METHODOLOGIES FOR EVALUATING THE IMPACT ON SAFETY OF INTELLIGENT VEHICLE HIGHWAY SYSTEMS

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ABSTRACT

The IVHS program includes a wide variety of types of systems all of which are intended to improve some aspect of highway travel. As these systems evolve, it is important to know if they are accomplishing their design goals; and it is also Important to ensure that they are not introducing unwanted degradation of other aspects of travel. Safety is one of those aspects which should not be degraded; and if possible, should be improved. All operational tests which are supported by the United States Department of Transportation (USDOT) include safety as an element of the evaluation. The impact on safety of systems which are already being deployed is also being studied This paper addresses the goals, methodologies, and preliminary results from safety evaluations and presents a summary of studies which are underway. Systems which are discussed include the TravTek route guidance and navigation demonstration. collision avoidance systems, and the TravelAid in-vehicle hazard warning demonstration.

INTRODUCTlON

This paper discusses methods for evaluating the safety impact of Intelligent vehicle highway systems (IVHS). The discussion is tailored to specific situations; however, the common focus throughout the paper is the following set of core questions:

- Do drivers drive more, or less, safely with the system than without it, in way related to the system?
- Do vehicles equipped with the system have fewer, or more, collisions than vehicles without the system?
- If all vehicles in the fleet were equipped with the system. would there be a decrease. or increase. in the total number of collisions and collision-related injuries?

The third question is the fundamental question about performance ofcollision avoidance systems, and other systems. that have an impact on safety However, frequently the data to directly answer this question are difficult or impossible obtain. Also, the answer to this question does not provide basis for understanding the reasons for the impact on safety. The first and second questions are important because they fill these gaps. The first question provides a basis for understanding the reasons for an impact and the second question provides preliminary collision data complements the answer to the first question.

Two perspectives are used as the framework for the discussion. One point of view is the maturity of the technology. The most mature systems are those that have been reduced to commercial products and are available to the general public. The next level of maturity includes systems which have been reduced to producible systems, but which are not yet a marketed product. These systems are candidates for operational tests. The third level includes systems which are available as prototypes. These systems would be candidates for laboratory and test track evaluations. The fourth level includes systems for which design concepts exist. but which have not been produced as prototypes.

A second point of view for distinguishing types of system is in the context of the "intensity of action diagram" shown in Figure 1 [1] This paper discusses three types of system which have a potential impact on the ability of drivers to avoid collisions. At one end of the spectrum are systems which help drivers reach their destinations in an efficient manner. These systems would be included in the "normal driving" region at the left end of the spectrum of systems in Figure 1 They are not designed to provide direct collision avoidance assistance and therefore require minimal level of effort. Systems which would be one step to the right are those which provide advance warning of roadway hazards. Examples of hazards are rockslides. snowplows, and closed lanes. These systems require the driver to take action. such as reducing speed or selecting an alternative route, in response to a hazardous situation. However, advice is provided sufficiently in advance of the situation that the driver has time, probably on the order of several minutes, in which to prepare for the needed action. Still further to the right of Figure 1 are systems which are typically classified as collision avoidance systems. These systems augment the driver's collision avoidance capability when hazardous situations or collisions are imminent.

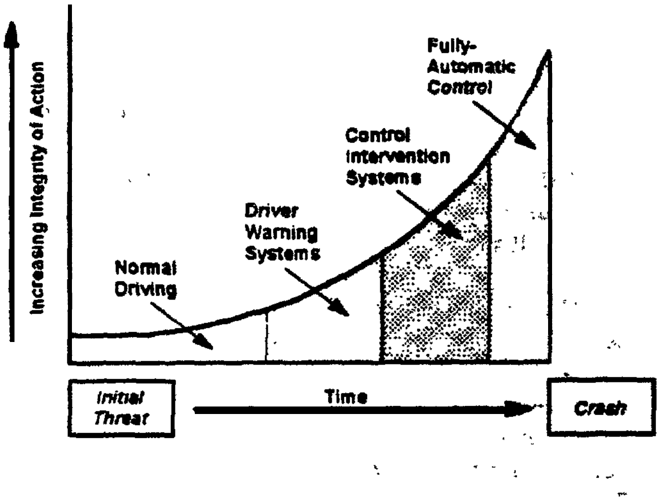


Figure 1. **Time vs. Intensity Diagram**

The remainder of this paper discusses methodologies for evaluating the safety impact of each of the three types of systems described above. The discussion for each type of system includes separate discussions for each of the three core questions

ROUTE-GUIDANCE AND NAVIGATION SYSTEMS

This type of system has reached a state of maturity that prototype systems are available for use in operational tests. A key advantage of operational tests is that they provide an opportunity to not only assess driver perceptions and reactions to use of a system but also an opportunity to view operation of the system under a variety of controlled conditions.

Examples of route-guidance and navigation of systems are the TravTek system which was the subject of an operational test from April 1992 through March 1993 [2], the ADVANCE system which is the subject of a current operational test [3], and the FastTrac system which is also the subject of a current operational test [4]. Of these three systems, the operational test of TravTek is closest to completion. For this reason, the discussion in this paper is limited to the TravTek program. The TravTek program included a strong commitment to a comprehensive evaluation from the beginning of the project [5, 6]. The evaluation, which is being done by Science Applications International Corporation (SAIC) under contract to the Federal Highway Administration is not yet complete. Thus, the discussion in this paper is necessarily incomplete and focuses on methodologies; with only a preliminary review of results.

Two of the operational elements of the TravTek system are the in-vehicle subsystem and the traffic management center. These two subsystems were connected by radio links that allowed the Vehicles to receive information on current traffic conditions and the traffic management center to receive information of travel delays from the vehicles. The in-vehicle subsystem provided navigation assistance plus autonomous on-board routing capabilities based on map-matching combined with signal from the satellite-based global positioning system (GPS) and dead-reckoning units for determining position. There were a total of 100 TravTek vehicles available for use during the operational test.

The system in each vehicle could be programmed by the vehicle-operations team to be in one of three system configurations. One configuration known as the "Navigation" configuration; provided in-vehicle route-planning and navigation capability but did not include the radio link to receive traffic information. A second configuration, known as "Navigation Plus", provided the in-vehicle capability plus the radio link that provided enhanced route planning capability based on current traffic conditions. The third configuration was a control condition which provided "yellow pages" information but did not provide any route-guidance and navigation capability.

The system in each vehicle also had six driver-selectable display configurations. The six consisted of three visual displays in combination with either an audio backup or no audio backup. One of the visual systems, known as the "Guidance Display", provided turn-by-turn instructions for reaching the designated destination. A second visual display . known as the "Route Map". provided routing instructions through a highlighted depiction of the route superimposed on a graphic of the surrounding traffic network grid. The third visual display did not provide any route guidance.

The evaluation of the safety impact, as well as the other elements of the evaluation, was organized to methodically move from stated objectives to analysis of relevant data for each sub element. This approach is shown in Table 1 [7].

Table 1
Study Definition [7]

Objectives	Hypothesis	**Measures of Effectiveness (MOE)**	**Measures of Performance (MOP)**	**Data Sources**	**Methods of Analysis**
Objectives are stated in terms **of what to** measure of **what to evaluate**	These include a statement of the primary hypothesis	MOEs are conceptual measures that convey "goodness" or ability to meet a set of criteria	These are data elements required to satisfy the MOEs (the variables needed to compute the MOEs)	This column refers to the TravTek data sources (e.g., in-vehicle logs, TMC logs, TISC logs) required to compute the MOPs	This column broadly defines the types of analytical procedures that will be used

The process includes establishment of meaningful measures of safe or unsafe driving (measures of effectiveness), determination of collectable data elements (measures of performance) that can be used to relate safe or unsafe driving situations to use of the TravTek equipment, and development of analytical methodologies which can be used to establish the relationship between use of TravTek equipment and instances of safe or unsafe driving. In this, as in all aspects of the evaluation. it is also important to establish control conditions so that comparative assessments can be done.

There were a total of five driving scenarios which provided data for use in the evaluation. Two of them allowed drivers to operate the vehicle in a naturalistic way with no direct oversight. These drivers were instructed to drive normally and there were no restrictions on destinations or other aspects of travel. One group of drivers was composed of visitors to the Orlando area who were from other states. This group was known as the "B1" drivers. A second group was composed of local residents in the Orlando area who were grven use of a TravTek vehicle for a two-month period. This group was known as the "B2" drivers. The Bl drivers were assigned a vehicle with one of the three configurations and the B2 drivers were provided either a Navigation or a Navigation Plus configuration. The drivers were free to operate the vehicle with their choice of display configuration including not using the TravTek system [8].

The other three driving scenarios, known as the Cl, C2, and C3 studies. imposed controls on vehicle operation [9]. In all three studies, the conditions of operation included use of a limited number of pre-determined origin/destination pairs and presence of an observer during vehicle operation. These include the Cl study, a yoked-driving test in which sets of three drivers with the same destination simultaneously left a single origin. Each vehicle in the set was equipped with a one of the three system configurations described above. The C2 study was a second test which also included common origins and destinations. In this case each driver sequentially drove between a specified origin and a specified destination with each of the six display configurations described above. The third study, known as the C3 study, used a specially instrumented vehicle and also required drivers to drive between a specified origin and destination with a preselected display configuration. The Navigation system configuration was used for the C2 and C3 studies. In all three studies. the drivers were compensated for taking part in a controlled experiment.

QUESTION 1(Do drivers drive more, or less, safely with the system than without it, in ways related to the system?)

This question, posed in the Introduction. has been subdivided into two component questions for purposes of the TravTek evaluation. These two subquestions are:

- What is the safety impact of the TravTek improvement in navigation and congestion avoidance?
- What is the impact of display type and driver experience on driver performance. behavior, and perceptions?

Among the sources of data for answering the first subquestion is a questionnaire which all participants in the B I and B2 studies were invited to complete. Responses to the questions provide perceived safety benefits as well as perceived useability of the system. Preliminary analyses of the questionnaires have been reported- in other papers [10.1 1]. Two questions which provide insight into the drivers' perception of savings in time and avoidance of congestion are:

- Do you think TravTek helped you save time in reaching your destinations?
- Do you think TravTek helped you avoid congestion?

Based on the preliminary analysis. the average value of the response to these two questions for Bl drivers with the Navigation Plus configuration was 4.6 and 2.9 respectively compared to responses from drivers of the control configuration which on the average were 2.6 and 1.9, respectively. For each question, a "1" corresponded to the most negative response and a "6" corresponded to the most positive response.

It is clear from these answers that the rental drivers believed that the system helped them have quick and efficient trips. This perception of the Bl drivers was confirmed in the C2 study where, on the average, drivers with the TravTek system covered the assigned trips in significantly less time [9] than it took when they used a paper map.

Partial answers to the second subquestion can also be found in the questionnaire data. A sampling of entries from the questionnaire and preliminary responses is shown below. A complete analysis of all of the data will be included in the final report of the evaluation contract.

- The TravTek system helped me pay more attention to my driving. The average response of Bl drivers with the Navigation configuration was 4.5

- The TravTek system interferred with my driving. The average response of Bl drivers with the Navigation configuration was 2.1

- Do you think TravTek 'helped' you drive more safely in Orlando? The average response of Bl drivers with the Navigation configuration was 4.1

The followmg cluster of questions on "close calls" was also included in the questionnaire.

- How frequently did you experience "close calls" (or near-accidents) while driving the vehicle?

- How many times did you experience "close calls" (or near-accidents) while driving the vehicle?

- What were you actions immediately prior to the close call?

- Who or what caused the "close call" to occur?

- How does the number of "close calls" you experienced in Orlando compare with the number you usually experience in your hometown?

The data from this cluster have not yet been completely analyzed. However, a preliminary review indicates that drivers believed they had almost no close calls. For example, the average response by Bl drivers to the first question of the cluster was 1.3, on a scale 1-6. where 1= "never" and 6= "frequently". The preliminary analysis of data from questionnaires also suggests that drivers believed they had fewer close-calls with the TravTek system than with their own vehicle. However, these data also suggest that some of the close-calls may have been related to use of the TravTek system. Further analysis of these data will include comparison of data from the in-vehicle log to questionnaire responses.

Additional data to help answer the safety part of the question will come from analysis which will include the in-vehicle data logs and records of close calls and other safety related information that was collected during the Cl. C2. and C3 studies. This analysis has not yet been completed.

The most detailed data for answering the second subquestion will come from the C3 study. In this study, a specially quipped vehicle was used to collect detailed information about driver actions. The additional instrumentation included accelerometers; monitors of motion of steering wheel, accelerator pedal and brake pedal; and four cameras which simultaneously monitored the driver's face. the road ahead of the vehicle, the lateral position of the vehicle relative to lane markings, and the TravTek display. In addition to the instrumentation, the onboard observer noted each event and activity which might be related to the safety of a driver' s performance. The preliminary analysis indicates that visual turn-by-turn instructions with voice backup appears to provide the highest level of safety; and that the level of safety was not the same for all display configurations. The results also suggest that the level of safety improves as drivers gained experience in use the TravTek system [12].

The analyses which will be performed as part of answering the first basic question will involve several sources and types of data They will also address the subquestions and contributing factors from a number of perspectives. The final step in the analysis will be to consolidate all of the findings into functional relationships which describe the safety impact.

- Some of these functional relationships will be:

- Accident risk as a function of congestion

- Accident risk as a function. of navigational waste (a measure of trip efficiency)

- Driver performance as a function of display type and experience

- Driver behavior as a function of display type and experience

- Driver perceptions as a function of display type and experience

The complete analysis will be published in the final report from SAIC.

QUESTION 2 (Do vehicles equipped with the system have fewer, or more, collisions than vehicles without the system?)

A key advantage of operational tests is that they provide an opportunity to observe drivers in normal driving situations. This includes the opportunity to determine the number of collisions experienced by drivers. It also provides an opportunity to do detailed analysis of the conditions associated with each collision. Thus, the analysis of collision data from an operational test can provide two forms of insight. One is the size of the collision experience compared to appropriate reference or control groups. The second is an assessment of the strong points and weak points in the system design based on details such as pre-crash activity by the drivers, types of collision, and extenuating circumstances associated with the collisions.

In the TravTek program, the vehicles were rented to participants by Avis Car Rental Company. Thus. a logical comparison group would be one drawn from other Avis renters. However. it was learned late in the program that data on the collision history of Avis renters is not kept in a retrievable manner within the company records. Thus, it was not possible to make a direct comparison with a control group of other Avis customers. Another comparison which can be made is to the total national population of collisions. The General Estimates System (GES) which is maintained by the National Highway Traffic Safety Administration provides such a national perspective based on police-reported collisions which occurred on public roads [13].

During the operational test participants in the Bl study drove appoximately 0.8 kilometers and experienced 3 collisions on public roads. This relatively small exposure of the TravTek fleet makes it difficult to reach definitive conclusions on relative collision rate for the TravTek fleet. However, based on the summary above, it is seen that the collision rate during the operational test was about four collisions per million vehicle-kilometers (MVK) of travel. As a comparison the national rate is two police-reported collisions per MVK [14]. A detailed analysis. which takes into account the fact that there are about three additional collisions which are not reported to police for every two collisions that are reported to police. was done as part of the overall evaluation and shows that there is no statistically significant difference between the national collision rate and the rate for the TravTek fleet [15]. Ideally it would be possible to determine the impact on the relative collision rates of relevant factors such as driver age, driver familiarity with the road network, driver familiarity with the vehicle, type of collision, and contributing circumstances. However. there was insufficient data to do such an analysis. One consideration which may have an impact is the fact that most of the drivers were members of the American Automobile Association (AAA). Members of AAA are predominantly in the age range that has a lower collision rate that the national average. Another consideration is that most of the TravTek participants were visitors to the area and were renting vehicles with which they were not familiar. This consideration may lead to a higher collision rate than the national average [16].

QUESTION 3 (If all vehicles in the fleet were equipped with the system, would there be a decrease. or increase, in the total number of Collisions and collision-related injuries?)

An important step in the analysis of data from any operational test is the extrapolation of results to a population that includes a large percentage of vehicles with enhanced capability. In the case of TravTek. there were no more than 75 TravTek vehicles being driven at any one time. Thus. the impact of having TravTek vehicles in the system was negligible. However, if a large percentage of the vehicle fleet bad TravTek capability, there may be impacts on several aspects of the overall traffic network. Among these impacts, are emissions, number of collisions, and total travel time for all users of the traffic network.

To estimate these impacts, a specialized version of the INTEGRATION computer model of traffic flow was developed for the Orlando area [17]. This computer program models each individual vehicle as it travels from origin to destination in the simulated Orlando traffic network. The model has the capability of including vehicles with and without TravTek capability. By combining this basic model with algorithms for estimating emissions, fuel consumption. and number of collisions, the results from the operation of TravTek vehicles can be extrapolated to populations with higher percentages of TravTek-like vehicle.

To address the safety impact, an algorithm is being developed which can predict the collision experience of a vehicle based on circumstances along the route between origin and destination. The concept, in simple terms. of the algorithm is that the instantaneous collision rate (e.g. collisions per kilometer) for a vehicle as it travels through a uaffic network can be described by two components; one which describes the vehicle-related factors, and a second which describes the roadway-related factors. For purposes of this analysis, only one vehicle-related factor is considered; absence of TravTek capability (the baseline or control group) and presence of TravTek capability. The roadway-related factors are condensed into a single relationship between collision rate and level of congestion. Input for this relationship will be based on published results from other studies as well as the results from the TravTek program. Data from the Orlando traffic network will also be used to estimate the goodness-of-fit of the model. Use of this relationship also simplifies the interaction with the traffic flow model. Based on this concept. the likelihood of a vehicle having a collision while traversing the traffic network along route "a" from origin to destination ($L_{c/a}$) can be expressed by:

$$L_{c/a} = \int K \cdot W(x)dx$$

where:

$L_{c/a}$ is the likelihood of having a collision if route "a" is used

K is a constant that quantifies the effects of vehicle-related factors.

W(x) is the level of congestion along the route.

Based on this terminology, the total number of collisions during a specified period of time (N) will be expressed by:

$$N = \sum_{i=1}^{M} \mathbf{m}iK\ W(x)dx$$

where M is the total number of trips taken by all users of the traffic network during the designated period of time.

This algorithm relies on the results from controlled experiments and other sources of data from the TravTek program as the basis for parameter values and other boundary conditions. The value(s) for K will be derived from the analysis described in the discussion about answering Question 1 and from additional literature on driving performance. For basic analyses, two values of K will be needed, one for baseline vehicles and a second for vehicles with TravTek capability. If the data can support further subdivision, it may be possible to have values of K, which vary according to such variables as driver age, driver experience with the local traffic network and level of congestion along the route.

The function W (x) will be derived from an analysis of collision and congestion patterns in the Orlando area. One source of these data will be records from the Freeway Management Center which show levels of congestion prior to collisions which occurred on the portion of interstate 4, that was in the TravTek traffic network; to the extent possible, the function W(x) Nil1 Include variations-due to facility type (freeway. arterial. etc J, level of congestion (whether free flowing or queued), and intensity of traffic flow [18].

Once the values for K and W(x) have been established, the model will be exercised for a number of driving simulations; for example: mid-day, rush hour, weekend. It will also be exercised for different levels of penetration of vehicles with TravTek capability. The results of these simulations will be combined to estimate the impact on the total number of collisions of having an increasing percentage of vehicles with TravTek capability.

COLLISION AVOIDANCE SYSTEMS

At the opposite end of the spectrum of intensity-of-action shown in Figure 1 are collision avoidance systems. These systems are purposely designed to augment a driver's ability to avoid collisions.

Before discussing the methodologies for evaluating collision avoidance systems. It is helpful to discuss several characteristics of systems, which are related to the evaluation process.

The first characteristic is the category of the system. There are three basic categories for collision avoidance systems. The categories are determined by the function of the driver interface. Systems, which advise the driver of a situation which has the potential for producing a collision, but for which no immediate collision avoidance action is necessary, belong to the first category (denoted as Category I). Examples of this category are systems that advise of current headway, systems that indicate that another vehicle is present in an adjoining lane, and systems that advise the driver of reduced friction coefficient.

Systems, which advise the driver of an imminent collision and elicit collision avoidance action, belong to the second category (denoted as Category 2). Some examples of this category are: systems that advise the driver to apply the brakes when the system has determined that a collision will occur otherwise; systems which advise the driver to reverse steering inputs to avoid a collision with another vehicle in the driver's blind spot; and systems which advise the driver of the need for braking and/or steering to avoid an unintended road departure. The form of the advice may be specific (e.g. a direct statement to "brake") or unspecific (e.g. a light or tone, in which case the driver wil1 need to determine the meaning of the signal).

The third category of system (Category 3) encompasses those systems which direct the vehicle to take collision avoidance action automatically when a collision is imminent and the driver has not taken appropriate collision avoidance action. Examples of this category art systems which automatically apply the brakes when a rearend collision is imminent and systems which automatically apply the brakes when a pedestrian is behind a backing vehicle. Some systems may be hybrids, which combine features from more than one of these stereotypes. Some features of these three system categories are summarized in Table 2.

The second characteristic is the set of three functional elements, which form the building blocks for collision avoidance systems (and also systems that provide most of the other IVHS services). These functional elements are the sensing portion of the system, the processing part of the system, and the mechanism for interacting with the driver. Typical sensing elements, which are found in collision avoidance systems, include microwave radar, infrared radar, passive infrared, and ultrasonic transducers. The processing element takes signals from the sensors and converts them to useable messages that can be transmitted to the driver or vehicle control system. This element contains the algorithms for establishing the level of threat associated with any situation and for making a judgement about the imminence of a collision. The driver interaction element includes a broad range of presentations to the driver, including visual, audible and tactile. This element also may be a control system, which automatically takes action.

Table 2
Description of System Categories

	Feature	
	Significance of Vehicle Posture	**Action Needed**
Category 1	Potential for collision exists - vehicle(s) not on a collision course	Caution needed but no immediate collision avoidance action is necessary
Category 2	Collision is immment - vehicle(s) on a collision course	**Immediate collision avoidance action by the driver is needed**
Category 3	Collision is imminent - vehicle(s) on a collision course	**Immediate collision avoidance action will provided by an automatic control system**

The third characteristic is the set of dynamic situations which a system is designed to address. A dynamic situation is a set of conditions that can be described by time and space relationship and the interaction of drivers. The qualitative basis for establishing dynamic situations is contained in the cluster of precrash variables that was added to NHTSA collision data bases starting in 1992 The five variables are Movement Prior to Critical Event, Critical Event, Corrective Action Attempted, Vehicle Control After Corrective Action, and Vehicle Path After Corrective Action. This sequence of events is then followed by the First Harmful Event. The goal of collision avoidance systems is to intervene at one of the initial five pre-crash stages so that the first harmful event dots not occur. The processing functional element will include quantitative descriptions of these cucumstances and the logic for providing the needed intervention. Descriptions of dynamic situations will be denved from a combination of dynamics analysis and analysis of collision data.

The NHTSA has put in place four contracts to develop performance specifications for collision avoidance systems. Each contract addresses one of the following four specific types of collision: rearend, lane change and other “blindspot”. intersection, and off-road. As part of these contracts, each contractor will acquire available systems. These may be prototypes or they may be commercially available units Data from the evaluation tests will be used to answer the first and third of the three basic questions noted in the Introduction. However, it will not be possible to answer the second question because these tests will not include driving for extended periods under normal driving conditions as is possible in operational tests.

The evaluation of available systems will consist of three steps. The first step will be to determine which of the three categories each system represents. This will be followed by a determination of which dynamic situations each system was designed to address. The third step will be to develop a series of appropriate tests which will provide a basis for assessing the performance of each of the functional elements of the system. It is important to note that a thorough evaluation of a system needs to address each functional element and assess the performance of each. This then forms the basis for an assessment of the performance of the entire system. The evaluation also needs to address the four possible outcomes of traditional experiments shown in Table 3.

Table 3
Conceptual Experimental Results

System Response	Situations Requiring a Signal	Situations in Which a Signal is not Required
Signal	True Positive	False Positive
No Signal	False Negative	True Negative

Based on Table 3. the performance of the individual elements, or the entire system, can be described by several measures. One would be the ratio of times that the element, or system, gives a true positive to the number of times it gives a false positive. (The inverse of this ratio is sometimes referred to as the false alarm rate) Another would be the ratio of number of times it gives a true negative to the number of times it gives a false negative.

As an example of collision avoidance systems, consider the following two systems which address the problem of collisions that occur during a lane change. The systems address the problem in two different ways, one continuously provides information while the other provides information only when a collision is imminent. As will be seen in the following discussion, the details of the systems are different and the procedures for evaluating the systems are also different. Each of these systems would address the problem of collisions that occur during a lane change. This type of collision accounts for approximately 250,000 police-reported collisions per year, of which approximately 200 involved a fatality [19].

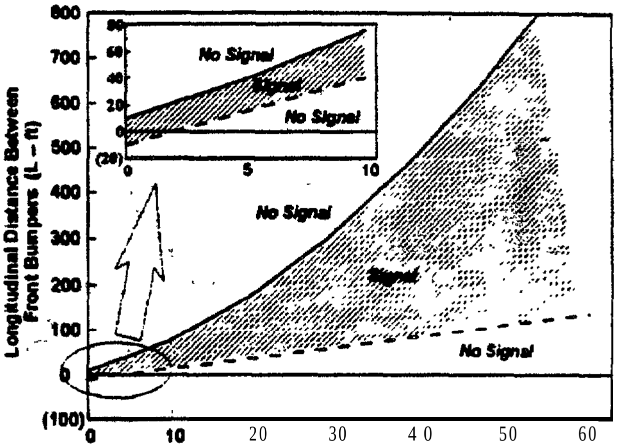
The first system is one which is designed to provide a driver with an indication of the presence of another vehicle in a potentially hazardous position in an adjacent lane. This system would be in the first category of systems; that is, those which advise the driver of a situation which has the potential for producing a collision. For this system, the vehicle which might change lanes is denoted vehicle 1 and the vehicle in the adjacent lane is denoted vehicle 2. The system is designed to provide the indication when an adjacent vehicle is in a position that which would result in a conflict if the driver of vehicle 1 chose to change lanes,.

The second system is one which interacts with the driver only when a collision is imminent. Thus, this would be in the second category, or a Category 2, system. For lane-changing situations such a system would monitor the relative motion between the vehicle with the system, which will be denoted as vehicle 1, and other vehicles in the vicinity, vehicle 2. When the system determines that the trajectories of the two vehicles put them on a collision course and that they are reaching the point of no return on that course. it will issue a message to the driver that control action is necessary. A key distinction between this system and the first one is that this one interacts with the driver only when action is needed whereas the first system interacts with the driver in a continuous manner when the potential for a collision exists but before a collision course has been established.

QUESTION 1(Do drivers drive more. or less, safely with the system than without it, in ways related to the system?)

Reducing this situation to a quantitative description is an important step in the evaluation process. For example, the time-history of vehicle motion must be described. Two features of thus time history are the rate at which the driver would normally change lanes and the lateral distance that the driver would move in a normal lane change For purposes of this example, it is assumed that the driver would take five seconds to change lanes and that the lateral distance is one lane width.

Actions by the other driver also need to be considered. For example, if vehicle 2 is traveling at a higher speed and the lane change would bring vehicle I in front of it. the driver of vehicle 2 will need to decelerate. For purposes of this example, it is presumed that the driver will not decelerate until vehicle 1 has completed the lane change and then the deceleration will be at 0.1 the acceleration of gravity. For the case where vehicle 1 pulls in behind vehicle 2, no deceleration is necessary. This dynamic situation can be reduced to a set of conditions when the driver of vehicle 1 should be advised of the presence of the other vehicle. These conditions are shown in Figure 2.



$2.5\ v - 10 < L < v^2/6.4 + 2.5\ v + 10$

Figure 2. Envelope for Providing a Signal to Inform the Driver of a Potential Threat Situation

From Figure 2, it is seen that the sensing functional element must have the capability of reliably and accurately detecting the presence of a vehicle when the relative velocity and distance are within the shaded area of the figure. This means that the sensing element must provide data on the relative velocity, the length of vehicle 2. the relative longitudinal distance, and lateral distance to vehicle 2. Thus, a test of the sensing element for this system would include a matrix of test-track conditions that would exercise these features. The primary variables would be relative speed and relative longitudinal position between vehicles in adjacent lanes. Secondary variables would the be absolute speed of vehicle 1, background clutter (Jersey barriers, third lane of vehicles, street signs. parked vehicles, buildings, etc.), weather conditions, and road geometry (hills and curves).

Similarly, the functional element for convening sensor data to meaningful driver information should reliably give a signal to the driver if and only if a vehicle is present in the adjacent lane with the conditions of velocity and distance shown in the shaded area of Figure 2. The test for this functional element would seek to determine if the processing element can extract the necessary information from the sensor and accurately make a determination of whether vehicle 2 is in an adjacent lane or further away from vehicle 1 and whether the dynamic conditions are within the shaded area or outside of it. Testing of the sensing element and the processing element might need to be combined into a single test if the system does not include a port that can provide direct access to the sensor output. The functional element for interfacing with the driver should effectively, and in an unambiguous way. communicate this information to the driver.

The tests for the driver interface might include a means of determining how long it takes a driver to realize that a signal is present, the driver’s interpretation of the meaning of the signal, and the driver’s perception of the usefulness and distraction of the system. The tests’ for the driver interface functional element might be based on highway travel, probably with an observer. During this travel. data would be gathered to determine the length of time needed for the driver to recognize that a signal was present (with careful attention to the conditions that existed at the time of the signal) and the interpretation of the meaning of the signal by both naive and trained drivers. The combination of results from these tests would be used to estimate the effectiveness and the error rate, as summarized in Table 3, of the system.

A thorough evaluation of the second tvpe of system would include a description of the various dynamic situations which produce collisions as a result of one vehicle changing lanes coupled with a determination of a quantitative description of the details of relative motion. This analysis would then be followed by an assessment of the features of the situation which must be sensed by the sensing functional element, the control law that needs to be applied to the data to be able to make a determination that a collision is imminent, and the control action message which should he transmitted to the driver. The evaluation of a candidate system would then consist of determining the capability of each of the three functional elements. This would include a determination of the capability of the sensing functional element to accurately gather all of the necessary data in a timely manner. It would also include a determination of the capability of the processing functional element to convert the sensed information into a cogent and timely message to the driver. Thirdly, the evaluation would determine if the driver interface effectively elicits the proper control action from the driver.

For the example described above, it is seen that the sensing functional element must include the capability of sensing the variables needed in the Category 1 case, plus at least the relative lateral velocity between the two vehicles. It will also need the capability for higher resolution of the relative lateral distance (In the Category 1 system it is only necessary to know that vehicle 2 is in the adjacent lane) Tests to determine the performance of the sensing functional element would need to include situations where the vehicles are placed on a collision course This can be accomplished safely by having constant communications between a test director and the drivers of both vehicles with both vehicle 1 and vehicle 2 directed to follow preplanned trajectories The performance of the processing functional element may be determined from this same test protocol. However, this protocol is not appropnate for determining the effectiveness of the driver interface in eliciting proper action from an unprepared driver. The tests for detemining effectiveness of the driver interface may require actuation of the control action message by an observer during a lane change when there is no other vehicle present. The details of this test need to be carefully developed to ensure that the results are scientifically valid and that the test does not expose the subject driver to abnormal risks.

QUESTION 2 (Do vehicles equipped with the system have fewer, or more, collisions than vehicles without the system?)

There are currently no operational tests being performed with collision avoidance systems. Thus, there currently is no opportunity for collecting data on collisions. and near misses. for collision avoidance systems. However, the work done in answering Question 1 will provide a basis for understanding the details of performance that will be involved in evaluation of operational tests. It will also provide a basis for determining data collection needs for support of operational test evaluation.

QUESTION 3 (If all vehicles in the fleet were equipped with the system, would there be a decrease, or increase. in the total number of collisions and collision-related injuries’)

The process that is currently used to estimate the national impact of potential collision avoidance systems has two steps The first is to estimate the effectiveness of the system in eliminating or ameliorating the severity of specific types of collision. This estimated effectiveness is then applied to data from national files of collision data to estimate the number and severity of collisions that would have been eliminated had the system been in place when the collision data was collected.

The basic expression for this process is:

$$E = (N_{wo} - N_{w})/N_{wo}$$

where:

E is the estimated effectiveness of a countermeasure

N_{wo} is the number of collisions that occurred when no vehicles were equipped with the countermeasure

Table 4.
Effect of Rear-Axle Antilock (RWAL) Brakes on Single-Vehicle Pickup Trucks Crashes [20]

Type of Crash Involvement	Last 2 Model Years without RWAL		First 2 Model Years with RWAL	
	N	%	N	%
Primary Rollover	1095	14.5	737	9.6
Side Impact with Fixed Object	759	10.1	633	8.2
Frontal Impact with Fixed Object	2044	27.1	2095	27.3
Control Group (Multivehicle)	3634	48.3	4215	54.9
	7532	100.00	7680	100.00

Nw is the number of collisions that would occur if all vehicles were equipped.

An estimate of the number of collisions that would have occurred if all vehicles had been equipped with a countermeasure can be obtained by rearranging the equation.

$$N_W = N_{WO}(1 - E)$$

Estimated of effectiveness can be obtained from laboratory tests or from collisions records. One of the purposes for testing the performance of IVHS collision avoidance systems is to obtain estimates of effectiveness. A recent study of antilock brakes (ABS) provides an example of the latter approach [20]. In this study, records of single-vehicle collisions involving pickup trucks from the state of Michigan were used. These data are summarized in Table 4. Based on these data and a modification of the above equation which uses multivehicle collisions as a control group, an estimate of effectiveness for installation of ABS on the rear axle of pickup trucks would be 42 percent.

Another approach to estimating effectiveness utilizes the Monte Carlo method of statistical analysis. In this method, assumptions are made about the statistical distribution of critical parameters in the equations that represent performance of a specific system. A series of simulated encounters is then run with a determination made for each encounter of whether a collision would have been avoided or not. In an example of this type of analysis, a rearend collision avoidance system was modeled using a simple single-degree-of freedom model of the system dynamics [2 1]. In this example, drivers were assumed to have perfect detection and driver compliance and to have a reaction time which fit a lognormal distribution with a mean value of 1.21 seconds, the level of deceleration was assumed to have a uniform distribution between 0.5g and 0.85g, and the acquisition range of the system sensor was assumed to be approximately 100 meters. The simulated encounters were of a vehicle approaching a stationary vehicle with a variety of initial speeds. A total of 40,000 combinations of reaction time and level of deceleration were randomly generated according to the specified distributions for each initial speed. The results of this simulation are shown in Figure 3:

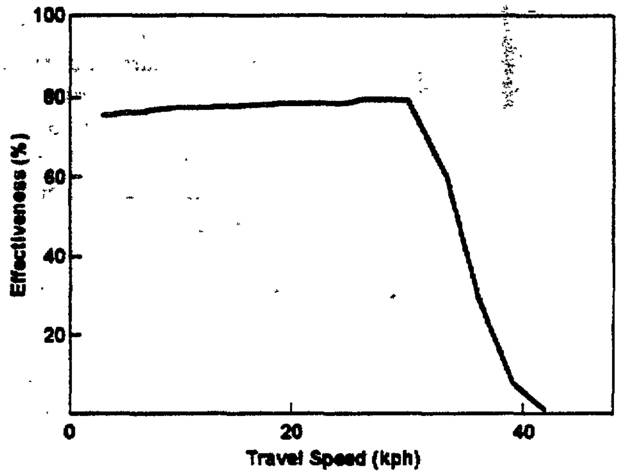


Figure 3. Examples of Estimates of Rearend Collision Avoidance system Based on Monte Carlo Methodology [21]

From this figure it can be seen that the esttmate of effectiveness for this system is a function of the initial speed. Thus, to be able to calculate an estimate of overall effectiveness, it is necessary to combine this functional relationship with an estimate of the distribution of initial speeds. For this example, the speed distribution was obtained from an analysis of collision data. Using this distribution, the estimated overall effectiveness is 77 percent.

In the four contracts discussed previously, an estimate of effectiveness for each system will be developed for each relevant dynamic situation The basis for these estimates will be the tests described in the discussion of Question I The collision tiles will be subdivided by the causal factors, For example, the five precrash variables discussed previously which were initiated in 1992 files provide a basis for more detailed description of causal factors associated with each dynamic situation. The estimates of effectiveness for each dynamic situation will then be combined with the fraction of total collisions for each dynamic situation. The total effect of the system will be obtained by combining the effect for each of the relevant dynamic situations.

In the future, the process described above will be augmented by a process that uses data on near-misses and other non-collision driving actions. The data to support this process will be collected using tools that are currently being developed. One of these tools will be capable of observing vehicles motions and converting this information to a quantitative description of the motion of individual vehicles as well as the relative motion between adjacent vehicles. A second tool which is being developed will provide a means of observing the detailed actions of drivers (e.g. eye point of regard. and time that eyes are off the road) and relating the actions to circumstances around the vehicle (e.g. close proximity of another vehicle). These tools for developing a more in-depth understanding of pre-crash circumstances are discussed in more detail in the companion paper by Leasure and Burgett [22].

IN-VEHICLE DRIVER ADVISORY SYSTEMS

The last type of system to be considered is an in-vehicle hazard warning system. These systems collect information about road conditions and hazards, convert it to meaningful messages to drivers and present these messages to drivers through in-vehicle displays.

Conceptually, these systems are similar to the Category 1 collision avoidance systems discussed in the preceding section because they both advise drivers of situations which have the potential for producing a collision. However, the systems are different in at least two major ways. One difference is in the location of the sensing functional element. In Category 1 collision avoidance systems, the sensors will in all likelihood be in the vehicle. By contrast, the sensors for hazard warning systems will probably be part of the highway infrastructure. The second way these systems are different is in the imminence of the potential collision. In medical terminology, hazard warning systems can be thought of as advising about situations that are distal, in both time and space, from the driver and vehicle. Similarly, Category 1 collision avoidance systems can be thought of as advising about situations that are *proximal* to the driver and vehicle. (Proximal describes biological features which are near the central body while distal describes biological features which are distant from the central body For example. the shoulder is proximal while the hand is distal.) These differences lead to different evaluation procedures for the two types of system.

The system to be discussed is called TravelAid the subject of an operational test on a section of Interstate 90 (I-90) east of Seattle, Washington [23]. This section of Interstate experiences extensive snow and ice during winter months and carries a heavy load of both recreational and commuter traffic due to its proximity to Seattle and several winter recreation areas. The collision rate on this section is significantly higher during winter months than during the remainder of the year as can be seen in Figure 4 [24]. The TravelAid system will provide timely information on traffic, road, and weather conditions as well as information on specific situations such as presence of snowplows. The purpose of the TravelAid system is to reduce he number and rate of collisions by convincing drivers to reduce their speed to one which is consistent with prevailing conditions. by minimizing speed differentials within the traffic stream and by facilitating installation of snow chains and other overt actions. The TravelAid system will gather data from stationary roadside sensors as well as mobile observers such as road crews and police. These data will be transmitted by radio to a central control center. The control center contains the capability of converting sensor data into messages which can be sent to motorists TravelAid will use three different driver interfaces for presenting messages to drivers; in-vehicle displays. variable message signs, and variable speed limit signs.

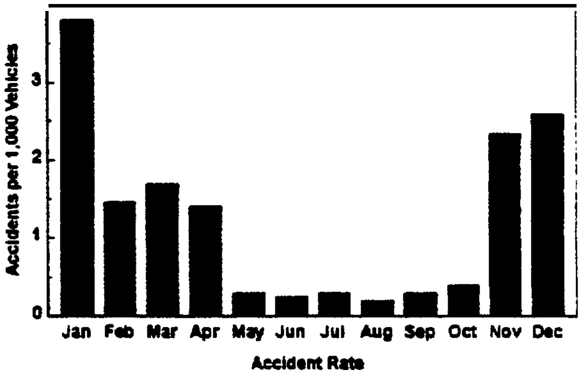


Figure 4. Accident rate by Month (Composite Data from 1988, 1989, and 1991)

This project provides a unique opportunity for evaluation because it includes both an in-vehicle display and variable message signs. The in-vehicle display will be installed in approximately 200 vehicles and the variable message signs will provide information to all highway users. It is expected that the infrastructure support, such as sensors and communicationa, for the in-vehicle units will be available about one year before support for the variable message signs will be available. This will help make it possible to separate the effects of the two types of driver interface. The evaluation of the performance of the in-vehicle unit is the focus of the discussion in this paper.

QUESTION I (Do drivers drive more. or less. safely with the system than without it, in ways related to the system?)

In this project three methods will be used to answer this question. Details of driver interaction with the in-vehicle unit will be obtained from a driving simulator. The simulator will be used to realistically reproduce conditions where a message would be transmitted to the driver. The simulator will be used to observe driver behavior while driving with the TravelAid in-vehicle unit and without it. Time-to-recognition of the presence of the signal as well as interpretation of the meaning of the signal will be determined. Distraction caused by the in-vehicle unit will also be determined, as will any unsafe driving actions as the result of the distraction. Use of a driving simulator is an element of this evaluation which has not been used in the evaluation of other operational tests. A second method for addressmg this question will be to request each user to complete a questionnaire about their experience. They will be requested to record in a post-crossing travel diary all instances when and where they received a signal from the in-vehicle umt as well as their response to the signal. The simulator will also be used as a means of checking and calibrating the answers to these questionnaires. A third method for addressing this question will be the inclusion of instrumentation in the subject vehicles. This instrumentation will be capable of recording time and location of messages as well as keepmg a record of changes in speed. There are several challenges associated with acquisition of in-vehicle data. One is to find sufficiently inexpensive instrumentation that can be readily installed in the participants' vehicles. A second challenge will be to separate normal driving activities from those that are precipitated by a message from the in-vehicle unit. The results from the simulator studies may provide a basis for meeting this second challenge.

QUESTION 2 (Do vehicles equipped with the system have fewer, or more, collistons than vehicles without the system?)

The analysis of collision data will consist of three parts. The first part establishes the baseline. This will be done by reviewing collision data for this section of road from previous years. Additional analysis of state and national files will also be done to provide a quantitative description of collision conditions before availability of the TravelAid system; The second part of the analysis will consist of additional statistical analysis of state files after TravelAid is in use. The third part of the analysis will be a detailed investigation of each collision involving a vehicle with an in-vehicle unit. This detailed study of each collision will help establish the impact of the in-vehicle unit on occurrence of collisions:

QUESTION 3 (If all vehicles in the fleet were equipped with the system. would there be a decrease, or increase, in the total number of collisions and collision-related injuries?)

The TravelAid project consists of both an in-vehicle display and variable message sign display of information about hazards. Additionally, the in-vehicle units till be available during the winter of 1993-94 while the variable message signs will not be available until the winter of 1994-95. This provides an interesting possibility for extrapolating the results from the limited number of vehicles with the in-vehicle units to an estimate of effectiveness if all vehicles were equipped During the first year. data will be gathered on driver reactions to the in-vehicle messages During the second year. it will be possible to gather the same data, but in this case the driver actions will also be influenced by the information from variable message signs. During the second year, it will also be possible to gather data on the reaction of the general public to the information from variable message signs. These three sets of data can then be combined to provide an estimate of impact on collisions if all vehicles were equipped with an in-vehicle unit and there were no variable message signs. A key element of this analysis will be the opportunity to gather data on the reductions in speed that are produced by the variable message signs and the number of collisions which occur during inclement conditions. Thus, it will be possible to directly test the hypothesis that the number of collisions will be reduced if speed is reduced during snowy and icy conditions and when there are hazards in the road. A number of methodological approaches are being considered for this analysis. A detailed analysis approach will be formalized as the project progresses.

CONCLUSIONS

This paper has developed concepts and reported on results for obtaining answers to three fundamental questions about systems which can have an impact on the safety of driving. The three questions are:

- Do drivers drive more, or less. safely with the system than without it, in ways related to the system?
- Do vehicles equipped with the system have fewer. or more, collisions than vehicles without the system?
- If all vehicles in the fleet were equipped with the system. would there be a decrease, or increase, in the total number of collisions and collision-related injuries?

The paper discusses three systems and the methodologies for obtaining answers to these questions. The systems are discussed in the context of the criticality of the information they provide relative to the need for immediate action to avoid a collision.

The three systems discussed in detail are a route-guidance and navigation system, TravTek, which has been the subject of an operational test; two hypothetical collision avoidance systems; and an in-vehicle hazard warning system. TravelAid, which will be the subject of an upcoming operational test. These systems span part of the spectrum of systems which impact the collision avoidance capability of drivers.

This review of methodologies shows that there is no single approach to achieving answers to the above questtons. For the first question. the methodologtes include extended highway use of the TravTek route-guidance and navigation system by participants coupled with in-vehicle data logging and post-driving questionnaires. The TravTek project also included controlled experiments that documented details of the driver interaction with the TravTek system, including relationships between use of TravTek and near misses.

The discussion of collision avoidance systems focused on the need to use test track and laboratory experiments to address the three common functional elements; the sensing element, the processing element and the driver/vehicle interface. It was also pointed out that these tests need to be related to quantitatively described dynamic situations which represent pre-crash circumstances associated with each type of crash. This is especially true of systems which have not reached the point of being available to the public. The methodologies which will be used to evaluate the hazard warning system include the same basic elements as the TravTek evaluation. However, in this case, the controlled experiments will be performed on a driving simulator instead of on the traffic network.

The discussion of methodologies for answering the second question point out the importance of establishing a representative control group which can provide a baseline for comparison of collision rates. This discussion also pointed out the insight on causes and interactions that can be obtained from detailed analysts of each collision that occurs during an operational test.

The paper discusses three different approaches which are being used to estimate the national impact of systems. In the evaluation of TravTek, a computer model which relates collision rates to roadway characteristics and conditions is used to estrapolateresults from the experience of the 100 vehicle fleet that operated for a year. In the evaluation of collision avoidance systems, a statistical approach which combines results from laboratory and test track results with data from crash data files is used. The third approach, which will be used in the evaluation of TravelAid, is to compare results from in-vehicle display of hazard information to a limited subset of drivers with results from the presentation of hazard information to all drivers through variable message signs.

Perhaps the most significant conclusion which can be drawn from this paper is that there is a variety of methodologies that can be used to answer the common set of questions about safety impact. As new projects are started the results from current projects can be used as guideposts for selection of the most appropriate methodologies.

The TravTek project is the only project discussed in this paper which is sufficiently complete to see the results from these methodologies. Even in this project, the evaluation is not complete and the results presented here are based on preliminary analysis. The preliminary analysts suggests that the collision rate during the test was about the same as the national average. The preliminary analysis also indicates that visual turn-by-turn instructions with voice backup appears to provide the highest level of safety; and that the level of safety was not the same for ail display configurations. The results also suggest that the level of safety improves as drivers gained experience in use the TravTek system. Finally, the preliminary analysis of data from questionnaires suggests that drivers believed they had fewer close-calls with the TravTek system than with their own vehicle. However, these data also suggest-that some of the close-calls may have been related to use of the TravTek system.

CLOSURE

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