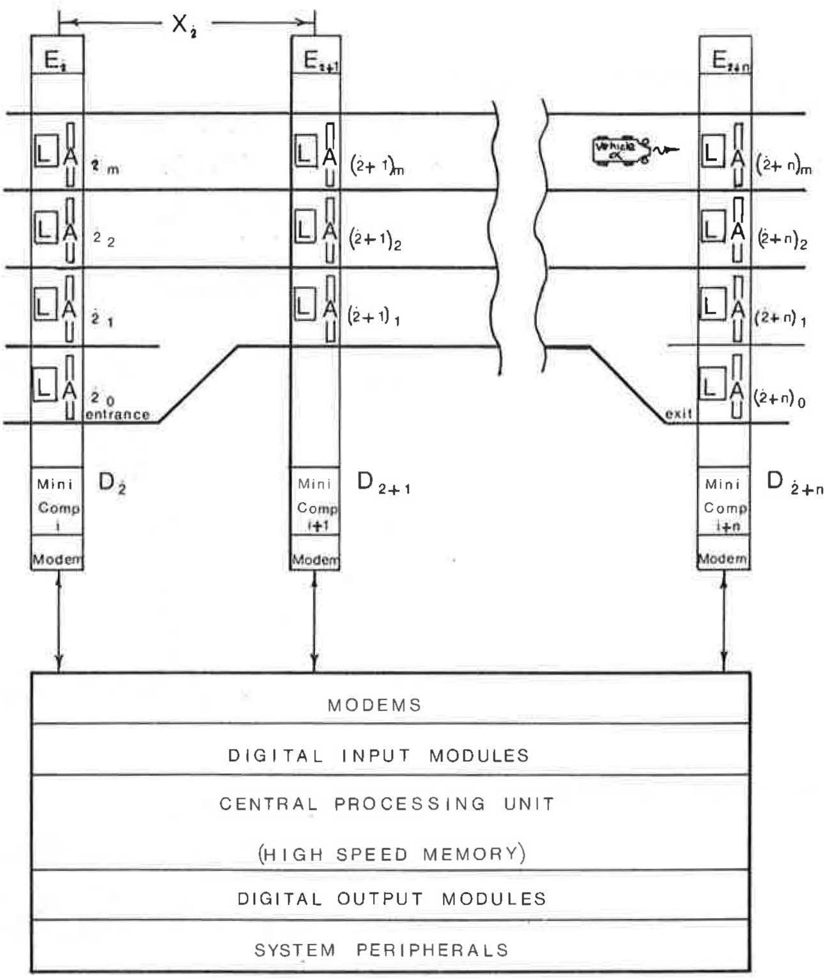


Figure 5. Distance-time diagram for operating under REVIS.

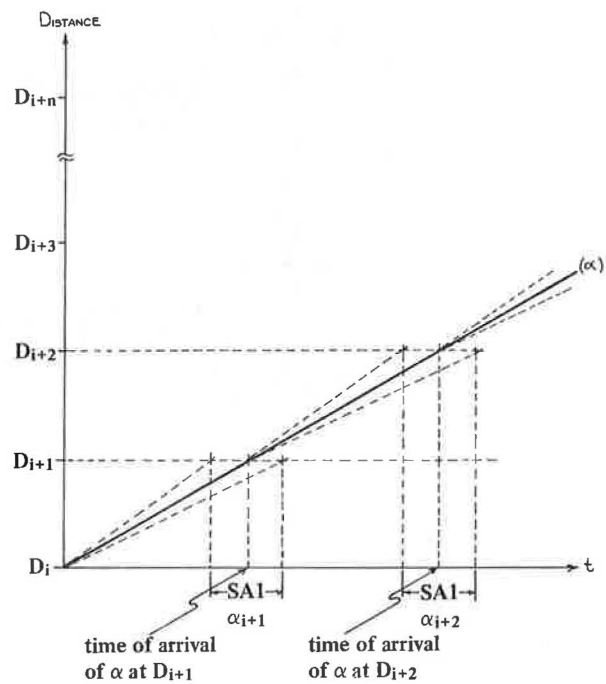


Figure 6. Priority coding of α and β operating under REVIS.

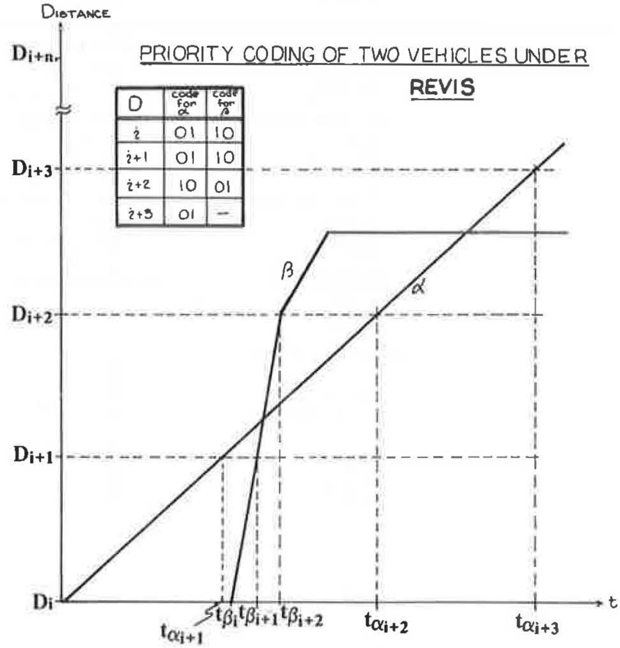
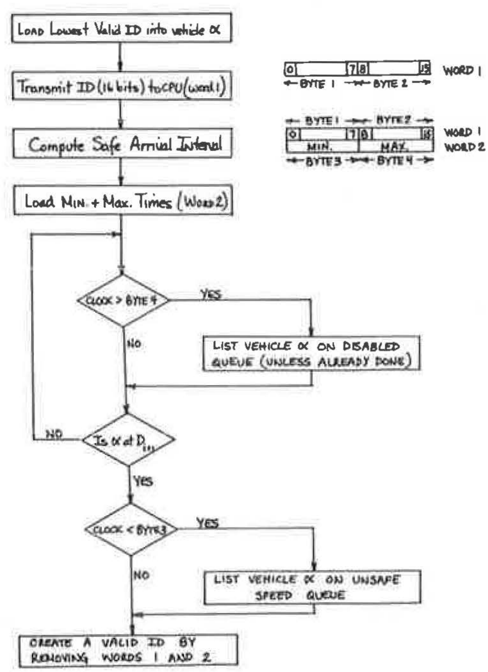


Figure 7. REVIS algorithm for data from α.



β was involved in an incident as indicated by the slope of the distance-time diagram becoming zero. When clock time exceeds the precomputed maximum SAI(β_{i+3}), β might be disabled, stopped, involved in an accident, or otherwise impaired as shown in Figure 8. The REVIS algorithm lists this occurrence at the control console. An aid vehicle is dispatched to the indicated location of the incident after waiting an additional time interval, T_D, based on a design trade-off between false alarm rate and level of service; that is, when T_D increases, the false alarm rate decreases and the incident-detection time increases. T_D, a design decision, is dependent on the class of the detected disabled vehicle, current traffic parameters, time of day, severity of the weather, and current availability of an aid vehicle.

COMPARISON OF REVIS TO CONVENTIONAL POLICE PATROL

In this section the annual operating cost and performance of a REVIS-equipped, 20-mile (32.2-km), 4-lane highway are compared to the annual operating cost and performance of a single police patrol vehicle performing a continuous tour of duty on the same highway segment. A digital simulation is used to estimate the operating cost and performance of both police patrol and REVIS. For both methods of incident detection, cost and performance are evaluated as a function of the average number of incidents per hour per mile, λ. The value of λ may be related to the other highway parameters; these parameters and their associated units are as follows (1 mile = 1.6 km; 1 ft = 0.3 m):

H_T = time headway in seconds,
V = vehicle speed in miles per hour,
H_D = distance headway in feet,
N = number of vehicles per mile per lane
$= 1 + \frac{5280}{H_D} = 1 + \frac{3600}{VH_T}$,
L = number of lanes,
ADT = average daily traffic, and
VMBI = vehicle miles between incidents.

λ is given as a function of the highway parameters:

$$\lambda = \left[1 + \frac{3600}{VH_T}\right]\left[\frac{VL}{VMBI}\right] \qquad (1)$$

The average number of accidents per million vehicle miles (vehicle kilometers) has been found empirically by Lundy (32) to be a function of the ADT from which the VMBI (vehicle kilometers between incidents) may be estimated. For a 4-lane highway, if one assumes that the number of accidents per million vehicle miles (vehicle kilometers) is 10 percent of the number of incidents per million vehicle miles (vehicle kilometers) and uses the regression line from Lundy (32), one can obtain VMBI as follows (1 mile = 1.6 km):

$$VMBI = \frac{10^6}{5.226 + (21.64)\,(10^{-5})\,ADT} \qquad (2)$$

In Table 1, λ is evaluated for traffic conditions ranging from heavy urban to light rural.

In digital simulation it is assumed that, spatially, incidents are uniformly distributed and, temporally, occur as a Poisson process with average λ. It is assumed that aid vehicles (police or REVIS) spend 15 min servicing each incident and that the REVIS vehicle responds immediately when the incident is detected ($T_D = 0$). Incidents are serviced in the order in which they are encountered spatially. The REVIS aid vehicle returns to its garage after 1 circular tour of the highway segment [40 miles (64.4 km) round trip] unless additional incidents have been detected while it is out on call. The policy of keeping the REVIS aid vehicle stationary in the garage will be shown to be cost effective for small λs.

The annual cost for police patrol may be written as

$$C_{\text{highway patrol}} = C_{\text{fixed annual}} + C_{\text{fuel}} \quad (3)$$

where C = cost. It is assumed that the fixed annual cost of administering, maintaining, and operating a police patrol vehicle 24 hours per day is $90,000. The fuel cost is taken as $0.50 per gallon (13.2 cents/liter). It costs $2.00 for a vehicle averaging 10 miles per gallon (4.25 km/liter) to make one 40-mile (64.4-km) trip. Equation 3 may therefore be rewritten as

$$C_{\text{highway patrol}} = \$90{,}000 + 2T \quad (4)$$

where T = number of trips that a patrol makes on the highway segment.

The cost structure assumed for a REVIS aid vehicle is

$$C_{\text{REVIS}} = \$15{,}000 + 10T + 3S \quad (5)$$

where S = number of services rendered by the aid vehicle. The fixed annual cost of $15,000 represents payment on a contractual basis for an aid-vehicle owner to be available 24 hours per day. A fee of $10 is paid to the aid-vehicle owner every time a 40-mile (64.4-km) round trip is completed. In addition, a $3 fee is paid for each service rendered.

The simulation results are shown in Figures 9 through 15. In Figure 9, the total number of incidents is a straight line passing through the origin. At low incident rates the number of trips per year for the highway patrol greatly exceeds the total number of incidents. However, for REVIS (with either 1 or 2 aid vehicles) more than 1 disabled vehicle is serviced per trip. At high incident rates, police patrols become increasingly efficient because aid vehicles spend more time servicing incidents than cruising the highway. At very high incident rates, both systems spend all of their time servicing incidents, and they behave equivalently.

From Figure 10 it may be observed that REVIS (with 1 aid vehicle) has a lower operating cost than does a police patrol for a λ of less than approximately 0.07. Thus, on limited-access rural highways REVIS detects incidents at substantially lower cost than does conventional police patrol. Under heavy urban traffic conditions conventional police patrol is less costly.

Comparable incident detection is obtained between police patrol and 1 REVIS aid vehicle, as shown in Figures 11 through 15. However, when 2 REVIS aid vehicles are available, the range of high performance for REVIS may be extended to higher incident rates at additional cost. At low incident rates, such as λ = 0.04, the cost of incident detection and rendering aid to disabled motorists for a REVIS system with 2 aid vehicles is lower and performance is better than with conventional police patrol. On a limited-access rural Interstate highway, REVIS aid vehicles perhaps could be distributed every 30 miles (48.3 km)—a configuration making the REVIS incident-detection system still more cost effective to operate.

Figure 8. Operation of REVIS under action-required conditions for β.

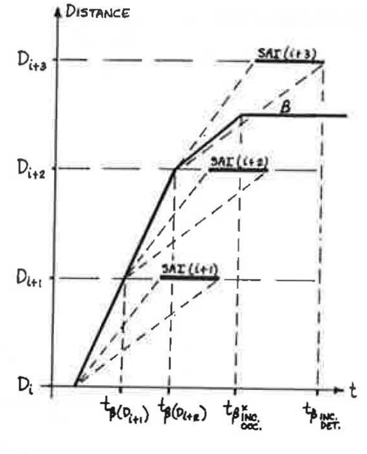


Table 1. Incident rate for various highway parameters.

Nature of Traffic	V	H_T	L	ADT[a]	VMBI	λ
Heavy urban	60	2	6	129,600	58,995	0.189
Moderate	55	4	6	64,800	87,342	0.066
Heavy rural	70	15	4	10,520	129,557	0.010
Rural	60	30	4	5,760	154,505	0.005
Light rural	60	60	4	2,880	170,965	0.003

Note: 1 mile = 1.6 km.

[a]ADT = $\frac{12 \times 3600 \times L}{H_T}$. It is assumed that the value of H_T prevails for 12 h per day.

Figure 9. Trips per year versus incident rate.

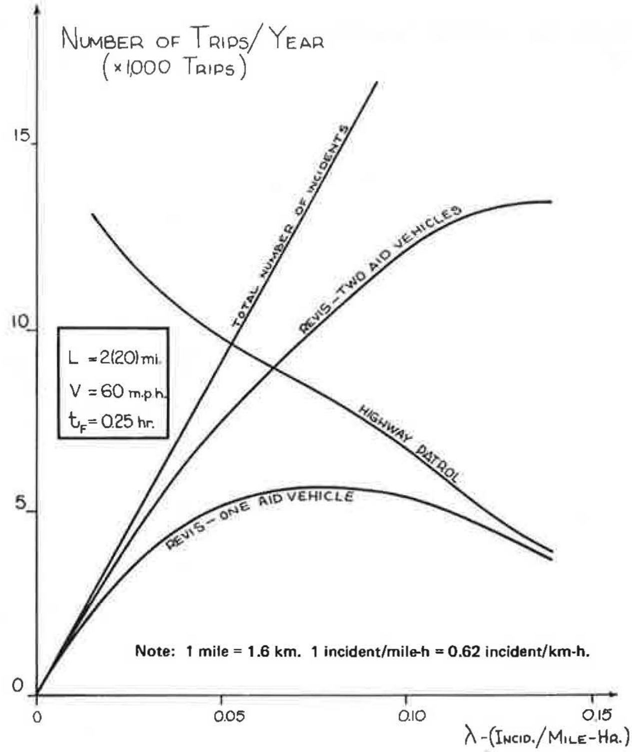


Figure 10. Highway cost versus incident rate.

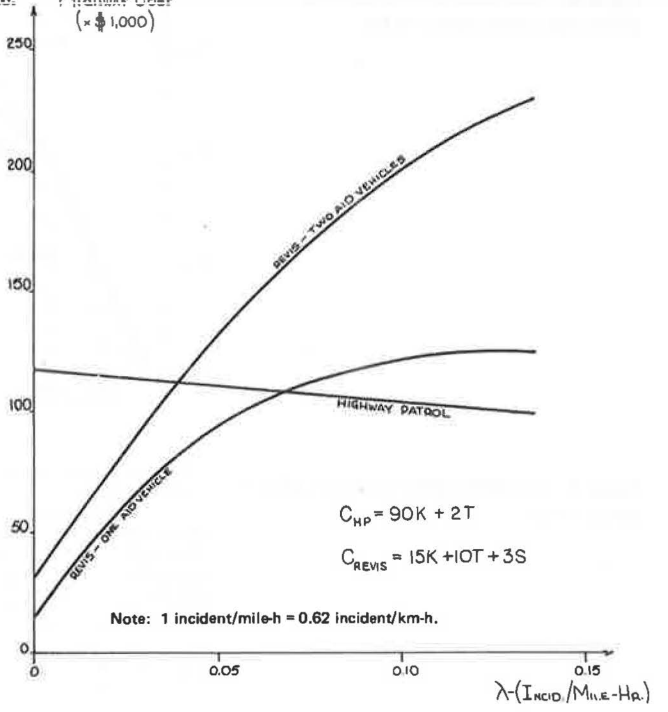


Figure 11. Mean wait time versus incident rate.

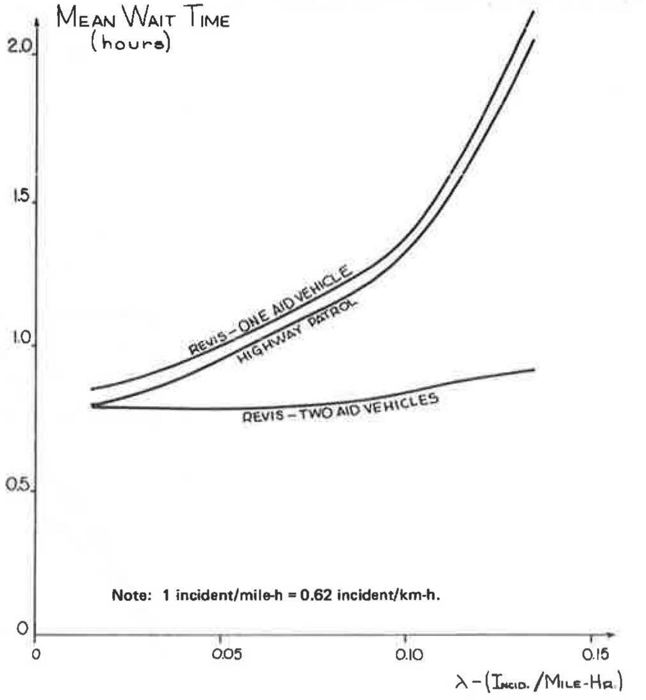


Figure 12. Mean square wait time versus incident rate.

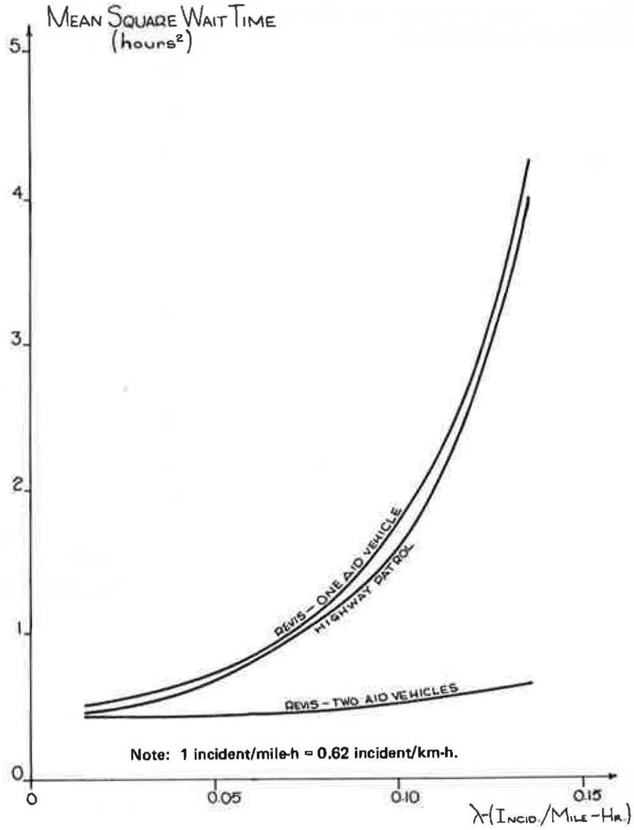


Figure 13. Wait time versus incident rate for REVIS with 1 aid vehicle.

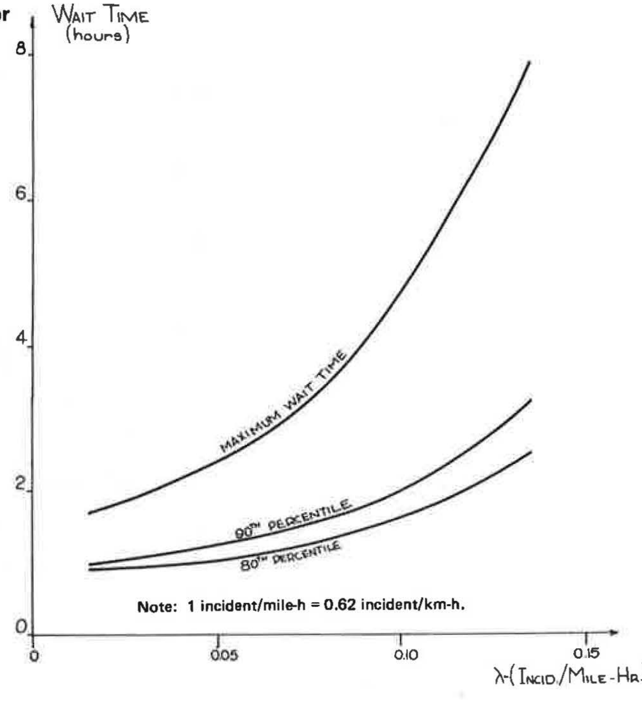


Figure 14. Wait time versus incident rate for REVIS with 2 aid vehicles.

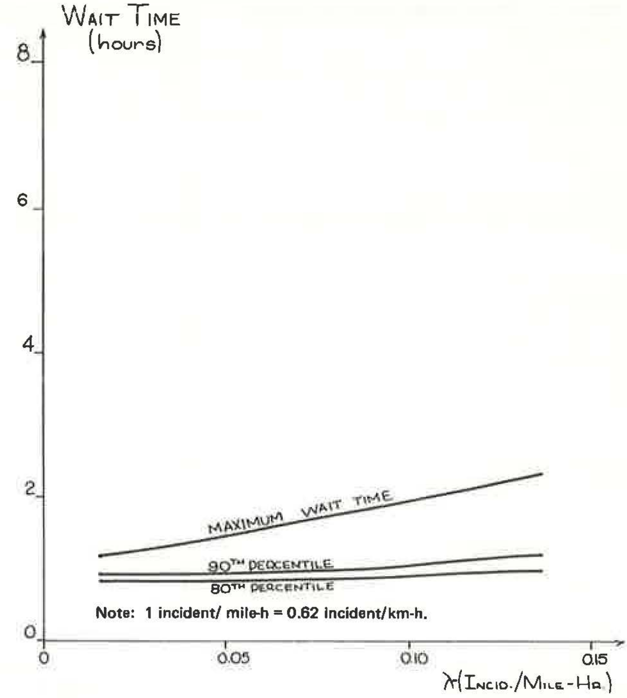
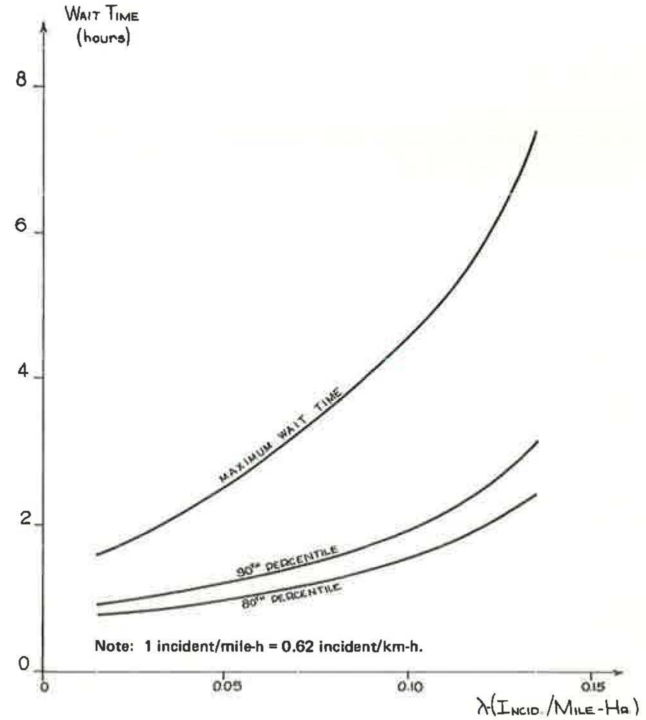


Figure 15. Wait time versus incident rate for highway patrol.



ESTIMATED CAPITAL COST OF REVIS

The capital cost of REVIS may be divided into 4 categories: communications, computation, roadside detectors, and vehicle transducers. Because these costs depend on installation a comparison with existing aid-to-disabled-motorist systems is made to establish an order of magnitude estimate for REVIS.

Communication of data between the roadside detectors and the traffic monitoring computer is accomplished by leased telephone line or buried cable installed in the road. In many cases the latter is already available and has been included in the construction cost of the road where it is not significant. The cost of the former is further dividable into subcategories of construction, monthly charges, and maintenance. Fruchter (25) calculated that the total communication cost per detector site per month is approximately $54 for a rural network when construction cost is prorated over 5 years. Ghobadi (26) calculated the average monthly communication cost per telephone to be as follows:

Item	Cost (dollars)
Construction cost per month for 378 telephones prorated over 5 years	2,677.50
Maintenance	3,791.67
Monthly charges	300.00
Total cost per month	6,769.17
Total cost per month per telephone	17.91

The magnitude of computational power required is estimated by examining the instrumented Los Angeles Freeway and Tangenziale di Napoli (TANA) systems. The former uses an XDS Sigma 5 computer with 24 thousand words (32 bits/word) of cpu core memory and has a cycle time of 950 ns (27). The TANA system (28) uses a Selenia GP16 computer featuring 12 thousand words (16 bits/word) of cpu core memory and has a 2-μs cycle time. In addition, each system uses standard I/O devices and a peripheral magnetic memory. The Los Angeles system has been modified to 40 thousand words to allow concurrent real-time and batch-processing capability for software development and report generation. When assembled in a minimum configuration consisting of a cpu with 24 thousand words (16 bits/word) of submicrosecond cycle time core memory, 5 million bytes of disk memory, a digital input-output controller having at least 128 input and output points, a control console, and associated enclosures, power supplies, and clocks, systems of this type may cost approximately $75,000, which, when prorated over 5 years, comes to $1,250 per month.

The number of interdetector spaces serviceable by such a computer, N_D, may be estimated by examining the REVIS algorithm shown in Figure 7 by assuming that the operating system resides in 8 thousand words of cpu core and that each vehicle is monitored at least once every t_1 s. Because processing the REVIS algorithm for data from the α vehicle typically would require 50 μs and because each interdetector space maximally generates 64 thousand sets of data, $N_D = t_1/3.2$. For example, for surveillance once every 2 min, $t_1 = 120$, and N = 37 serviceable interdetector spaces. When the interdetector space is 2 miles (3.22 km) this machine is capable of a 74-mile (119.1-km) surveillance at a cost of approximately $17 per mile per month ($10.54 per kilometer per month). Machine cost is therefore comparable to the cost of telephone emergency systems now in existence and cannot be considered prohibitive. Transfer of data from disk to cpu memory at 100 thousand words per second allows 16 thousand words of data to be loaded in 160 ms, which is more than adequate for the system under consideration.

The installation of induction-loop detectors currently costs approximately $500, including purchase of the loop and interface electronics. To this must be added the cost of the UHF antenna (about $100) and the cost of a data modem constructed on a special purpose integrated circuit (about $100). A semiconductor chip would contain the circuitry necessary for transmitting and receiving data, preprocessing the data into a form suitable for transmission to the cpu, and buffering and interfacing with the modem. The total detector cost is therefore \$4,200 per site or \$70 per site per month for 4 lanes prorated over 5 years.

The in-vehicle transponder circuitry consists of a receiver-decoder, a 16-bit shift register used to store the identification code, and a frequency-shift-keying, UHF, low-power transmitter capable of being modulated by the contents of the shift register. Such a device would contain at most 250 active devices and occupy a chip approximately 50 × 50 mils (127 × 127 μm) in size. Because switching speed and power requirements are minimal, low-threshold PMOS circuitry seems suitable to minimize cost. In quantities sufficiently large to make the amortized setup charge negligibly small, the cost of this small-to-medium-scale integrated device is estimated to range from \$5 to \$7. The low-threshold voltage devices would allow a planar chemical 1.5-Volt power supply, similar to the P-70 battery, that uses a standard carbon-zinc technology, such as that in Polaroid SX-70 film in the transponder. Including assembly, the transducer cost should be less than \$10 with an anticipated lifetime of more than 1 year. Should passive transponders prove feasible, lower cost would be anticipated.

This cost analysis of REVIS is not based on a specific detailed design or hard data, but we believe it represents a realistic estimate of the capital cost of microscopic surveillance of a vehicle by REVIS. The cost analysis for the instrumentation of a 75-mile (120.8-km) length of 4-lane Interstate highway with interdetector spacing of 2 miles (3.22 km) is given in Table 2.

For a road operating with $\lambda = 0.04$, the cost accrual rate (difference in operating costs between highway patrol and REVIS with 1 aid vehicle) is found from Figure 10 to be \$40,000 per year per 20-mile (32.2-km) highway length or \$150,000 per year for the 75-mile (120.8-km) example. The operating agency therefore may balance decreased operating costs for the highway patrol against increased capital costs for REVIS.

A significant increase in the maximum number of detectors serviceable by a given cpu, and hence cost reduction, may be attained by handling normal event computation at the detector site. In effect, the cpu only monitors traffic parameters and handles vehicle service requests. Communication between the detector site and cpu still is required for system reliability and evaluation of traffic parameters for use in the REVIS algorithm. This system, shown in Figure 16, is, in reality, a distributed computing network and is classified as a type-1 REVIS because data are transmitted directly to the first nearest neighbor only. Design of a type-1 REVIS is under consideration and will be reported on later.

CONCLUSIONS

The major benefit of REVIS is the substantial reduction in incident-detection time afforded by the system particularly on rural, limited-access Interstate highways. For rural traffic with $\lambda = 0.005$ an average of 1,650 incidents occurs per year for a 75-mile (120.8-km) length of highway. Consider the following example in which the mean time between highway patrol vehicles on a fixed schedule is 2 hours on a stretch of rural highway and the average distance to the nearest tow truck or aid vehicle is 50 miles (80.5 km). Without REVIS, the average wait for aid is approximately 2 hours, 1 hour for incident detection plus 1 hour for the aid vehicle. With REVIS, the average total wait is approximately 1 hour. The same substantial reduction in total waiting time is achieved by REVIS when it monitors urban highways during the night. It is the ability of REVIS to track each vehicle microscopically that distinguishes this system of automatic incident detection from other systems.

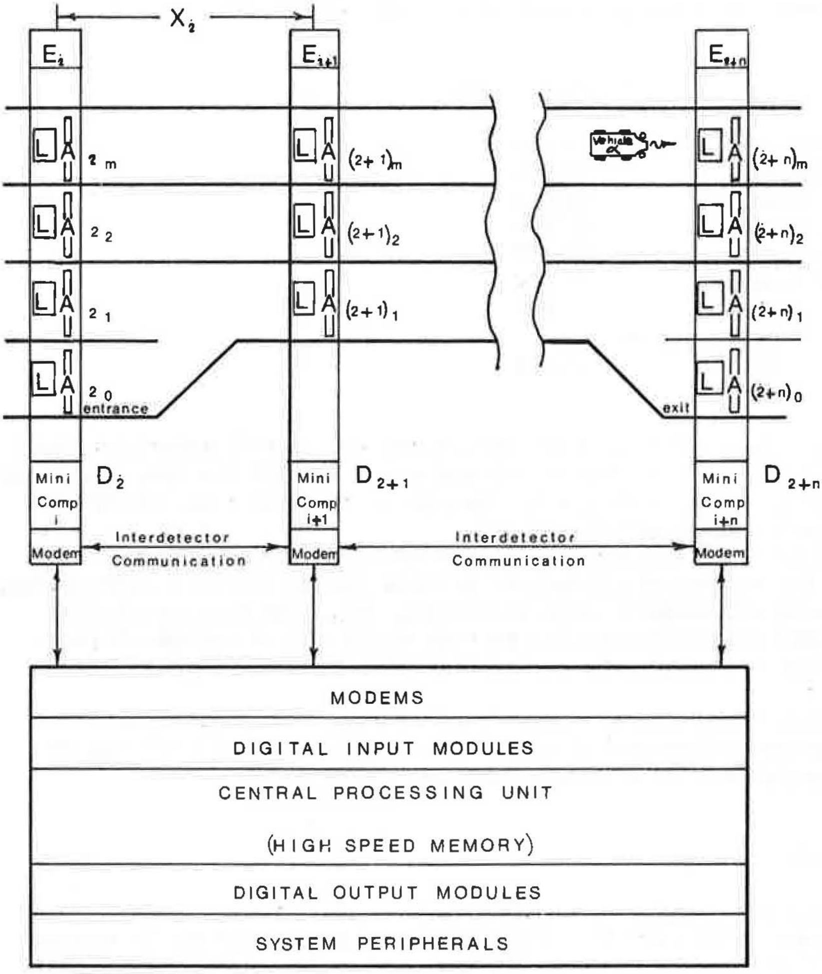
The cost of police patrol service along a highway is at least \$90,000 per year per vehicle, including salaries, maintenance and fuel, depreciation, and administrative costs. The primary service performed by such a patrol car is incident detection; additional services include incident management, traffic law surveillance and enforcement, road condition inspection, and rendering aid to disabled motorists. The functional effective-

Table 2. Capital cost estimate of REVIS.

Item	Total Cost (dollars)	Cost Per Mile (dollars)	Cost Per Month (dollars)
Communication	–	–	663
Computation	75,000	1,000	1,250
Roadside detectors	155,400	2,070	2,590
Vehicle transducers	10 per vehicle	–	–

Note: 1 mile = 1.6 km.

Figure 16. Type-1 REVIS.



ness of patrol vehicles may be increased by assigning the incident-detection task to REVIS and reassigning the police resource to the remaining areas. By using the police resource in an intelligent manner REVIS serves as a police manpower multiplier.

By suitably modifying the system and adding peripheral equipment, REVIS can be used as an important research tool in determining patterns of driving behavior that create a high propensity for accidents. Investigation of spatially sampled speed and lane position records of vehicles involved in an accident may reveal significant features. Furthermore, the presence of detectors coupled to an on-line computer may be useful in other transportation studies.

The total cost of a REVIS instrumented road, including operating, maintenance, and capital cost, prorated over 5 years is less than the total cost for conventional highway patrol of the same road. Specifically, for the 75-mile (120.8-km) highway length example previously considered the total annual REVIS cost is itemized as follows:

Item	Cost (dollars)
Communication	7,956
Computer equipment	15,000
Computer maintenance	10,000
Vehicle transponders	57,600
Roadside detectors	31,080
Detector maintenance	11,000
REVIS personnel	40,000
Operation [λ = 0.005 scaled to 75 miles (120.8 km)]	70,000

These costs result in a total REVIS cost of $242,636 per year per 75 miles (120.8 km). From Figure 10, scaled to 75 miles (120.8 km) and when λ = 0.005, the total annual cost for conventional highway patrol is $402,500. Therefore, at a lower cost, REVIS provides a higher level of incident-detection service.

An important adjunct to any incident-detection system is an effective aid-vehicle dispatch program. The number of aid vehicles available for service on a given section of highway significantly influences the time aid arrives (29). The service priority policy when the number of disabled vehicles exceeds the number of aid vehicles currently is being developed by queuing theory and digital simulation to improve system performance.

We do not propose to instrument the entire length of rural Interstate highway with REVIS because of the prohibitive capital costs. However, on selected stretches of rural roads, implementation may be effective and affordable.

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James K. Williams and K. B. Johns, Transportation Research Board staff

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