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.

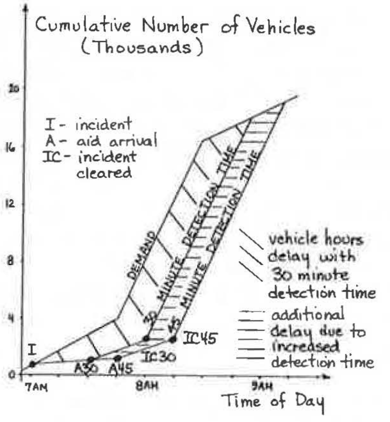


Figure 2. Vehicle transceiver on a toll card or inspection sticker.

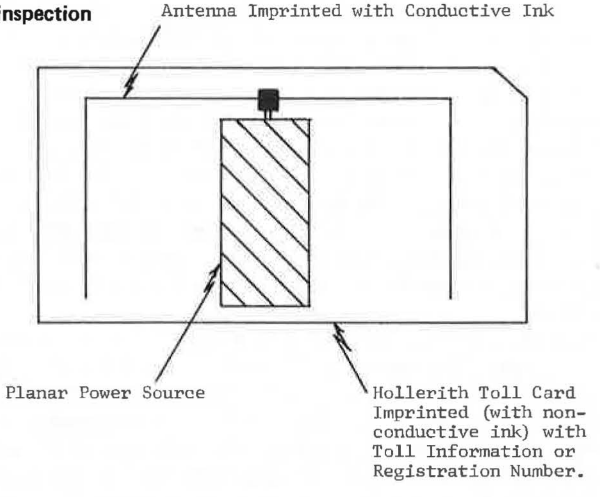
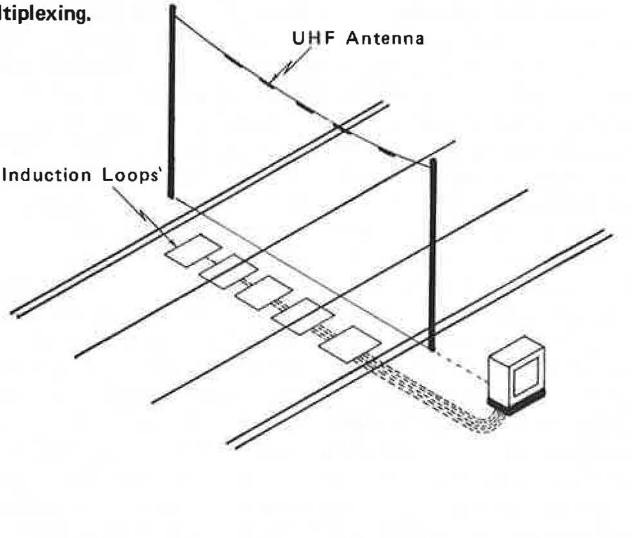


Figure 3. Typical detector site with spatial multiplexing.



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_o, 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 $(i + n)_o$ 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_o, 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.

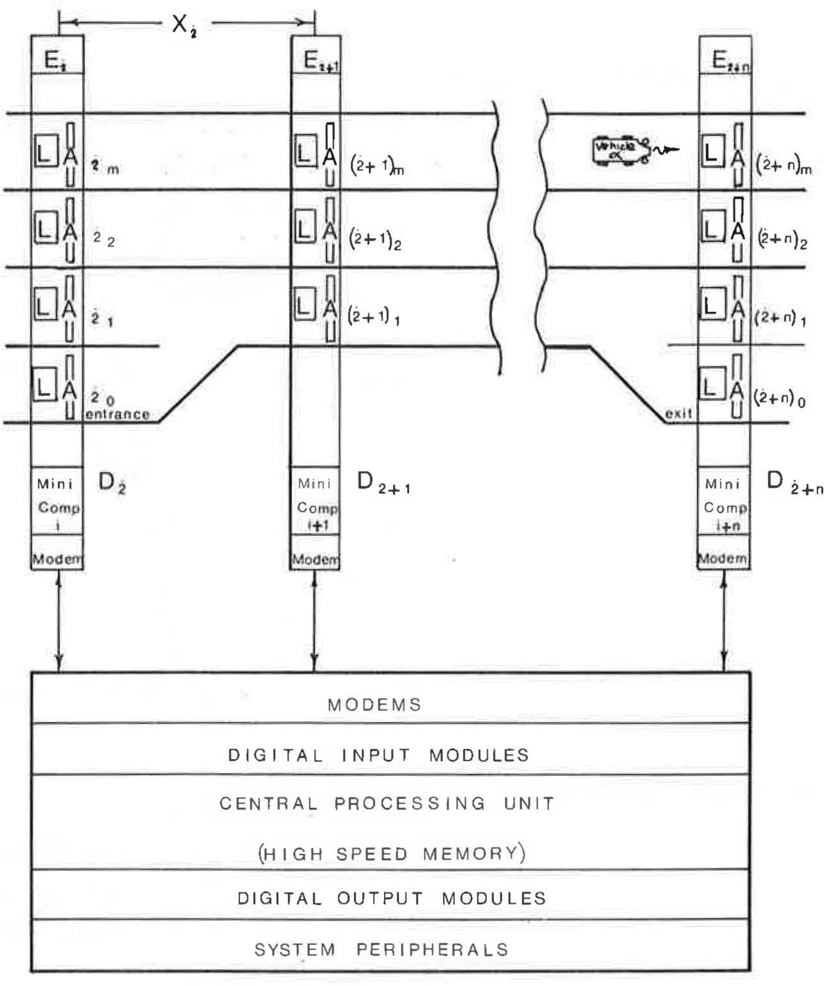
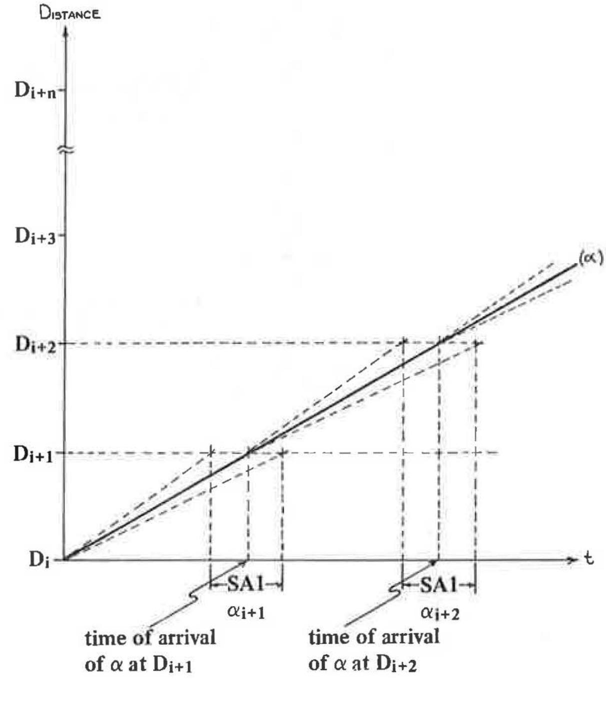


Figure 5. Distance-time diagram for operating under REVIS.



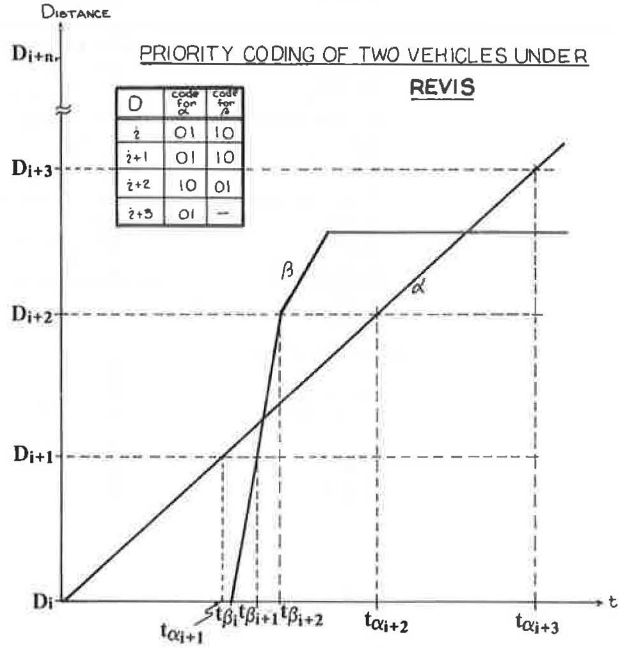


Figure 6. Priority coding of a and β operating under REVIS.

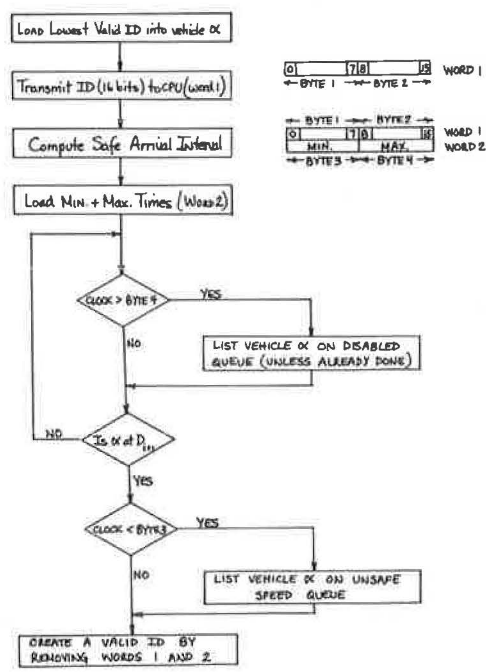


Figure 7. REVIS algorithm for data from a.

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
$= 1 + \dfrac{5280}{H_D} = 1 + \dfrac{3600}{VH_T}$,
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

$$C_{\text{highway patrol}} = C_{\text{fixed annual}} + C_{\text{fuel}} \tag{3}$$

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

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

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

The cost structure assumed for a REVIS aid vehicle is

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

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 $\lambda = 0.04$, 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.

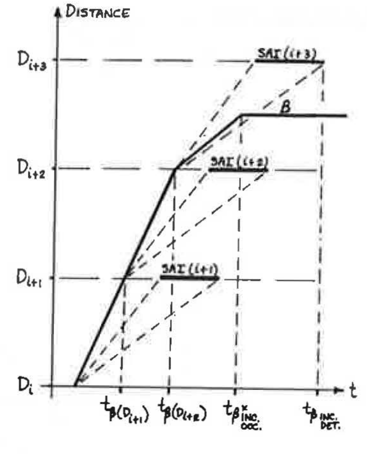


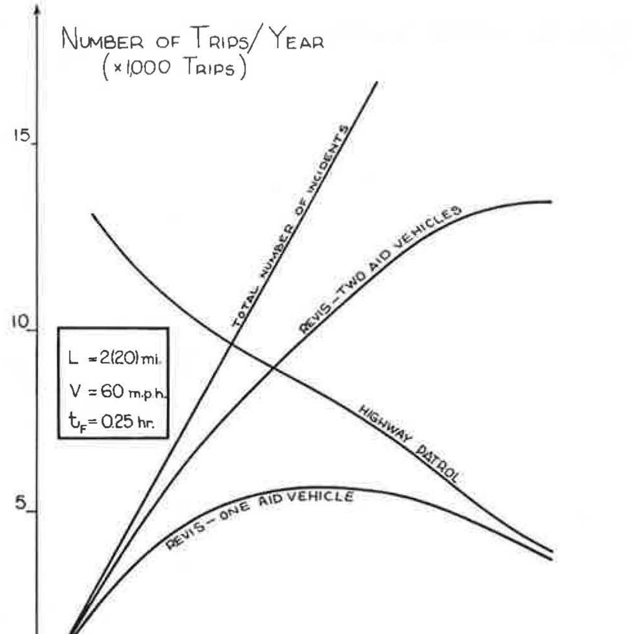
Table 1. Incident rate for various highway parameters.

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.



Note: 1 mile = 1.6 km. 1 incident/mile-h = 0.62 incident/km-h.

Figure 10. Highway cost versus incident rate.

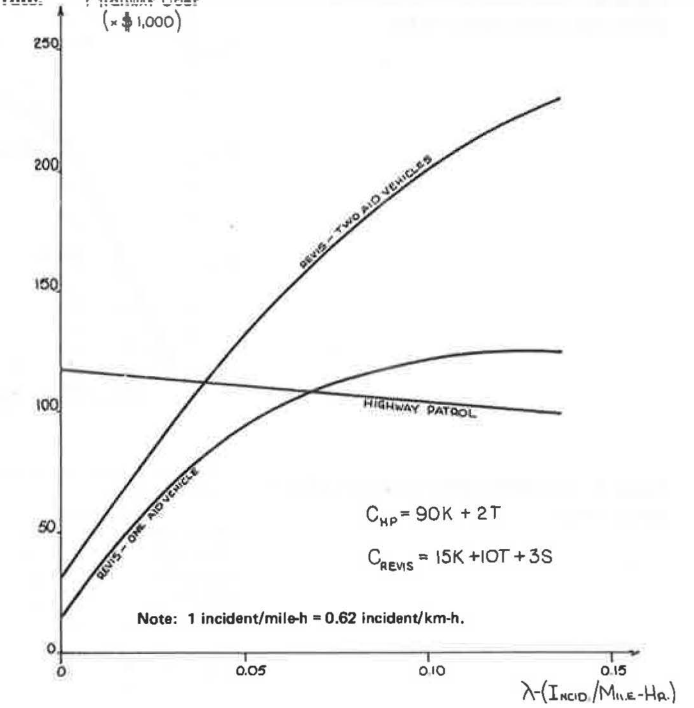


Figure 11. Mean wait time versus incident rate.

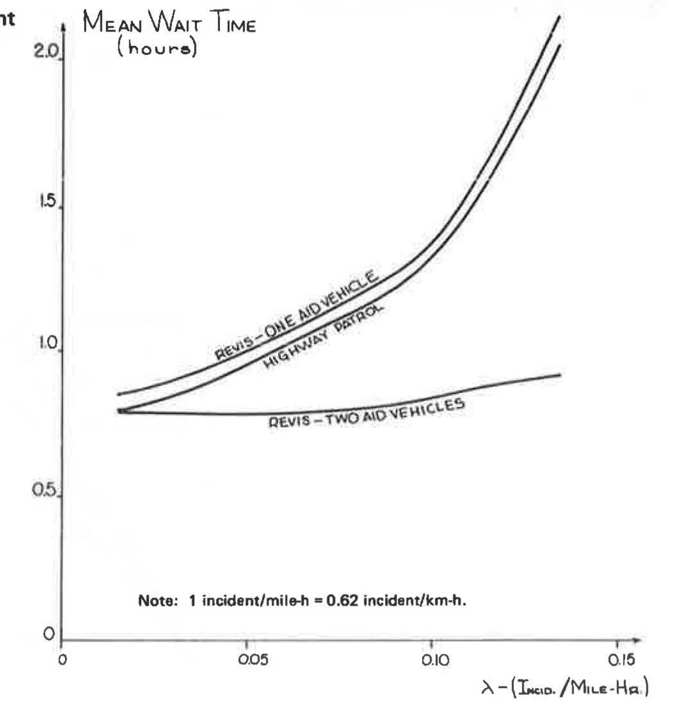


Figure 12. Mean square wait time versus incident rate.

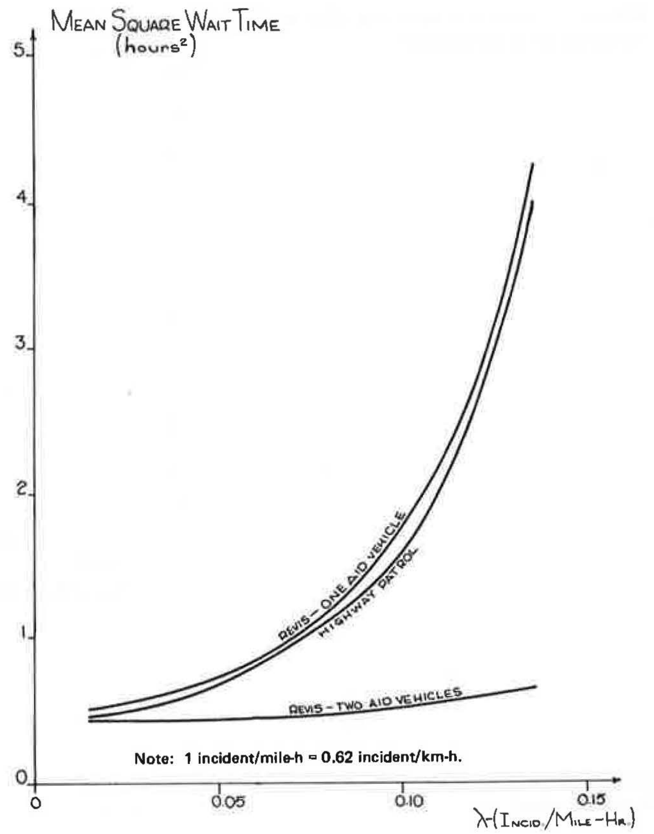


Figure 13. Wait time versus incident rate for REVIS with 1 aid vehicle.

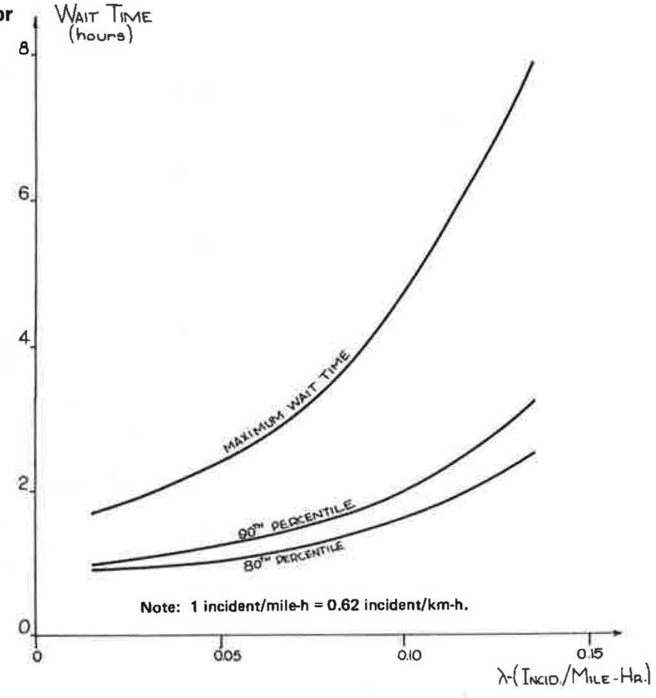


Figure 14. Wait time versus incident rate for REVIS with 2 aid vehicles.

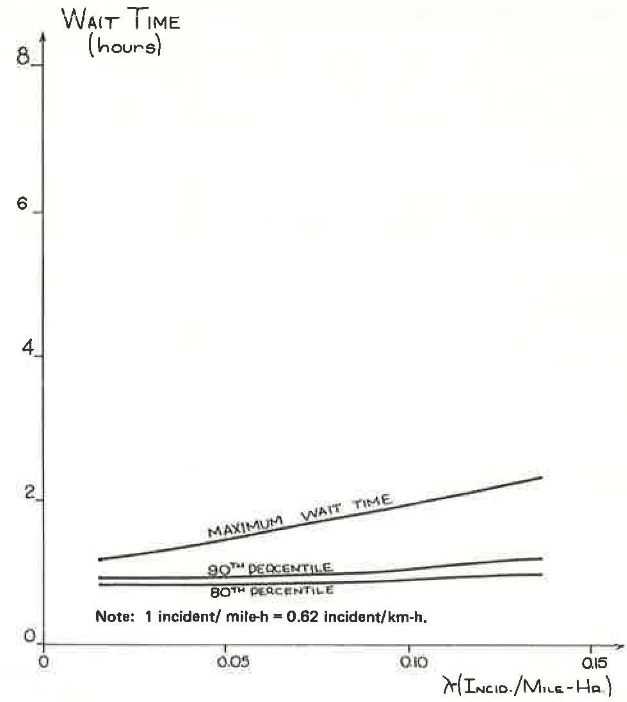
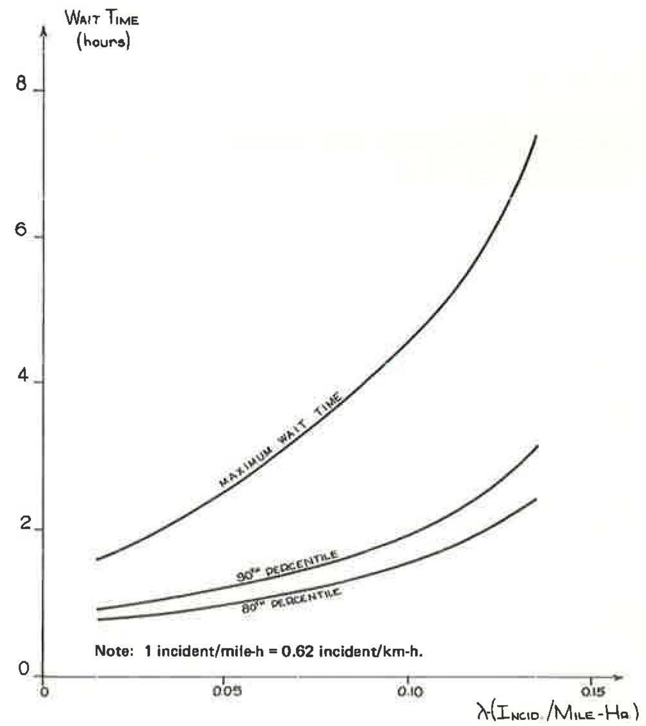


Figure 15. Wait time versus incident rate for highway patrol.



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.

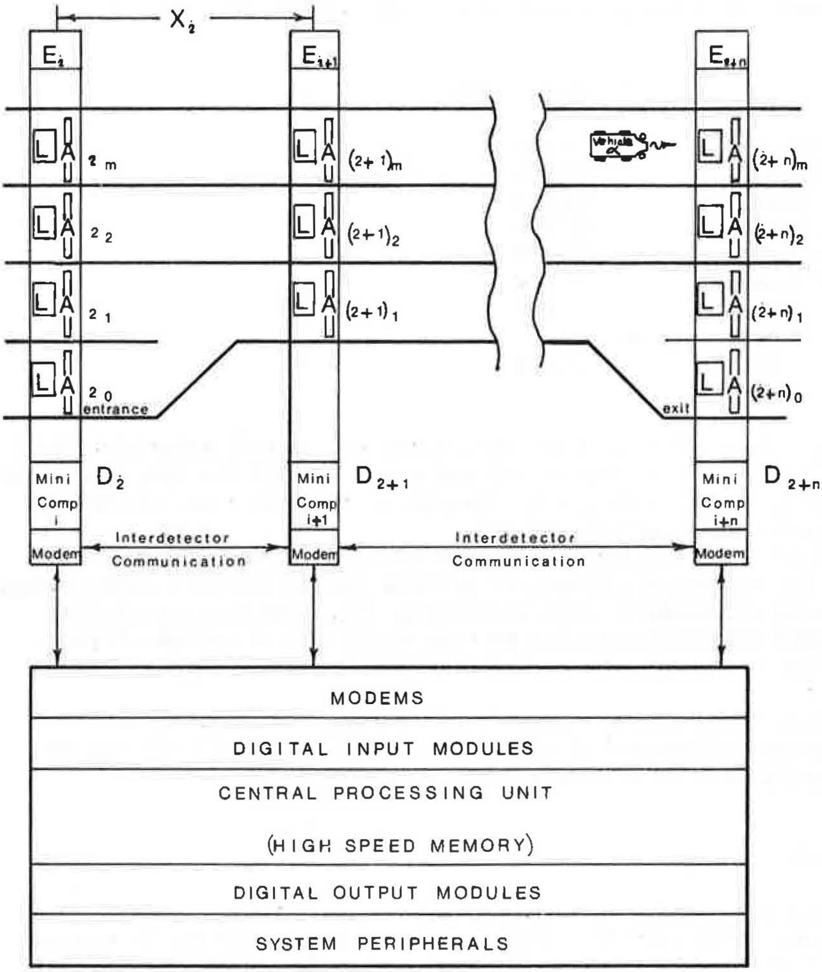
The cost of police patrol service along a highway is at least \$90,000 per year per vehicle, including salaries, maintenance and fuel, depreciation, and administrative costs. The primary service performed by such a patrol car is incident detection; additional services include incident management, traffic 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 $\lambda = 0.005$, 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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