SAVE-IT

SAfety VEhicles using adaptive Interface Technology (Task 2a)

Estimating Driving Task Demand from Crash Probabilities: A Review of the Literature and Assessment of Crash Databases

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2.0 Program Overview

Driver distraction is a major contributing factor to automobile crashes. National Highway Traffic Safety Administration (NHTSA) has estimated that approximately 25% of crashes are attributed to driver distraction and inattention (Wang, Knipling, & Goodman, 1996). The issue of driver distraction may become worse in the next few years because more electronic devices (e.g., cell phones, navigation systems, wireless Internet and email devices) are brought into vehicles that can potentially create more distraction. In response to this situation, the John A. Volpe National Transportation Systems Center (VNTSC), in support of NHTSA's Office of Vehicle Safety Research, awarded a contract to Delphi Electronics & Safety to develop, demonstrate, and evaluate the potential safety benefits of adaptive interface technologies that manage the information from various in-vehicle systems based on real-time monitoring of the roadway conditions and the driver's capabilities. The contract, known as SAfety VEhicle(s) using adaptive Interface Technology (SAVE-IT), is designed to mitigate distraction with effective countermeasures and enhance the effectiveness of safety warning systems.

The SAVE-IT program serves several important objectives. Perhaps the most important objective is demonstrating a viable proof of concept that is capable of reducing distraction-related crashes and enhancing the effectiveness of safety warning systems. Program success is dependent on integrated closed-loop principles that, not only include sophisticated telematics, mobile office, entertainment and safety warning systems, but also incorporate the state of the driver. This revolutionary closed-loop vehicle environment will be achieved by measuring the driver's state, assessing the situational threat, prioritizing information presentation, providing adaptive countermeasures to minimize distraction, and optimizing advanced collision warning.

To achieve the objective, Delphi Electronics & Safety has assembled a comprehensive team including researchers and engineers from the University of Iowa, University of Michigan Transportation Research Institute (UMTRI), General Motors, Ford Motor Company, and Seeing Machines, Inc. The SAVE-IT program is divided into two phases shown in Figure i. Phase I spans one year (March 2003--March 2004) and consists of nine human factors tasks (Tasks 1-9) and one technology development task (Task 10) for determination of diagnostic measures of driver distraction and workload, architecture concept development, technology development, and Phase II planning. Each of the Phase I tasks is further divided into two sub-tasks. In the first sub-tasks (Tasks 1, 2A-10A), the literature is reviewed, major findings are summarized, and research needs are identified. In the second sub-tasks (Tasks 1, 2B-10B), experiments will be performed and data will be analyzed to identify diagnostic measures of distraction and workload and determine effective and driver-friendly countermeasures. Phase II will span approximately two years (October 2004--October 2006) and consist of a continuation of seven Phase I tasks (Tasks 2C--8C) and five additional tasks (Tasks 11-15) for algorithm and guideline development, data fusion, integrated countermeasure development, vehicle demonstration, and evaluation of benefits.

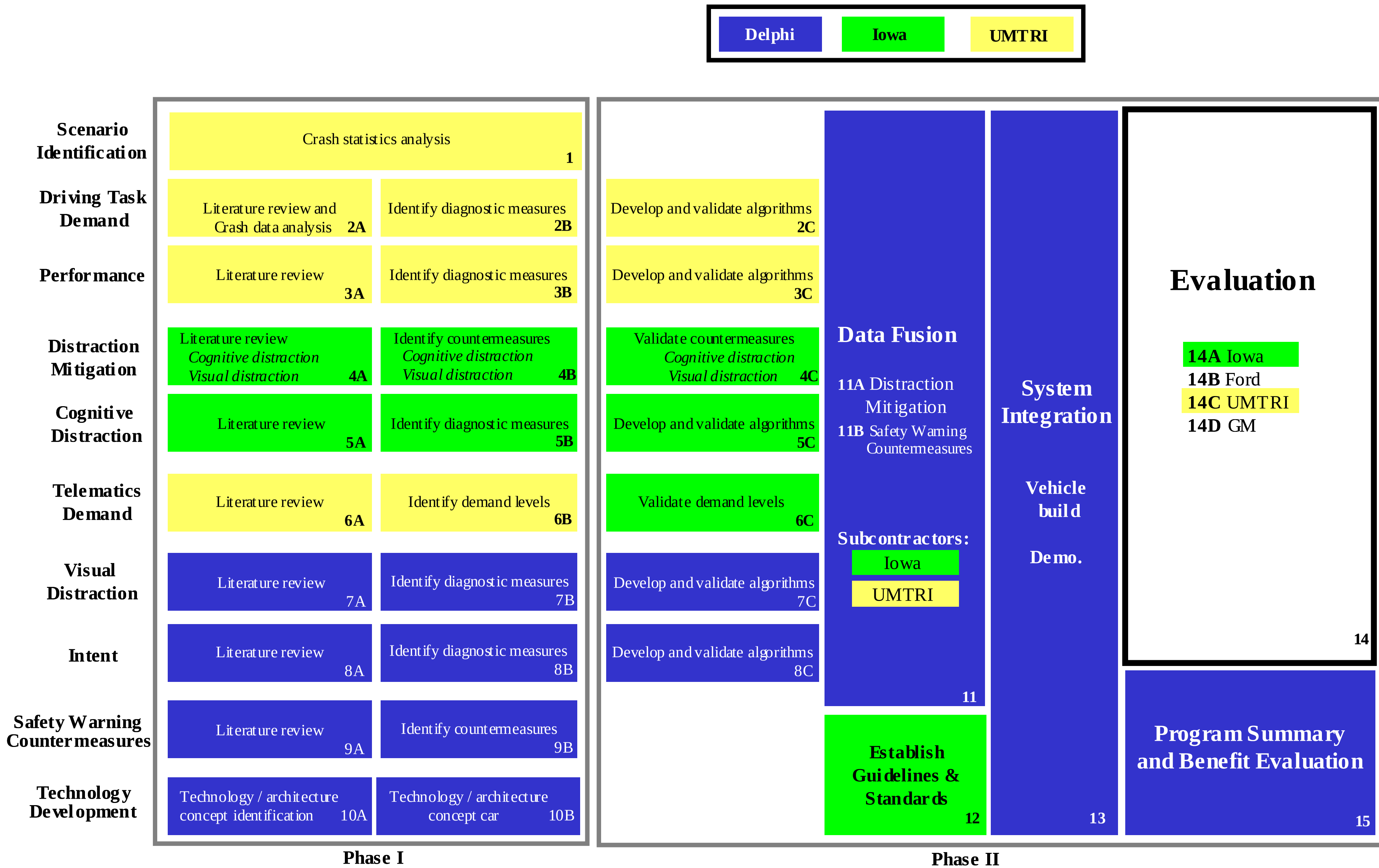

Figure i: SAVE-IT tasks

It is worthwhile to note the SAVE-IT tasks in Figure i are inter-related. They have been chosen to provide necessary human factors data for a two-pronged approach to address the driver distraction and adaptive safety warning countermeasure problems. The first prong (Safety Warning Countermeasures sub-system) uses driver distraction, intent, and driving task demand information to adaptively adjust safety warning systems such as forward collision warning (FCW) systems in order to enhance system effectiveness and user acceptance. Task 1 is designed to determine which safety warning system(s) should be deployed in the SAVE-IT system. Safety warning systems will require the use of warnings about immediate traffic threats without an annoying rate of false alarms and nuisance alerts. Both false alarms and nuisance alerts will be reduced by system intelligence that integrates driver state, intent, and driving task demand information that is obtained from Tasks 2 (Driving Task Demand), 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction), and 8 (Intent).

The safety warning system will adapt to the needs of the driver. When a driver is cognitively and visually attending to the lead vehicle, for example, the warning thresholds can be altered to delay the onset of the FCW alarm or reduce the intrusiveness of the alerting stimuli. When a driver intends to pass a slow-moving lead vehicle and the passing lane is open, the auditory stimulus might be suppressed in order to reduce the alert annoyance of a FCW system. Decreasing the number of false positives may reduce the tendency for drivers to disregard safety system warnings. Task 9 (Safety Warning Countermeasures) will investigate how driver state and intent information can be used to adapt safety warning systems to enhance their effectiveness and user acceptance. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of adaptive safety warning systems and evaluate and document the effectiveness, user acceptance, driver understandability, and benefits and weaknesses of the adaptive systems. It should be pointed out that the SAVE-IT system is a relatively early step in bringing the driver into the loop and therefore, system weaknesses will be evaluated, in addition to the observed benefits.

The second prong of the SAVE-IT program (Distraction Mitigation sub-system) will develop adaptive interface technologies to minimize driver distraction to mitigate against a global increase in risk due to inadequate attention allocation to the driving task. Two examples of the distraction mitigation system include the delivery of a gentle warning and the lockout of certain telematics functions when the driver is more distracted than what the current driving environment allows. A major focus of the SAVE-IT program is the comparison of various mitigation methods in terms of their effectiveness, driver understandability, and user acceptance. It is important that the mitigation system does not introduce additional distraction or driver frustration. Because the lockout method has been shown to be problematic in the aviation domain and will likely cause similar problems for drivers, it should be carefully studied before implementation. If this method is not shown to be beneficial, it will not be implemented.

The distraction mitigation system will process the environmental demand (Task 2:

Driving Task Demand), the level of driver distraction [Tasks 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction)], the intent of the driver (Task 8: Intent), and the telematics distraction potential (Task 6: Telematics Demand) to determine which functions should be advised against under a particular circumstance. Non-driving task information and functions will be prioritized based on how crucial the information is at a specific time relative to the level of driving task demand. Task 4 will investigate distraction mitigation strategies and methods that are very well accepted by the users (i.e., with a high level of user acceptance) and understandable to the drivers. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of using adaptive interface technologies in distraction mitigation and evaluate and document the effectiveness, driver understandability, user acceptance, and benefits and potential weaknesses of these technologies.

In particular, driving task demand and driver state (including driver distraction and impairment) form the major dimensions of a driver safety system. It has been argued that crashes are frequently caused by drivers paying insufficient attention when an unexpected event occurs, requiring a novel (non-automatic) response. As displayed in Figure ii, attention to the driving task may be depleted by driver impairment (due to drowsiness, substance use, or a low level of arousal) leading to diminished attentional resources, or allocation to non-driving tasks[1]. Because NHTSA is currently sponsoring other impairment-related studies, the assessment of driver impairment is not included in the SAVE-IT program at the present time. One assumption is that safe driving requires that attention be commensurate with the driving demand or unpredictability of the environment. Low demand situations (e.g., straight country road with no traffic at daytime) may require less attention because the driver can usually predict what will happen in the next few seconds while the driver is attending elsewhere. Conversely, high demand (e.g., multi-lane winding road with erratic traffic) situations may require more attention because during any time attention is diverted away, there is a high probability that a novel response may be required. It is likely that most intuitively drivers take the driving-task demand into account when deciding whether or not to engage in a non-driving task. Although this assumption is likely to be valid in a general sense, a counter argument is that problems may also arise when the situation appears to be relatively benign and drivers overestimate the predictability of the environment. Driving environments that appear to be predictable may therefore leave drivers less prepared to respond when an unexpected threat does arise.

A safety system that mitigates the use of in-vehicle information and entertainment system (telematics) must balance both attention allocated to the driving task that will be

[1] The distinction between driving and non-driving tasks may become blurred sometimes. For example, reading street signs and numbers is necessary for determining the correct course of driving, but may momentarily divert visual attention away from the forward road and degrade a driver's responses to unpredictable danger evolving in the driving path. In the SAVE-IT program, any off-road glances, including those for reading street signs, will be assessed in terms of visual distraction and the information about distraction will be fed into adaptive safety warning countermeasures and distraction mitigation sub-systems.

assessed in Tasks 3 (Performance), 5 (Cognitive Distraction), and 7 (Visual Distraction) and attention demanded by the environment that will be assessed in Task 2 (Driving Task Demand). The goal of the distraction mitigation system should be to keep the level of attention allocated to the driving task above the attentional requirements demanded by the current driving environment. For example, as shown in Figure ii, “routine” driving may suffice during low or moderate driving task demand, slightly distracted driving may be adequate during low driving task demand, but high driving task demand requires attentive driving.

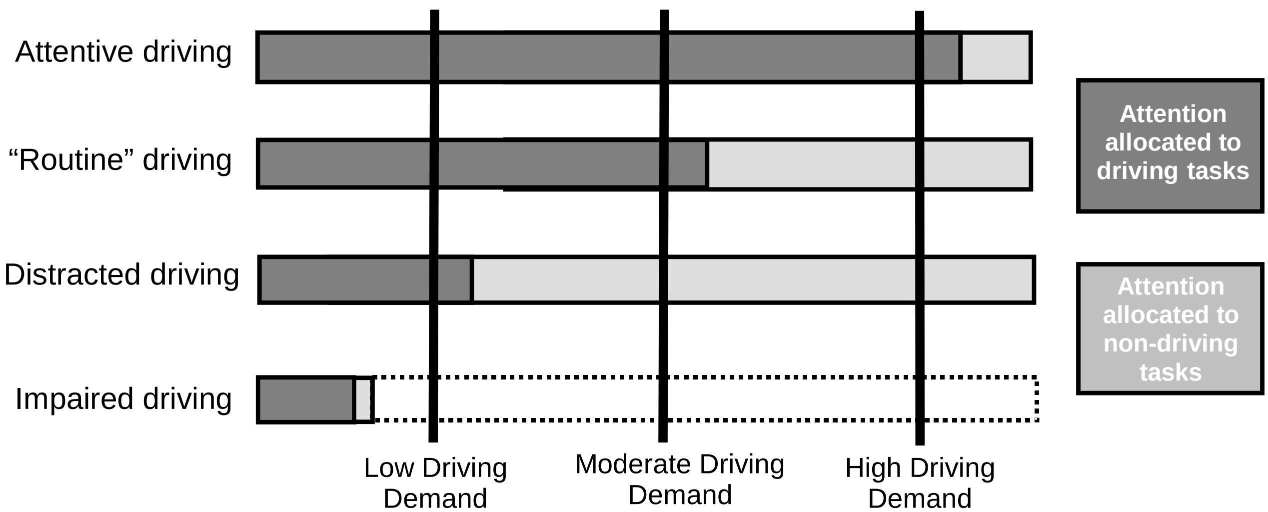

Figure ii. Attention allocation to driving and non-driving tasks

It is important to note that the SAVE-IT system addresses both high-demand and low-demand situations. With respect to the first prong (Safety Warning Countermeasures sub-system), the safety warning systems (e.g., the FCW system) will always be active, regardless of the demand. Sensors will always be assessing the driving environment and driver state. If traffic threats are detected, warnings will be issued that are commensurate with the real time attentiveness of the driver, even under low-demand situations. With respect to the second prong (Distraction Mitigation sub-system), driver state including driver distraction and intent will be continuously assessed under all circumstances. Warnings may be issued and telematics functions may be screened out under both high-demand and low-demand situations, although the threshold for distraction mitigation may be different for these situations.

It should be pointed out that drivers tend to adapt their driving, including distraction behavior and maintenance of speed and headway, based on driving (e.g., traffic and weather) and non-driving conditions (e.g., availability of telematics services), either consciously or unconsciously. For example, drivers may shed non-driving tasks (e.g., ending a cell phone conversation) when driving under unfavorable traffic and weather conditions. It is critical to understand this "driver adaptation" phenomenon. In principle, the "system adaptation" in the SAVE-IT program (i.e., adaptive safety warning countermeasures and adaptive distraction mitigation sub-systems) should be carefully implemented to ensure a fit between the two types of adaptation: "system adaptation" and "driver adaptation". One potential problem in a system that is inappropriately implemented is that the system and the driver may be reacting to each other in an unstable manner. If the system adaptation is on a shorter time scale than the driver adaptation, the driver may become confused and frustrated. Therefore, it is important to take the time scale into account. System adaptation should fit the driver's mental model in order to ensure driver understandability and user acceptance. Because of individual difference, it may also be important to tailor the system to individual drivers in order to maximize driver understandability and user acceptance. Due to resource constraints, however, a nominal driver model will be adopted in the initial SAVE-IT system. Driver profiling, machine learning of driver behavior, individual difference-based system tailoring may be investigated in future research programs.

Communication and Commonalities Among Tasks and Sites

In the SAVE-IT program, a "divide-and-conquer" approach has been taken. The program is first divided into different tasks so that a particular research question can be studied in a particular task. The research findings from the various tasks are then brought together to enable us to develop and evaluate integrated systems. Therefore, a sensible balance of commonality and diversity is crucial to the program success. Diversity is reflected by the fact that every task is designed to address a unique question to achieve a particular objective. As a matter of fact, no tasks are redundant or unnecessary. Diversity is clearly demonstrated in the respective task reports. Also documented in the task reports is the creativity of different task owners in attacking different research problems.

Task commonality is very important to the integration of the research results from the various tasks into a coherent system and is reflected in terms of the common methods across the various tasks. Because of the large number of tasks (a total of 15 tasks depicted in Figure i) and the participation of multiple sites (Delphi Electronics & Safety, University of Iowa, UMTRI, Ford Motor Company, and General Motors), close coordination and commonality among the tasks and sites are key to program success. Coordination mechanisms, task and site commonalities have been built into the program and are reinforced with the bi-weekly teleconference meetings and regular email and telephone communications. It should be pointed out that little time was wasted in meetings. Indeed, some bi-weekly meetings were brief when decisions can be made quickly, or canceled when issues can be resolved before the meetings. The level of coordination and commonality among multiple sites and tasks is un-precedented and has greatly contributed to program success. A selection of commonalities is described below.

<u>Commonalities Among Driving Simulators and Eye Tracking Systems In Phase I</u>
Although the Phase I tasks are performed at three sites (Delphi Electronics & Safety, University of Iowa, and UMTRI), the same driving simulator software, Drive Safety™ (formerly called GlobalSim™) from Drive Safety Inc., and the same eye tracking system, FaceLab™ from Seeing Machines, Inc. are used in Phase I tasks at all sites. The performance variables (e.g., steering angle, lane position, headway) and eye gaze

measures (e.g., gaze coordinate) are defined in the same manner across tasks.

Common Dependent Variables An important activity of the driving task is tactical maneuvering such as speed and lane choice, navigation, and hazard monitoring. A key component of tactical maneuvering is responding to unpredictable and probabilistic events (e.g., lead vehicle braking, vehicles cutting in front) in a timely fashion. Timely responses are critical for collision avoidance. If a driver is distracted, attention is diverted from tactical maneuvering and vehicle control, and consequently, reaction time (RT) to probabilistic events increases. Because of the tight coupling between reaction time and attention allocation, RT is a useful metric for operationally defining the concept of driver distraction. Furthermore, brake RT can be readily measured in a driving simulator and is widely used as input to algorithms, such as the forward collision warning algorithm (Task 9: Safety Warning Countermeasures). In other words, RT is directly related to driver safety. Because of these reasons, RT to probabilistic events is chosen as a primary, “ground-truth” dependent variable in Tasks 2 (Driving Task Demand), 5 (Cognitive Distraction), 6 (Telematics Demand), 7 (Visual Distraction), and 9 (Safety Warning Countermeasures).

Because RT may not account for all of the variance in driver behavior, other measures such as steering entropy (Boer, 2001), headway, lane position and variance (e.g., standard deviation of lane position or SDLP), lane departures, and eye glance behavior (e.g., glance duration and frequency) are also be considered. Together these measures will provide a comprehensive picture about driver distraction, demand, and workload.

Common Driving Scenarios For the tasks that measure the brake RT, the "lead vehicle following" scenario is used. Because human factors and psychological research has indicated that RT may be influenced by many factors (e.g., headway), care has been taken to ensure a certain level of uniformity across different tasks. For instance, a common lead vehicle (a white passenger car) was used. The lead vehicle may brake infrequently (no more than 1 braking per minute) and at an unpredictable moment. The vehicle braking was non-imminent in all experiments (e.g., a low value of deceleration), except in Task 9 (Safety Warning Countermeasures) that requires an imminent braking. In addition, the lead vehicle speed and the time headway between the lead vehicle and the host vehicle are commonized across tasks to a large extent.

Subject Demographics It has been shown in the past that driver ages influence driving performance, user acceptance, and driver understandability. Because the age effect is not the focus of the SAVE-IT program, it is not possible to include all driver ages in every task with the budgetary and resource constraints. Rather than using different subject ages in different tasks, however, driver ages are commonized across tasks. Three age groups are defined: younger group (18-25 years old), middle group (35-55 years old), and older group (65-75 years old). Because not all age groups can be used in all tasks, one age group (the middle group) is chosen as the common age group that is used in every task. One reason for this choice is that drivers of 35-55 years old are the likely initial buyers and users of vehicles with advanced technologies such as the SAVE-IT systems. Although the age effect is not the focus of the program, it is examined in some tasks. In those tasks, multiple age groups were used.

The number of subjects per condition per task is based on the particular experimental design and condition, the effect size shown in the literature, and resource constraints. In order to ensure a reasonable level of uniformity across tasks and confidence in the research results, a minimum of eight subjects is used for each and every condition. The typical number of subjects is considerably larger than the minimum, frequently between 10-20.

Other Commonalities In addition to the commonalities across all tasks and all sites, there are additional common features between two or three tasks. For example, the simulator roadway environment and scripting events (e.g., the TCL scripts used in the driving simulator for the headway control and braking event onset) may be shared between experiments, the same distraction (non-driving) tasks may be used in different experiments, and the same research methods and models (e.g., Hidden Markov Model) may be deployed in various tasks. These commonalities afford the consistency among the tasks that is needed to develop and demonstrate a coherent SAVE-IT system.

The Content and Structure of the Report

The report submitted herein is a literature review report that documents the research progress to date (March 1--September 10, 2003) in Phase I. During the period of March-September 2003, the effort has been focused on the first Phase I sub-task: Literature Review. In this report, previous experiments are discussed, research findings are reported, and research needs are identified. This literature review report serves to establish the research strategies of each task.

2.1 INTRODUCTION

Like other complex human behaviors, operating a motor vehicle requires a driver to focus a substantial portion of his or her attentional resources on the driving task. The level of attention required for safe driving is likely to be highly correlated with the complexity of the driving environment. The influence of driving task demand on traffic safety was identified more than 40 years ago, as stated by Versace (1960) in his interpretation of crash-data factor-analysis results:

> "*There are more accidents at those places where the situation places a greater demand on the momentary perceptual-decision-motor capacities of the driver*" (Versace, 1960; page 29).

Highway design and standardization efforts have undoubtedly lowered the driving task demands by reducing road complexity and increasing its predictability (American Association of State Highway and Transportation Officials, 2001; Federal Highway Administration, FHWA, 2000). Some road segments, however, require a greater level of attention from drivers than others. The driving task demand of a particular road segment may change with variations in traffic volumes, density, mix of vehicle types, and presence of construction or repair activities. Driving the same road segment in rain, in the dark, or under other inclement conditions may also require increased driving task demand. As the demand on driving increases, fewer attentional resources are available for non-driving tasks leading to a greater likelihood of crashing, particularly when the driver is distracted.

Crash databases have been selected by the SAVE-IT team as potential data sources for developing a surrogate measure of driving task demand. Crash rates can be thought of as indicators of the volatility or unpredictability of the environment and likely correlate highly with the amount of attention that is demanded by the environment for certain combinations of road, traffic, and environmental conditions.

This document has three purposes: 1) synthesize previous research on crash prediction models that were based on analysis of crash data that can be related to driving task demand; 2) review and synthesize human factors literature that address the attentional demands of the roadway, traffic, or environmental conditions; and 3) review available crash databases to identify relevant databases and potential measures of driving task demand for our future research.

2.2. WHAT DRIVING TASK DEMAND TRENDS CAN BE IDENTIFIED FROM PREVIOUS CRASH DATABASE RESEARCH?

The working hypothesis of the SAVE-IT project is that roadway locations and conditions of higher driving task demand should have higher crash rates than locations and conditions of lower driving task demand. Therefore, relationships that predict crash occurrence for roadways and environmental conditions should be an invaluable resource for understanding driving task demand. The ability to describe and predict the occurrence of crashes on roadways has been a challenge to the transportation profession since the early days of motorized transportation. Although the reason for seeking relationships between crash occurrence and characteristics of the roadway system was to identify locations with safety problems so that countermeasures could be evaluated and highway funds allocated wisely, the findings from these studies should be useful in identifying trends in driving task demand.

Most empirical and theoretical efforts to model crash occurrence as a function of road system characteristics consider either roadways or intersections. Because of the large number of possible design configurations and operational features possible for each characteristic, studies were usually limited to some subset of roadways or intersections, (e.g., two-lane rural roads, urban freeways, four-legged signalized intersections, etc.) A good example of this is the procedure used in the development of the Interactive Highway Safety Design Model (IHSDM) by the FHWA (2003). The IHSDM is a suite of software analysis tools intended for explicit, quantitative evaluation of safety and operational effects of geometric design decisions during the highway design process. The IHSDM consists of various modules, among which is the crash prediction module, which estimates the number and severity of crashes that could be expected on specified road segments based on its geometric design and traffic characteristics. The initial focus has been on two-lane rural highways, and the crash prediction module of the 2003 release of IHSDM includes only two-lane rural roads and at-grade intersections on two-lane rural roads. Future releases will include crash prediction modules for other types of roads and intersections.

An exhaustive review of studies that have explored the effects of roadway features on crash occurrence is beyond the scope of this article, as the literature on the effects of any subset of roadway features on crash occurrence is very extensive. This review examines a set of studies that have analyzed large crash databases (usually together with other data) to obtain relationships between crash rates and characteristics of the location of the crash that could be useful for understanding driving task demand.

2.2.1 Roadways

The primary geometric and operational elements in roadway design and, thus, also in roadway characteristics which have been studied in relation to crashes are: cross-section; horizontal and vertical alignment; access control (i.e., are there driveways and at-grade intersections or is access to the roadway controlled, either fully or partially); the density of access points; area type (urban, rural); and land use at the roadside.

2.2.1.1 Roadway Cross-Section

The major elements of cross-section include the number and width of lanes, presence and type of median, type and width of shoulders, and roadside features (e.g., side slope, clear zone, placement and types of roadside obstacles).

The effects of cross-sectional elements on crash occurrence have been examined in many empirical studies. A classic early study by Schoppert (1957) examined crash occurrence on two-lane rural roads in Oregon and developed descriptive and predictive models using regression analysis. Schoppert found that vehicle crashes were directly related to traffic volume and certain features of the roadway, including lane and shoulder width. Schoppert found that the crash rate increased with reduced cross-section width, but reported that lane width and shoulder width did not serve as good predictors of the number of crashes. Versace (1960) further analyzed Schoppert's data. He recognized that roadway features were correlated with each other; that is, good cross-sectional elements usually go together, and furthermore, good cross-sectional elements were usually found together with good alignment. These, he noted, are the result of road design and construction practices. Versace identified shoulders and lane width as factors affecting crash occurrence but noted that their effects were not as important as that of traffic volume. Increased crash rates with decreased lane and shoulder widths were also reported by Dart and Mann (1970) and Roy Jorgensen and Associates, Inc. (1978).

Kilberg and Tharp (1968) investigated the relationship between motor vehicle crashes and highway design elements (including cross-section) using data from five states by analyzing crash counts on homogenous road segments of two- and multi-lane roadways. They found that number of lanes and median affect crash rates. The effect of the median, however, was not very marked and was found in only some of the states examined.

Cleveland, Kostyniuk, and Ting (1984, 1985) examined crash data for two-lane rural highway segments from 14 states using statistical categorical techniques. They confirmed Versace's observation that good (or bad) geometric features were usually found together, and concluded that it would be difficult to construct a good experimental design from "real-world" crash data. For their analysis, they grouped cross-sectional features (lane width, shoulder width, side slope, ditch condition) that were usually found together in roads into a set of "geometric bundles" that varied from excellent to poor. An effect of the geometric bundles on crashes was found, but it was not as important as the effects of traffic volume and access density and the interactive effect of the geometric bundles and access density.

A study by Zeeger and Deacon (1987) quantified the effects of lane width, shoulder width, and shoulder type on highway crash experience based on the analysis of data for nearly 5,000 miles of two-lane highway from seven states. The study controlled for many roadway and traffic features, including roadside hazard, terrain, and traffic volume. Lane width and shoulder type and width were found to be related to crash rates and could also be related to crash type. A crash prediction model was developed and used to determine the expected effects of lane and shoulder widening improvements on related crashes.

A large effort at the Federal Highway Administration (FHWA, 1982; Cirillo, Dietz, and Beatty, 1969; Cirillo, 1970) investigated the effects of geometric and traffic parameters on crashes on the Interstate System. Using data from 24 states, regression models were developed for 19 model categories for various segments of interstate system, including interchanges of the mainline roadway. The basic finding of these analyses concerning geometric elements which included cross-section, was that because the geometrics on interstate roads are generally very good, their variations, when they occur, have little influence on crashes.

The IHSDM includes an algorithm for predicting the safety performance on two-lane rural roads (Harwood, Council, Hauer, Hughes and Vogt, 2000). The base model provides an estimate of the safety performance on a roadway or intersection for a set of assumed nominal conditions. The modification factors adjust the base model predictions to account for the effects on safety for roadway segments of various geometric and operational features. For cross-sectional elements, the base conditions are two 12 ft. lanes, paved 6 ft. shoulders, and a roadside characterized as marginally recoverable. The adjustment factors vary by traffic volume conditions. Basically, the effects of lane width and shoulder type and width at low traffic volumes are very limited, but become larger at traffic volumes over 2,000 vehicle per day.

The IHSDM crash prediction algorithm also includes the effects of passing lanes on crash rates on two-lane rural roads. Based on the work of Harwood and St. John (1984), the algorithm predicts a reduction of crash rates with the installation of short four-lane sections that allow passing.

It is clear that because of design policy and construction practices, the design level of cross-sectional elements varies by type of road. More importantly, the amount of variation in the quality of the cross-sectional elements varies by type of road. Two-lane rural roads have the most variation in cross-sectional elements and freeways tend to be more homogenous. Most of the studies of crash data examined here indicate a relationship between lane width, shoulder width, and shoulder type on crashes for road types where there is significant variation in these elements. Furthermore, the effects of the cross-sectional elements on crashes are usually interactive with traffic volume and access density. There are several implications of these studies on driver task demand. The first is that road type may provide a useful classification by which to address driving task demand. The second is that combinations of standard lane widths, shoulder width, and shoulder types probably can be associated with some basic level of driver task demand that may vary with deviations from those standards.

2.2.1.2 Horizontal and Vertical Alignment

Elements of horizontal alignment include degree and length of horizontal curve, presence of spiral or other transition curve, and the superelevation. Elements of vertical alignment include vertical lines or grades and vertical curves (sags and crests).

In a study of two-lane and multi-lane rural roads from 15 states, Raff (1953) found that crash rates increased with the degree of curve. On two-lane roads, the crash rate increased with curve frequency. Crash rates also increased with sight distance restrictions, which are primarily due to crest vertical curves. The study also found that grade alone did not have an effect on crash rates on tangent (straight) sections of road, but there was an increase in crash rates when both grade and horizontal curvature were present. Increased crash rates on combinations of grades and horizontal curves have also been reported by Bitzel (1957). Bitzel data was from 25,500 crashes on 1,300 miles of German highways. However, Bitzel found that crash rates increased as grades increased. Kilberg and Tharp (1968) found effects on crash rates of horizontal curves only for curves of four degrees or more and for grades of four percent or more.

The effect of horizontal curves on crashes was also investigated by Glennon, Neuman, and Leisch (1986). A database that included crash, geometric, and traffic data for two-lane rural highway segments from four states was developed for this study. There were over 3,000 segments with horizontal curves and about 350 control tangent sections. Care was taken to select sites with uniform lane and shoulder conditions and to avoid influences of bridges, intersections, curbs and other nearby horizontal curves. Analysis of covariance methods were used to develop a model which related the number of crashes on curves to the traffic volume, degree of curve, and length of curve.

Matthews and Barnes (1988) analyzed curve crashes on 2000 km of highways in New Zealand. They identified prior curvature (total number of curvature in the two km preceding the curve where a crash occurred) as having the largest effect on curve crash rates, followed by grades, and radius of curve. They also report that crash risk was particularly high on short radius curves located at the end of long tangents and on steep down grades.

A more recent study of safety effects on horizontal curves on two-lane rural roads was conducted by Zeeger et al. (1990). Data from Washington state included five years of crash data, information on degree of curve, length of curve, curve direction, central angle, presence of spiral transition, roadside data (recovery distance, roadside hazard rating), cross-sectional information (lane width, also width and type of shoulder), and traffic volume. In all, there were over 12,000 crashes with an average of 0.22 crashes per curve. Statistical analysis revealed significantly higher curve crashes for sharper curves, narrower lane width on curves, lack of spiral transitions, and increased superelevation deficiency. All else being equal, higher traffic volume and longer curves were associated with significantly higher curve crashes.

Federal Highway Administration studies (FHWA, 1982; Cirillo, Dietz, & Beatty, 1969; Cirillo, 1970) of the effects of geometric and traffic parameters on crashes on the Interstate System did not find a significant contribution of horizontal or vertical alignment on crash rates on freeways. However, a study by Dunlap, Fancher, Scott, McAdam and Segal (1978) that examined the effects of horizontal and vertical curves on crash rates on the Pennsylvania and Ohio Turnpikes found no significant relationship between crash rates and grades and horizontal curves in Ohio, but there were increases in crash rates with increasing curvature of horizontal curves in Pennsylvania.

The IHSDM crash prediction algorithm for two-lane rural roads (Harwood et al., 2000) includes the effects of horizontal and vertical alignment. The base model provides an estimate of the safety performance on a tangent and flat road segment. The crash rate for long flat curves is only slightly higher than for tangent roadways. However, the crash rate increases with the sharpness and shortness of the curve. Spiral transitions to the curve mitigate the crash rates as does adequate superelevation. The algorithm also predicts an increase in crash rate for increases in grades at steeper grades.

The implications of these studies for driver task demand is that horizontal curves increase driver task demand as the curve radius and curve length decrease. The presence of spiral transitions and superelevation mitigate the situation somewhat. The frequency of the horizontal curves is also likely to affect driving task demand. However, the relationship does not necessarily have to be linear. A series of frequent curves may have a high driving task demand, but so may an isolated curve. These studies also imply that driving task demand increases with combinations of horizontal curves and vertical grade and also with the steepness of vertical grades.

2.2.1.3 Access Density

Roadways can be accessed from driveways and from other roads directly at intersections (at-grade intersections). On some roads access is restricted either fully or partially. Thus, roads with no at-grade intersections or driveways, such as freeways, are fully controlled for access; roads with no driveway access and/or some at-grade intersections are partially controlled for access; and roads with driveways and at-grade intersections are not access controlled. The effect of the type of access control and the density of access points on crash occurrence have long been of interest to the traffic safety community.

Many studies have found that crash rates increased with access density at all levels of traffic volume (Schoppert 1957; Kilberg and Tharp, 1968; Fee, Beatty, Dietz, Kaufman, & Yates, 1970; McGuirk, 1973; Glennon & Azzeh, 1976; Stover, Tignor & Rosenbaum, 1982; Cleveland, Kostyniuk, and Ting,1985, 1986). The effect of access control was clear-cut and substantial. Kilberg and Tharp (1968) report that crash levels on road segments with partial or full access control were measurably lower than at road segments with no access control. Crash rates on road segments with full access control were lower by as much as two-thirds than sections with no access control. For roads with no access control, crash rates increase with increasing density.

Driveway density is included in the IHSDM crash prediction algorithm for two-lane rural roads (Harwood, et al., 2000). Crash rates increase with driveway density. However, the increases in crash rates at various levels of access density are related to the traffic volume. Crash increases are greater at lower traffic volume than at higher traffic volume. The implication is that driving task demand increases with decreasing access control. Another implication is that increasing access point density increases driving task demand.

2.2.1.4. Construction Zones

The presence of work activities and construction zones on the roadway is known to affect crash occurrence. Juergens (1972) reported increased crash rates of 7-21% relative to a pre-construction baseline for ten long-term construction projects. Liste, Bernard, and Melvin (1976) reported an increase of 119% in crash rate during work zone operation compared with the pre- work zone period. Graham, Paulsen, and Glennon (1977) reported on pre- work zone and during work zone crashes for 79 long-term construction projects in seven states. Their analysis indicated an average increase of 7.5 percent in crash rates during the work zone period. Nemeth and Migletz (1978) reported an increase of 7 percent in work zone crashes relative to pre-work zone period. Rouphail, Zhao, Yang, and Fazio (1988) studied three long-term and 25 short-term work zones. For one long-term work zone site, they reported an 88% increase in crash rates relative to pre- work zone period. For short-term sites, they found a nearly constant rate of 0.8 crashes per mile per day that was independent of the length and duration of the work activity. Khattak, Khattak, and Council (2002) report a total increase of 21.5 percent in the rate of crashes relative to pre- work zone rate in an analysis of 36 work zones on California freeways. Although the rate of increase varied across the studies, there is agreement that construction activity on a road site increases its crash rates. The implication is that driving task demand is probably higher on road segments with construction activity than on those without this activity.

2.2.2 Intersections

Intersection configurations include a multitude of patterns. The most common configurations are: four-legged, three-legged, T-type, Y-type, and offset. Intersections can also have different traffic control devices: stop signs, yield signs, or traffic signals. Among the variables of interest included in the various studies of intersection crashes are: urban/rural area; number of legs; angle of intersection; alignment; lane and shoulder widths; approach speeds; type of traffic control; intersection sight distance restrictions; number and configuration of lanes (number of through lanes, channelization, left and right turn lanes); traffic signal phasing; lighting; tire-pavement friction; turning radii; traffic volumes on approaches to the intersection; and turning volumes.

Early studies of intersection crashes found that intersection crash rate per volume of traffic was sensitive to changes in the proportion of traffic flow from the various legs of the intersection. An early and widely known study by Tanner (1953) using crash data from 232 rural three-leg intersections in England and Wales, found that the frequency of collisions between vehicles turning around either shoulder was approximately proportional to the square root of the product of the traffic volumes on the main road and around either shoulder. Other early studies of intersection crashes (McDonald, 1953; Raff, 1953; Webb, 1955) indicate that an increase in traffic on the major facility has a small effect on the crash rate, whereas an increase in traffic volume or an increase in the percent of traffic from the minor facility results in a rapid increase in the crash rate.

There have been many studies that explored the relationship between crashes and detailed descriptions of the features of the intersections, which were collected from highway department files and site visits. For example, Hannah, Flynn and Webb (1976) examined the relationship between crashes and characteristics of intersections in rural municipalities in Virginia. Data included crash reports for 2,300 crashes from 300 intersections in 42 towns and the description of the intersections. Their analysis produced crash rates for intersections by configuration, traffic control and traffic volume. David and Norman (1975) analyzed the three-year crash history of 558 intersections in Northern California. Data included crash histories and detailed on-scene inventory of geometric, design, and traffic characteristics at the intersections. Categorical analysis methods were used. Results indicate that sight distance obstruction, street names signs, use of left-turn storage lanes, use of raised marker delineation, bus loading zones, and multiphase signalization affected crash rates.

Still other studies concentrated on developing statistical models of the relationship between traffic crashes and geometric features. Bauer and Harwood (1996) developed statistical models incorporating the effect of traffic control features and traffic volumes on intersection crashes. Data were from the California Department of Transportation supplemented by field data from a sample of urban four-legged, signalized intersections. The statistical modeling approaches included Poisson, lognormal, negative binomial, and logistic regression, as well as discriminant and cluster analyses. Regression models of the relationships between crashes and intersection geometric design, traffic control, and traffic volume variables were found to explain between 16 and 38 percent of the variability in the crash data. However, most of the variability was explained by the traffic volume variables considered, whereas geometric variables accounted for only a very small additional portion of the variability.

Vogt and Bared (1998) analyzed data from Minnesota to build crash models for three- and four-legged intersections on rural two-lane roadway with stop-controls on the minor legs. Variables included traffic, horizontal and vertical alignment, lane and shoulder widths, roadside hazard rating, channelization, and number of driveways. Data were modeled with negative binomials and extended negative binomials. They found that the intersection crashes depended primarily on traffic volumes. Joksch and Kostyniuk (1997), examining four-legged signalized intersection crashes in California and Minnesota found that the complex relationships between crash counts and traffic volumes on the major and minor roads could not be adequately represented by standard loglinear models and used nonparametric regression in the form of kernal smoothing for a more realistic representation of complex relationships.

The IHSDM (FHWA, 2003) contains a module for predicting crashes on at-grade intersections on two-lane rural roads. The crash prediction algorithm contains base models for three- and four-legged stop controlled intersections and for a four-legged signalized intersection. Modification factors for the stop-controlled intersections are provided for the effects of skew angle, intersection sight distance limitations, and the presence of turning lanes. For four-legged intersections, factors for the effects of turning lanes are provided. All are given for various levels of traffic volume on the major and minor roads.

The implication of these studies on driving task demand is that it increases with the complexity of the intersection. The complexity of the intersection could be ranked by the traffic control, and turn lanes. Because most studies of intersection crash occurrence identified traffic volume as the most important predictor, the implication is that driving task demand would increase with traffic flow within each intersection category.

2.2.3 Weather

Weather constitutes a set of environmental factors that can influence crash occurrence by increasing crash risk. Empirical evidence suggests that a wet road surface increases crash frequency (Jones, Janseen, & Mannering, 1991) and that truck-involved freeway collisions increase on wet and icy road surfaces (Golob & Recker, 1987). Many studies have investigated the impacts of adverse weather and road geometry on crashes (Khattak, Kantor, & Council, 1998; Ivey et al., 1981; Jovanis & Delleur, 1981; Snyder, 1974; Brodsky & Hakkert, 1988; Shankar, Mannering & Barfield, 1995). Satterwaitte (1976) analyzing California data, found a ratio of the number of crashes during 24 hours when almost all crashes occurred in wet conditions to the number of crashes occurring in dry conditions to be 2.23 times. A study on Texas roadways (Ivey, et al., 1981) found that wet crash frequency per mile increased with higher AADT(annual average daily traffic); higher number of lanes; greater access density; higher proportion of time the road surface is wet; and higher traffic speed variation but lower speed and lower skid number (a measure of the surface friction). Shankar, Mannering and Barfield (1995) found that crash frequency on an Interstate in the Snoqualmie Pass area of Washington state increased with a higher number of horizontal curves; higher maximum grades; higher frequency of rainy days; higher maximum daily snowfall in a month; interactions of maximum snowfall with grade; and with curves. Overall, the literature shows that crash frequencies are higher in adverse weather conditions because of reduced visibility and reduced road friction. An implication of these studies is that driving task demand is higher in adverse weather conditions; that is, during conditions such as reduced visibility and low pavement friction.

2.2.4 Traffic Volume

Relationships between crash occurrence and geometric and operational characteristics of roadways often use a measure of traffic volume as the exposure measure of crash occurrence. However, there is strong empirical evidence of relationships between crash rates and traffic volume, conditional upon roadway characteristics (Schoppert, 1957; Versace,1960; Cleveland, Kostyniuk, and Ting, 1984,1985; Hall and Pendleton, 1989; Stokes & Mutabazi, 1996; Garber & Gadiraju, 1990). Schoppert's (1957) study found that crash rates increased with increases in vehicle volume. He also reported that crashes on low volume roads did not appear to be related to any roadway feature. Versace (1960) found ADT (average daily traffic, a measure of traffic volume) to be the variable most highly related to crash occurrence. Cleveland, Kostyniuk, and Ting (1984, 1985) found the relationship between crashes on road segments and ADT to be nonlinear and the best predictor of crashes on two-lane rural roads. They also found the interactive effects of access point density with ADT to be very important in predicting crashes. In roadways built for high-design speeds, such as freeways, traffic volume appears to be the most important predictor of crashes. Other studies that FHWA studied of crashes on the interstate system (Cirillo, Dietz, & Beatty, 1969; Cirillo, 1970) concluded that the traffic volumes and commercial traffic volumes were the main contributors to the explanation of the crashes on the interstate system of roads. ADT was also found to be the most important variable in the relationship between traffic crashes and highway geometric design elements and traffic volumes on interchange ramps and speed-change lanes (Bauer & Harwood ,1997).

As noted in the previous section, traffic volumes were also identified as being the variable most related to crash occurrence at intersections. The interactive effect of traffic volume on crash occurrence is built into the IHDSM crash prediction algorithm for two-lane rural roads and intersections (Harwood, et al., 2000). The effects of each of the design or operational features are given for different levels of ADT.

Traffic volume is a very important factor in crash occurrence by itself and in interactions with most, if not all, of the geometric and operational characteristics of roads and intersections. The implication is that the influence of traffic volume on driving task demand should also very important with driving task demands increasing with traffic volume. However, there is evidence that the effect of traffic volume on crash occurrence is not linear, and the occurrence of crashes at low volumes that cannot be attributed to geometric features argues for increased driving task demand at low levels of traffic volume also. Note also that traffic volume is a measure of traffic per unit time and is a separate concept from traffic density, which is a measure of the spacing between vehicles. High traffic volumes can lead to high traffic density, but not necessarily.

2.3 WHAT ARE THE ATTENTIONAL DEMANDS OF THE ROADWAY, TRAFFIC, AND WEATHER?

The roadway, traffic, and weather conditions present a wide array of stimuli that attract a driver's visual attention. As depicted in Figure ii, in most driving situations the driver's attentional capacity is adequate to handle the demands of the driving task. However, as the attentional demands increase due to a change in roadway, traffic, or environment, the driver's attentional capacity may become inadequate, which could increase the likelihood of a distraction-related crash.

Because of this increased potential for a crash, it is important to determine the visual-attention demands of various characteristics of the roadway, traffic conditions, and weather conditions. Nearly 40 years ago, Senders, Kristofferson, Levinson, Dietrich, and Ward (1967) presented a method for studying the visual demands of driving that involved intermittently occluding the driver's vision. The underlying principal of the visual occlusion method is that greater demands on visual attention will require increasing amounts of time viewing the road. Senders et al. (1967) developed a helmet worn by the driver with an opaque visor that could be lowered either by an experimenter or the driver him/herself. In this study, drivers operated an actual passenger vehicle on both straight sections of Interstate roadway and a closed course.

While clever, the method proved impractical for two important reasons. First, many important variables, such as traffic conditions, could not be studied reliably on a closed course. Second, Institutional Review Boards were reluctant to approve open-road studies in which the subject would drive, at least some of the time, without vision. Thus, very little was discovered about visual driving task demand until the relatively recent development of driving simulators in the last 15 years.

This section reviews the few human factors studies of visual driving task demand. We organize this section by three general categories of visual demand: roadway, traffic, and weather. In addition, because visual demand may be influenced by driver characteristics or behavior, we also include a driver category.

2.3.1 Roadway

As first described by Versace (1960), crashes seem to be more likely at certain roadway characteristics. This implies that the visual characteristics of certain road features may create higher demand than other features. While there are many roadway features that could be investigated in a human factors study, only two features have been researched: curves and lane widths.

2.3.1.1 Curves

The visual demand of driving horizontal curves has been studied extensively with the visual occlusion method (Courage, Milgram, and Smiley, 2000; Godthelp, 1986;

Mourant and Ge, 1997; Senders, et al., 1967; Shafer, Brackett, and Krammes, 1995; Tsimhoni and Green, 1999; Tsimhoni, Yoo, and Green, 1999; Wooldridge, Bauer, Green, and Fitzpatrick, 1999; Wooldridge, Fitzpatrick, Koppa, and Bauer, 2000). Generally, these studies show that drivers need more visual input for curves than for straight sections of roadway, indicating that curves require greater visual demand. Those studies that have systematically varied the features of curves (e.g., Shafer, Brackett, and Krammes, 1995; Tsimhoni and Green, 1999; Tsimhoni, Yoo, and Green, 1999; Wooldridge, Fitzpatrick, Koppa, and Bauer, 2000) have found that visual demand: 1) is inversely related to the radius of curvature; 2) does not vary much with deflection angle; 3) begins to rise at the end of the approach tangent and peaks at the beginning of the curve followed by a decline throughout the curve; 4) was higher for s-curves than for broken-back curves (a broken-back curve has two curves in the same direction whereas an s-curve has two curves in opposite directions) but the effect was weakened with a large separation between the curves; and 5) these finding held for both on-the-road and simulator studies.

Another potentially demanding curve-type is vertical curves (hill and valleys). Perhaps because driving simulators do not simulate vertical curves adequately and test-courses are usually flat, the effect of this roadway characteristic has not been studied. Future work should address the visual demand of various horizontal curves.

2.3.1.2 Lane Width

Another frequently studied roadway characteristic is lane width. Crash analyses on Highway Safety Information System data show that crash-rates are elevated for narrow lane widths (Zeeger, Huang, Stewart, and Williams, 1998), suggesting that visual demand might also be related to lane width. Indeed, studies utilizing the visual occlusion method have found that the percent of time not occluded increased with decreasing lane width; that is, visual demand increased with decreasing lane width (Courage, Milgram, and Smiley, 2000; Senders et al., 1967; Van der Horst and Godthelp, 1989). For example, Courage, Milgram, and Smiley (2000) varied lane width in a medium-fidelity driving simulator. They found that as width varied from 3.7 to 2.7 m (12 to 9 feet), visual demand increased by 6 percent. Thus, the effect of lane width is significant but not strong.

2.3.1.3 Other Characteristics

Several other roadway characteristics undoubtedly affect visual demand. These characteristics include: shoulder width, sight distance, pavement markings, and roadway surface. Theoretically, each of these features can increase the uncertainty of the driving task leading to increased visual demand. However, we could find no human factors studies that have investigated these variables in an attentional demand context.

2.3.2 Traffic Density

As the density of vehicles increase for a given driving situation, the likelihood of a vehicle doing something unexpected increases. As such, increases is traffic density should increase visual demand. Using a medium-fidelity simulator and the visual occlusion method, Mourant and Ge (1997) presented two levels of on-coming traffic density (no traffic and "moderate density") to subjects while they drove both curved and straight roadway sections. Results showed that the percent of nonoccluded vision increased with increasing traffic density; that is, visual demand was 8 percent higher for moderate traffic than for no traffic. This effect, however, was found only for driving curves. Whether or not visual demand was affected by high density traffic on straight sections of roadway is unknown, but would undoubtedly increase demand on curved sections of roadway.

2.3.3 Weather

The weather conditions during a particular driving situation should influence visual demand, especially if conditions degrade visual perception (such as rain or fog) or increase the difficulty of maintaining lane position (such as with a strong cross-wind or an icy road). Probably because these conditions are difficult to simulate in the laboratory and even more difficult to create artificially on a closed driving-course, an extensive search of the literature revealed no studies that have investigated visual demand of driving in inclement weather.

2.3.4 Driver

While characteristics of the roadway, traffic density, and weather may influence the visual demand of the driving task, demand is also affected by the driver's characteristics and behaviors. Here we review the literature on the visual demand of driving by age, sex, and driving speed.

2.3.4.1 Age

Whether considered on a per mile or a per population basis, crash rates vary as a function of age (National Highway Traffic Safety Administration, NHTSA, 2000). There is also clear evidence of age effects in selective, divided, and sustained attention (Comalli, Wapner, and Werner, 1962; Parasuraman and Greenwood, 1998; Sexton and Geffon,1979). Thus, it is likely that visual demand of driving would also exhibit age effects.

Tsimhoni, Yoo, and Green (1999) and Tsimhoni and Green (2001) assessed the differential effects of young drivers (age 21-28) and older drivers (aged 66-73) on visual demand. Utilizing the visual occlusion method, they found that older drivers had significantly higher visual demand for straight roadway sections and three curves of different radii. In a similar study, Tsimhoni and Green (1999) investigated differences in visual demand among three age groups (18-24; 35-54; 55-up). Again, subjects drove both straight and curved sections of roadway. These researchers found increased visual demand by age group for all curve radii studied. On straight roadways, however, visual demand was significantly different only for the oldest age group. Thus, these studies show that there is a clear interaction among age, roadway type, and visual demand and that for a given driving situation, older drivers will experience a greater visual demand than younger drivers.

2.3.4.2. Sex

Besides the obvious genotypical sex[1] differences, men and women differ in cognitive abilities (Halpern, 1992), risk taking (Jonah, 1997), and automobile crash rates (NHTSA, 2002a). These differences suggest that men and women may also differ in visual demand for a given driving situation. Several studies have addressed this issue (Courage, Milgram, and Smiley, 2000; Tsimhoni and Green, 1999; Tsimhoni and Green, 2001; Tsimhoni, Yoo, and Green, 1999). Generally these studies find that females drivers require more time viewing the road in a given situation than male drivers. For example, Courage, Milgram, and Smiley (2000) had subjects drive straight and curved roadways that varied in width. Over all conditions, they found that females required 8 percentage points more time viewing the road than did males. This significant difference was of the same magnitude as the effect of lane width found in the same study. Thus, balancing the subject sex in human factors studies of visual demand is important.

2.3.4.3 Driving Speed

While not a characteristic of the driver per se, the speed at which a driver travels influences occlusion study results. Numerous investigations have shown that as velocity increases, the percent of time viewing the forward scene also increases (Courage, Milgram, and Smiley, 2000; Godthelp, Milgram, and Blaauw, 1984; Mourant and Ge, 1997; Senders et al., 1967). Senders et al. (1967) studied velocities ranging from 5 and 75 MPH in an on-road occlusion study. They found a monotonic relationship between velocity and percent of time viewing the roadway. Mourant and Ge (1997) considered two velocities (20 and 60 MPH). They found a 9 percentage point increase in visual demand as velocity increased from 30 to 60 MPH. In a study utilizing similar speeds Courage, Milgram, and Smiley (2000) found slightly greater increases in visual demand. Thus, there is a clear relationship between the speed at which a driver is traveling and the visual demand of the driving situation.

[1] As suggested by Halpern (1992), the word “sex” rather than “gender” is used in this document. According to Halpern, gender is an inappropriate label for distinguishing differences between males and females because “gender” is: most often used as a euphemism for sex; borrowed from linguistics to distinguished between forms of nouns that have no relationship to maleness or femaleness; and the common use of gender to describe psychological differences and sex to describe biological differences is artificial since psychology and biology has closely coupled.

2.4. WHICH CRASH DATABASES ARE AVAILABLE AND FEASIBLE FOR DRIVING-TASK-DEMAND ANALYSES?

Several widely-utilized databases are available for these analyses. As a way of selecting the most useful database, we review each to determine which contains the richest information related to driving task demand: road features, traffic volumes, and environmental conditions. We also assess the ability to generalize from these databases. Each database is first reviewed and then conclusions are drawn.

2.4.1. National Automotive Sampling System General Estimates System

The National Automotive Sampling System General Estimates System (NASS GES, henceforth referred to as GES) contains crash data that is generally representative of all crashes in the United States (US). The crashes recorded in GES are from a nationally representative probability sample selected from the estimated 6.8 million police-reported crashes which occur annually and include all types of crashes involving all types of vehicles. GES is the best crash database for determining national estimates of police-reported crashes. The data records in GES are coded from the original police crash reports by trained personnel (NHTSA, 2002b, 2002c).

GES contains descriptive information about the location of the crash and about the environmental conditions at the time of the crash. Information about the location of the crash includes the number of lanes, the type of roadway surface, whether the roadway was divided, whether the roadway was one- or two-way, and the speed limit. Another variable notes if the crash occurred at an intersection or was intersection related. If the crash occurred at an interchange, the location within the interchange (e.g., on ramp) is recorded. The horizontal alignment is given as either straight or curved and a profile variable reports the vertical alignment as either level, grade, hillcrest, or sag. Presence and types of traffic controls are also recorded.

GES does not include variables on the traffic volumes, density, or traffic mix at the site of the crash. A rough surrogate variable, however, could be developed from the functional-road-class variable, which classifies roads into urban or rural, principle arterials, major arterials, major collectors, minor collectors, or local roads or streets. Because traffic volumes are usually higher in urban locations than in rural ones, and because traffic volumes are highest on principal arterials and lowest on local roads and streets, this functional road classification offers a reasonable hierarchy for ordering traffic volumes.

Environmental conditions that can be obtained from the GES include atmospheric conditions such as rain, sleet, snow, fog, smoke, smog, and blowing sand and/or dust. The light conditions are included as daylight, dark, dark but lighted, dawn, and dusk. There is also a road surface variable which denotes the condition of the road surface as dry, wet, snow, or slush.

2.4.2 The National Automotive Sampling System Crashworthiness Data System

The National Automotive Sampling System Crashworthiness Data System (NASS CDS, henceforth referred to as CDS) is a database designed to assist in studies of vehicle crashworthiness. CDS contains detailed information on a representative, random nationwide sample of police-reported crashes involving passenger vehicles (passenger cars, light trucks, vans, and sport-utility vehicles) in which at least one vehicle was damaged seriously enough to require towing from the crash scene. All crashes included in the sample (about 5,000 per year) are studied in detail by field research teams. The data records in CDS come from information and measurements at the crash site and from the crash-involved vehicles, other physical evidence, interviews with crash victims, and review of medical records (NHTSA, 2001, 2003b).

Data on the roadway in CDS is similar to that found in the GES. Information on the road cross-section includes the number of lanes, the type of road surface, whether the roadway was divided, whether traffic was one-way or two-way, and the speed limit. Horizontal alignment is denoted as either straight or curved and the profile is denoted as level, grade, hillcrest, or sag. Crash location at an intersection or within an interchange is noted. Presence and types of traffic controls are also included.

CDS does not have traffic volume information nor does it have a variable that could serve as a surrogate. The environmental conditions that could be obtained from the CDS data are the same as in GES and include atmospheric conditions (rain, sleet, snow, fog, smoke, smog, and blowing sand and dust), light conditions (daylight, dark, dark but lighted, dawn, and dusk), and roadway-surface conditions (dry, wet, snow, or slush).

2.4.3 Fatality Analysis Reporting System

The Fatality Analysis Reporting System (FARS) contains information on all vehicle crashes in all 50 states, the District of Columbia, and Puerto Rico that resulted in at least one fatality. Trained analysts code FARS records from police crash reports, other information including witness statements, and autopsy reports (NHTSA, 2002d, 2003a). This database is the best source of information available for those interested in traffic fatalities.

The variables in FARS that describe the roadway and environment at the time and location of the crash are the same as in GES. These include number of lanes, the type of road surface, whether the roadway was divided and whether traffic was one-way or two-way, speed limit, and traffic controls. Horizontal alignment (straight, curved) and profile (level, grade, hillcrest, or sag) are noted. Intersection and interchange crashes are also noted. FARS does not have information on traffic volumes or traffic mix. However, as in GES, a functional-road-class variable is available thus making it possible to use it as a rough surrogate for traffic volume. Some construction information is available.

The same environmental conditions that can be obtained from GES can be obtained from FARS. These include atmospheric conditions (rain, sleet, snow, fog, smoke, smog, and blowing sand and dust), light conditions (daylight, dark, dark but lighted, dawn, and dusk), and roadway-surface conditions (dry, wet, snow, or slush).

2.4.4 Highway Safety Information System

The Highway Safety Information System (HSIS) is maintained by the Federal Highway Administration and is used in studies of the relationship between road features and crashes. HSIS contains information on crashes, roadway inventory, and traffic volumes as well as other road geometric features for nine states: California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington. Ohio joined HSIS in 2002. Participation of states in HSIS is based on the availability and quality of their data and the ability to merge data from various files (Highway Safety Information System, 2000a, 2000b, 2000c, 2000d, 2001).

Data for each state comes in a set of relational databases that are different for each state. These data include a roadway inventory, information on traffic volumes for the roads included in the inventory, and crashes that occurred on the roads in the inventory. All roads in a state, however, are not necessarily in the inventory. In Michigan, for example, only the state trunkline roads are included in the inventory and therefore in HSIS.

Each state's HSIS data system has a roadlog data file that contains detailed information about the road system in the state. The road system is divided into homogenous segments along routes. Although the states' roadlogs are different from each other, each describes the road cross-section and alignment in detail. Other elements that may be included in the roadlogs are the traffic control information, rural/urban designation, functional classification, cross-sectional elements (such as the number of lanes), lane widths, type of roadway surface, width and type of each shoulder, median width, and access control. Parking lanes are noted as is the presence of curbs. Locations of traffic control devices are noted. Horizontal curves are described in some states by degrees of curvature (or radius) and length of curve. Vertical alignment is given in grades. Minnesota and California have additional intersection databases. Data include the intersection type, number of legs, traffic control, and description of the intersection approaches.

The HSIS files for each state also include data on traffic, including information on the Average Annual Daily Volume (AADT), speed limit or design speed, and for some states, the proportion of trucks on the road. The crash data files for each state contain the basic crash, vehicle, and occupant information for each crash. The location of the crash is included so it can be related to the other files. The crash files contain information on the weather, light, and road surface conditions. Some states have a specific variable for road construction activity. For other states it is possible to determine if there was road repair or construction at the time of the crash through other variables.

The feasibility of using HSIS data to simple predictive model using limited data that could be used for planning was explored by Mohamedshah (1994). He attempted to develop crash rates for eight categories of highway segments (urban freeways, urban two-lane highways, urban multi-lane divided highways, urban multi-lane undivided highways, rural two-lane highways, rural multilane divided highways, and rural multi-lane undivided highways) from HSIS data. Statistical analysis showed that data for all roadway types cannot be combined for all HSIS states (five at the time of this study). He was able to determine crash rates for road sections on eight different types of roadway for two states separately. The paper notes that developing of the crash rates requires judicious manipulation of the data and sound engineering judgment.

2.4.5 Regional Geographic Information System Databases

Many states and regions are developing regional Geographic Information System (GIS) databases that include the road network, traffic volumes, crashes, pavement condition, population, and land use. For example, the state of Michigan has developed a GIS database for the Michigan trunkline road system that includes road characteristics and crashes. Other organizations in Michigan have adapted the GIS database for their own purposes. The Southeast Michigan Council of Governments (SEMCOG) is using the GIS database as a tool for planning regional transportation policy. Several counties in southeast Michigan are also in the process of developing GIS databases of their roadways and crashes including the Traffic Improvement Association of Oakland County and the counties of Washtenaw and Jackson. The databases are used to identify traffic problem areas, manage resources, and produce maps rapidly and accurately. They were not developed for research purposes, but could be used for that purpose, if needed.

2.4.6 Summary

Each database reviewed has certain advantages and disadvantages relative to identifying and understanding driving task demand. Table 1 summarizes the features of the databases reviewed along with the dimensions important for identifying driving task demand.

As shown in Table 2.1, GES, CDS, and FARS are limited for use in analyses of driving task demand. They contain information on the environmental conditions at the time of the crash but information about roadway features at the crash site is general and little information on traffic volumes is available. Regional databases may contain the detailed information about the road and traffic, as well as crashes. However, the data are only representative of the region and linking the various databases may be difficult.

HSIS appears to be best suited for examining the relationship between crash occurrence and driving task demand (i.e., roadway features, environmental conditions, and traffic volumes). HSIS contains information about crashes including the environmental conditions, such as weather, light, and road surface condition at the time of the crash. In HSIS, an analyst can also obtain detailed information about the geometric features of the crash site, the traffic control devices, as well as information about the traffic volume. For most states in HSIS, it is also possible to determine if there was construction or maintenance activity at the site at the time of the crash.

Table 2.1 Summary of Database Assessment

Database	Road Features	Traffic Volumes	Environmental Conditions	Nationally Representative
GES	General data on cross-section, alignment, and traffic control	No, but can use functional class as surrogate	Yes, atmospheric, light, and road surface	Yes, national sample of all crashes
CDS	General data on cross-section, alignment, and traffic control	No	Yes, atmospheric, light, and road surface	Yes, national sample of crashes involving passenger vehicles with towable damage
FARS	General data on cross-section, alignment, traffic control, and road construction activity	No, but can use functional class as surrogate	Yes, atmospheric, light, and road surface	Yes, but only of fatal crashes
HSIS	Detailed data on road cross-section, alignment, and road construction activity	Yes, AADT percent trucks	Yes, atmospheric, light, and road surface	No, data from eight states. States were selected for data quality, not sampled.
Regional data bases	May have detailed data on road cross-section, alignment, and road construction activity	Yes, AADT, percent trucks, peak period volumes, average daily traffic volumes	Yes, atmospheric, light, and road surface	No, data are region specific

There are limitations with using HSIS in the analysis of driving task demand. The crashes in HSIS are not nationally representative because the states in HSIS were not sampled but selected for other reasons. Furthermore, the crashes included in each state's data are neither the population of crashes nor a random sample, but consist of all crashes that occurred on the roads that are in the state's road inventory (which usually does not cover all the roadways in the state). Despite this, HSIS is the only data system that contains the information desired for the analysis. It is also possible to minimize regional effects by selecting states from several regions of the country for analysis. It should also be noted that HSIS data are not available from Internet sites but must be requested from FHWA. Thus, there will be some time delay in obtaining these data.

2.5. DISCUSSION

This review has described the concept of driving task demand and the crash databases from which crash probabilities as a function of several variables are available for use as a surrogate measure of demand. Note that given the resources for this task, crash probability estimates cannot parallel the crash prediction models developed for two-lane rural road segments and intersections by Harwood et al. (2000). Their models were developed as part of a large multi-year FHWA Interactive Highway Design Model (IHDM) effort which, when completed, will provide methods and models to estimate the probability of crashes on many types of roads and intersections. This effort can, however, produce first-order estimates based on crash rates obtained from tabulations of available data. These crash rates could then be organized into a “look-up” table based upon the important variables. In the future, the look-up table could be replaced by the crash prediction models from IHDM as they are released.

2.5.1 Analysis Plan

The HSIS database was selected for this task because it contains information on roadways and intersections, traffic volumes, and crashes. Michigan will be selected from among the available HSIS states because the on-the-road tests in later SAVE-IT tasks are to be conducted in Michigan, even though Michigan no longer contributes to HSIS. The resulting crash probability look-up table will be applicable to Michigan.

The Michigan HSIS data system covers about 10,000 miles of state trunkline roadway and contains a crash data file and separate files with geometric and operational variables for road segments, intersections, and interchanges. The most recent Michigan HSIS data systems are from 1996 and 1997, and have information on about 50,000 road segments, 28,000 intersections, and 900 interchanges. HSIS data are obtained from HSIS/FHWA, after a process of application, review, and approval. HSIS data can be obtained as crash-based or element-based (segment, intersection, interchange). Crash-based files are those in which each record is a crash and information about geometric and operational elements has to be matched to the crash site. Element-based files are those for which there is a single record for each element and information about crashes that occurred on this element are added to it. An entire file of any type cannot be requested from HSIS. One has to specify a subset of variables and a custom file will be extracted for that request.

Because the objective is to obtain crash rates for specific types of locations, information will be requested on road segments, intersections, and interchanges. Information on geometric and operational characteristics of road segments is contained the Michigan Roadlog file. The segments are homogenous in geometric and operational characteristics and vary in length. Most segments are quite short. Section length is a variable in the file, as are beginning and ending mileages along the route. Table 2.2 lists the relevant variables from the segment file.

Table 2.2: Relevant Michigan HSIS road segment variables

Road Segment Variables	Michigan HSIS		Comment
	Variable Name	Categories	
Calculated section length	SEG_LNG	length of segment in miles	needed to determine crash rate per mile
million vehicle miles traveled	MVMT		may use to determine rate
traffic average # of vehicle per unit time	Annual Average Daily Traffic AADT	actual number	Only traffic volume variable for all traffic needed to determine crash rate per vehicle
road type	Roadway Class RODWYCLS	eleven codes for urban freeway to rural multilane	Useful for categorizing road types
	Functional Class FUNC_CLS	rural, urban interstate, arterial collector	Useful for categorizing road types
culture rural, urban, suburban, industrial	Functional Class FUNC_CLS (industrial classification not available)	rural, urban interstate, arterial collector	This is the best variable to urban/rural description
posted speed limit	SPD_LIMT SPD_LIM2	speed limit in MPH	may help to categorize road segments
Roadway Type	ONEWAY	1-way roadway, 2-way roadway, divided highway, freeway, 2-way roadway with 1-way trunkline	Can identify divided highways with this variable
# of lanes	basic number of lanes BAS_LNS	Actual number of lanes excluding miscellaneous extra lanes	
shoulder width	total shoulder width on left, on right and (WD2) is coded only for divided highways LSHLWID LSHL_WD2 RSHLWID RSHL_WD2	actual width in feet	It would also be useful to know if there is a curb if no shoulder
shoulder/curb type left	LSHL_TYP LSHL_TY2	six codes describing curb or shoulder	can identify if curb or shoulder are present on left
shoulder/curb type right	RSHL_TYP RSHL_TY2	six codes describing curb or shoulder	can identify if curb or shoulder are present on right
lane width	Average Lane width LANWID LANWID2 (for divided	8 ft or less 9 ft eight codes to	

	roadways)	15 ft	
Miscellanous extra lanes left EXT_LNL		six codes- from no aux lanes to extended r or l turn lane, etc	
Presence of median MED_TYP		nine categories of median including no median	
Miscellanous extra lanes right EXT_LNL		six codes- from no aux lanes to extended r or l turn lane, etc	
road geometry/sight distance restriction No passing Zone	PASS	codes for: passing allowed, no passing in one direction, no passing in both directions	usually indicates restricted sight distance associated with grades and curves
road geometry grade, vertical curvature	terrain type TERRAIN	level rolling	These are the only variables related to vertical curves in the Michigan file
road geometry horizontal curve	DIR_CURV	right curve, left curve ne, nw, se, sw	Separates curves and tangent sections. ne, nw, se, sw are bearings of tangent sections.
road geometry horizontal curve	curve or bearing degree DEG_CURV		Information on horizontal curves has to be separated from bearing (for tangent sections) using additional variable DIR_CURV

Two measures not available in this data system are traffic volumes at specific times during the day and driveway (access point) density. These variables are not found in any crash databases. Whenever these variables appear in crash causation studies, data were gathered through labor-intensive site specific field measurements (or photologs, for access density).

Intersection information is included in the Michigan HSIS file if at least one of the intersection roads is on the Michigan trunkline. Most of the information that can be obtained from this file is concerned with the trunkline. However, there is some information on the cross road. Table 2.3 shows the variables that are relevant from the Michigan HSIS Intersection file.

Table 2.3: Relevant Michigan HSIS road segment variables

Intersection Variables	Michigan HSIS		Comment
	Variable Description	Categories	
type of intersection stop sign vs traffic sight	Signal type SIG-TYP	No signal fixed time signal semi actuated signal fully actuated signal flasher	No signal means the intersection is stop or yield controlled. Flasher is a stop control The fixed, semi and fully actuated = signal control
type of intersection # of legs	Number of Intersection legs NBR_LEGS	3,4,5,6,7	
type of intersection	Intersection Type INT_TYP	8 categories of 4 legged intersections, 7 categories of T, 8 categories of Y, various merges and diverges	detailed information on the type of intersection
traffic average # of vehicle per unit time	Annual Average Daily Traffic AADT	11 categories from 1 to 40,000+	Available only for the trunkline approach to intersection
type of road (major vs minor)	int_flg	trline/not trline major leg of tline/tline minor leg of tline/tline tline/nonpublic road	if the intersection is with a non trunkline road, we do not know anything about the non trunkline road.
presence/absence of turn lanes (right)	Number of Aux Lanes - trunkline departure on right AXLN_DR Number if Auxillary lanes right side of trunkline approach AXLN_AR	actual number	
presence/absence of turn lanes(left)	Number of Aux Lanes - trunkline departure on left AXLN_DL Number if Auxillary lanes left side of trunkline approach AXLN_AL	actual number	

Information about on- and off-ramps and interchanges between freeways is contained in the Michigan Interchange file. The interchange file is different from the segment and intersection files in that crash counts (total and by several categories) are already included in the file. The crash counts are for a three-year period and are totaled for the entire interchange. The way the data file is structured it is not possible to get the crashes mapped to individual components of the interchange (i.e., on ramp, off ramp, etc). Table 2.4 shows the relevant Michigan HSIS interchange variables for driving task demand.

Table 2.4 Relevant Michigan HSIS interchange variables

Michigan HSIS		Comment
Variable Description	**Categories**	
Interchange type I_TPYE	diamond, tight diamond, cloverleaf, trumpet, 30 codes	will need to be collapsed - describe interchange
Activity Density ACT-DEN	rural urban	
Annual Average Daily Traffic AADT	11 categories from 1 to 40,000+	AADT on mainline
Total Accidents TOT_ACCS	categories by 5 up to 50, then 51+	
Summary of Dark Accidents DRK_ACCS	categories by 5 up to 50, then 51+	
Summary of Icy Accidents ICE_ACCS	categories by 5 up to 50, then 51+	
Summary of Wet Accidents WET_ACCS	categories by 5 up to 50, then 51+	
Junction Type Code JUN_TYP	20 codes interstate & local road Interstate &business loop, etc.	will need to be collapsed, may be useful for description
Ramp Terminal or Intersection Traffic Control RMP_TERM	5 codes free flow merge free flow/ add lane stop, signalized, yield	may be useful for description

The analysis approach for segments and intersections will be similar but separate. The first step will be to divide the major categories of each into the groups for which we will obtain crash rates, based upon the findings from the earlier sections of this document. For example, among roads, rural-two lane roads, multi-lane roads, and freeways are each treated separately; and among intersections, signalized and unsignalized intersections are treated separately. These major categories will be further partitioned by segmentation analysis (Lim, Loh, & Shin, 2000; Sonquist, Baker, & Morgan, 1973) using SEARCH software (Solenberger, 2003).

Segmentation methods are useful for empirically searching a database for strong relationships between nominal and categorical variables. Segmentation provides a model-free exploratory procedure that algorithmically partitions a set of observations to mutually exclusive and exhaustive subgroups. The data set is sequentially partitioned into subsets of observations based on the categories of the independent variables. The decision about whether or how to partition is based on a preset criterion, for example, maximizing the difference between the sum of the squares of the dependent variable. We will start with an unrestricted segmentation using the rate for total crashes as the independent variable, critically examine the results in light of previous studies, and, if necessary, specify some of the partitioning. The first analysis will yield crash rates for the various categories of roads and intersections. The analysis will be repeated using the crash rates by light conditions, weather conditions, and peak period as independent variables. The difference in the rates for the various conditions will allow us to determine the effect of the environmental conditions on the crash rates.

The data for interchanges is more limited than that for road segments and intersections. We have information on the type of interchange, whether it is in a rural or urban setting, the mainline AADT, and total crash counts and crash counts for various conditions. This will allow us to determine crash rates for rural and urban interchanges by interchange type for categories of mainline AADT. Because the data include crash counts for several weather and light conditions these environmental effects can be included in the analysis.

2.5.2. Conclusions

The use of crash probabilities as a surrogate measure of driving task demand is a reasonable first-pass method for establishing a “proof-of-concept” in the early phases of the development of the SAVE-IT system. It should be noted, however, that there are some limitations to this approach. As we have already described, all crash databases have limitations regarding either variable availability, accuracy, or generality, and this limitation is not likely to be alleviated in the future. Also as previously discussed, perhaps the most important variable affecting crash probabilities is traffic volume; the number of vehicles traveling a segment during a given time period. Traffic volume, which is a variable in crash databases, is distinct from traffic density (the spacing between vehicles), which is not contained in crash databases. Traffic volume and density are related through the speed of the traffic stream. While, traffic flow theorists have been studying this relationship for some time, the nature of the relationship is still a topic of research (see Gartner, Messe, & Rahti, 1999; Gerlough & Huber, 1975). However, usable relationships among the three variables for various types of roads could be obtained from the Highway Capacity Manual (Transportation Research Board, 2000). Obtaining the traffic density data needed to estimate the traffic volume from one independent vehicle, however, would be quite challenging. Thus, one of the strongest predictors of crashes from crash databases, may not be useful for SAVE-IT. A final limitation is that crashes happen under both low and high demand conditions. While we can remove the low demand crashes from our look-up table in the current project based upon expert opinion, this fact highlights the need for a more general surrogate measure of driving task demand.

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