NCHRP
REPORT 488

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Additional Investigations on Driver Information Overload

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Additional Investigations on Driver Information Overload

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Various Westat staff made important contributions to the work. Richard Huey developed the instrumentation for the laboratory and on-road experiments and Carina Tornow programmed control software. Dr. Paul Zador provided statistical advice. The conduct of the experiments and analyses was supported by Jerimiah Singer, Molly Fogash, Adele Bensur, Carolyn Kalinowski.

FOREWORD

By Charles W. Niessner,
Staff Officer
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This report presents the findings of a research project to investigate the information load imposed on drivers from freeway signs and to develop a model to predict driver information load. The model has been incorporated into a software tool to help practitioners identify driver information overload problems and evaluate alternatives for sign locations. The report will be of particular interest to traffic engineers with responsibility for freeway sign legends and installations.

"Driver information overload" results from providing too much information, through devices or conditions, for a driver to perceive and respond properly. Therefore, the information load on a driver is a property not only of the specific sign they are encountering, but also of the roadway context in which the sign occurs, the information context in which the sign occurs, the behavior characteristics of the driver, and the particular navigational task. Where drivers are confronted with more information than they can process, they may decelerate severely or drive unduly slowly, make late or erratic maneuvers, take an improper route alternative, ignore critical information, fail to monitor other traffic, or have excessive eyes-off-the-road episodes. These behaviors have obvious safety and operational consequences.

Under NCHRP Projects 3-50 and 3-50(2), "Driver Information Overload" and "Additional Investigations on Driver Information Overload," respectively, Westat, Inc. developed and validated a driver information overload model for freeways and translated the model into a practical tool for traffic and safety professionals to use in analyzing driver information loadings.

Based on a literature review and analysis of alternate approaches, NCHRP Project 3-50 made substantial progress in understanding the problem and developed a general model that captured the primary aspects of the problem. Two research experiments conducted under Project 3-50 provided some empirical basis for certain aspects of the model. However, at the conclusion of the project, the model remained primarily conceptual rather than empirical.

Project 3-50(2) expanded on the previous work by conducting additional laboratory and on-road experiments. The laboratory experiments attempted to bracket the range of information loads associated with each sign type and the manner in which individual signs of a sign array combine to determine the overall information load associated with processing the sign array. The on-road experiments used a unique procedure in which the drivers continuously operated a thumbwheel dial, mounted on the steering wheel, in order to reflect moment-to-moment changes in the subjective difficulty of taking in all of the information with which they were dealing. The experiments also recorded vehicle speed, navigational errors, and other overt driver problems. Taken together, the experiments provided an empirical basis for refining the general conceptual model.

The model and the associated empirical base still has some limitations. Among these, there was not a sufficient empirical basis for defining a "red line" level that indicates information overload. The model output is quantitative, but relative at this point. Thus, alternate sign treatments can be compared as better or worse, but more research or experience with the model will be required before a given information load rating can be taken to be good, questionable, or bad (overload).

The model can be used to evaluate a given system of signs or to seek improvements using a "what if" approach. In addition to the software tool, the project also provided a set of guidelines and recommendations for dealing with sign information overload problems.

CONTENTS

ADDITIONAL INVESTIGATIONS ON DRIVER INFORMATION OVERLOAD

SUMMARY

NCHRP Project 3-50(2), "Additional Investigations on Driver Information Overload," investigated the problems motorists face when confronted with a multitude of complex sign displays as they drive and navigate. It extends work begun under a predecessor project, NCHRP Project 3-50, "Driver Information Overload." Together, these projects involved research that developed a model that predicts the peak information demand experienced by drivers when encountering arrays of signs on freeways. The model was then adapted as a software tool to help practitioners identify problems related to driver information load and evaluate alternatives for locating signage.

"Driver information overload" is defined as providing a motorist with too much information, through a series of devices or conditions, for a driver to have adequate time to perceive and respond properly. Therefore, the information load on a driver is a property not only of the specific sign he or she is encountering, but also of the roadway context in which the sign occurs, the information context in which the sign occurs, characteristics of the driver, and the particular navigational task. Where drivers are confronted with more information than they can process, they may decelerate severely or drive unduly slowly, make late or erratic maneuvers, take an improper route alternative, ignore critical information, fail to monitor other traffic, or have excessive eyes-off-the-road time episodes. These behaviors have obvious safety and operational consequences.

On the basis of a literature review and analysis of alternative approaches, an initial model of the driver information load process was developed. The model was related to the concept of the "information load profile" of the Positive Guidance model. As developed here, the Driver Information Load model viewed two general sources of demand as drawing on driver attention resources. One source, termed Information Search Demand, comes from dealing with the information displays confronting the driver. The two components of the Information Search Demand are the characteristics of the specific sign array and the characteristics of the general information environment in which that display occurs. The other general source of demand on the driver, termed Driving Task Demand, comes from dealing with the roadway and traffic while simultaneously trying to navigate. The model treated two components of Driving Task Demand: (1) one concerns the general features of the roadway and (2) the other recognizes that attentional demand increases in some manner as a key navigational choice point is approached. This

model was further developed and refined through a series of four experiments, two in the laboratory and two on the road. The four experiments established the reasonableness of this simple model for predicting the information demand on the driver and generated a quantitative implementation of the model.

The first experiment dealt with the information load imposed by individual freeway signs. A “universe” of navigation-related freeway signs was defined based on the *Manual on Uniform Traffic Control Devices* (*MUTCD*), and the study attempted to bracket the range of information loads associated with each sign type. Participants in a laboratory study had to attempt to extract relevant information from the signs during brief views similar in duration to a single glance at a sign while driving. Based on this work, a look-up table was devised, so that an analyst could assign a reasonable information load value to any typical freeway sign. The second laboratory experiment then dealt with the manner in which individual signs of a sign array combine to determine the overall information load associated with processing the sign array. Photoediting techniques were used to manipulate scenes so that sign panels could be “added” or “subtracted” from roadway scenes, with a viewing procedure similar to the first experiment. Various “rules” were investigated as predictors of the information demand of a sign array, based on the use of individual sign ratings taken from the look-up tables of the previous experiment. On the basis of the findings of this experiment, an analyst could then use the look-up table for individual signs and apply a summation rule to determine the information load associated with a set of signs co-located with one another on a freeway. The remaining two experiments were the preliminary and primary on-road experiments, which addressed other aspects of the driver information load model. These included roadway factors, spatio-temporal aspects of information load, and overt indices of driving problems. The on-road experiments used a unique procedure in which the driver continuously operated a thumbwheel dial, mounted on the steering wheel, in order to reflect moment-to-moment changes in the subjective difficulty of taking in all of the information with which they were dealing. The experiments also recorded vehicle speed, navigational errors, and other overt driver problems. Taken together, the set of experiments provided an empirical basis for refining the general conceptual model.

The set of experiments produced the following conclusions:

- “Information load ratings” for individual signs, as operationalized in this study, were reliable and replicable. Ratings for a common subset of signs used in the two laboratory studies correlated at $r = 0.86$, despite a number of methodological differences between the experiments.
- The look-up tables developed in the initial experiment accurately predicted the empirically derived information load ratings of individual signs. When the tables were used to predict the information load of new signs in the second laboratory experiment, the correlation between the table-derived values and the laboratory findings was $r = 0.84$.
- The information demand of an *array* of signs could be well-predicted based on knowledge of the individual signs, using the lookup table. The multiple-R correlation was 0.95.
- The information load imposed by a sign array, as actually measured on the road, could be well-predicted by the four-factor model (described below). The group load ratings for mean peak information for drivers in the on-road experiment correlated at $R = 0.81$ with the model prediction. This means that even though the model is quite simple, it is still able to account for approximately two-thirds of the variance in the on-road ratings.

The model, and the associated empirical base, still suffer from a number of limitations, discussed in the report. Among these, there was not a sufficient empirical basis for defining a “red line” level that indicates “information overload.” The model output is quantitative, but relative at this point. Thus, alternative sign treatments can be compared as better or worse, but more research or experience with the model will be required before a given information load rating can be taken to be good, questionable, or bad (overload).

The model that emerged from this work was a four-factor multiple regression that included the following factors:

1. **Sign array information demand**: based on a method of summing individual sign values derived from a set of look-up tables.
2. **Maneuver proximity**: based on a ramping function that takes into account the distance of the sign array from the maneuver point. The function begins to ramp up 6,000 ft from the maneuver point and peaks 1,500 ft from the maneuver point, before ramping down from there to the maneuver point.
3. **Local information density**: based on the information demand and distance of the other sign arrays surrounding the target sign array.
4. **Roadway demand**: based on the geometric features of the roadway over the 11,000 ft preceding the maneuver point. The features include the number of lanes, curves, merges, exits, weaving sections, and lane drops.

The model does not include driver or traffic variables because it is based on the worst-case conditions. The driver is assumed to be either elderly or inexperienced, unfamiliar with the route, and navigating to an approaching destination. However, the driver is also assumed to be non-impaired and English-literate. Information load appears to be worst under conditions of moderately heavy but flowing traffic. When congestion is heavy and speeds are slow, the difficulty is not in acquiring the information but in accomplishing the maneuver. When traffic is light, there is less demand on the driver and there is more opportunity to slow down and to make maneuvers.

The model was implemented as a Driver Information Load software tool, designed for IBM compatible PCs with a Windows Operating System (Windows 95 or later). It uses Microsoft Access Runtime and Excel programs simultaneously. The program takes the analyst through the data entry process and use of the look-up tables for individual signs. Model output is in both tabular and graphic formats, and shows the contribution of the various model component elements to the overall information load. The model can be used to evaluate a given system of signs or to seek improvements using a “what if” approach. In addition to the software tool, the project also provided a set of guidelines and recommendations for dealing with sign information overload problems.

CHAPTER **1**

INTRODUCTION AND OVERVIEW

THE PROBLEM OF DRIVER INFORMATION OVERLOAD

Drivers are frequently confronted with a multitude of information displays, which they must perceive, comprehend, and evaluate while they are simultaneously controlling their vehicles, monitoring other traffic, dealing with distractions, and navigating to a destination. In most metropolitan areas, one can readily find examples of freeway sites where within a few minutes of driving time there are dozens of elements of route guidance information, in addition to other information sources and distractions. The need for signing is frequently associated with complex traffic operations, geometrics, or potentially hazardous situations, so that the information load confronting the driver is often greatest when the demands of vehicle control, guidance, and crash avoidance also impose their greatest workload. When drivers are confronted with more information than they can process, they may decelerate severely or drive too slowly, make late or erratic maneuvers, take an improper route alternative, ignore critical information, fail to monitor other traffic, or have excessive episodes of eyes-off-the-road time. These behaviors have obvious safety and operational consequences. Current standards permit rather high densities of destination signing, and current guidance is lacking in terms of helping the traffic engineer determine when there is too much information and what can be done to address it. The purpose of NCHRP Project 3-50 (*2*), "Additional Investigations on Driver Information Overload," was to address these issues. It sought to define the problem, provide a means for estimating information load, and provide guidance for dealing with potential driver overload. The "*Additional Investigations*" in the project title reflects the fact that this project extended work begun under an initial project, NCHRP 3-50, "Driver Information Overload" (*1*).

Driver information overload (DIO), as used in this project, is defined as providing a motorist with too much information, through a series of devices or conditions, for a driver to have adequate time to perceive and respond properly. Thus the definition is not based simply on the content of the relevant signs. Rather, it must include the content of all relevant signs, the time and distance available to view them, the simultaneous demands on the driver, and the cognitive demands of interpreting the information in the signs. "Information overload" is not a simple property of a particular sign array, but rather a more complex interaction of the sign, its context, and the driver's knowledge and task.

Gordon's (*2*) insightful work on the information load of highway signs emphasized this key point: "The naïve view that overload is simply accounted for by the amount of displayed information is erroneous. Information load is largely determined by what the driver does with the displayed information." In other words, the drivers of two vehicles travelling through the same site may have very different information loads imposed upon them by the existing environment. A driver who is familiar with the roadway and simply wants to stay on the current route does not have a particularly burdensome task. Even if there is extensive signing, he/she does not have to fully attend to all the information. In contrast, a driver who is lacking in perceptual/cognitive capabilities or driving experience, unfamiliar with the route, traveling when traffic is heavy, and looking for the appropriate route to an unfamiliar destination, has a very different demand for dealing with sign displays. What this means is that the information "content" of traffic control devices is not equivalent to the information "load" on the driver.

Because information overload is a complex and driver-specific process, there is a challenge in representing this process in a manner that is useful for the traffic engineer. Complex human information processing models, of the sort used to design advanced cockpit displays or process control consoles, might have the sophistication to represent the mental demands, given sufficiently detailed information cast in terms of psychological constructs. However, a practical traffic engineering aid should not require this level of effort or force the engineer to deal with psychological variables rather than traffic engineering variables.

OBJECTIVES AND SCOPE OF THE PROJECT

The objectives of the project were to develop a model of driver information load for freeway applications and to translate that model into a practical tool so traffic and safety professionals could analyze driver information load. The specific focus on freeway signing applications provided a reasonable scope for the effort because this was felt to be the primary locus of current traffic engineering concern. Ultimately, it would be useful to broaden the scope of guidance to include other types of roadways (e.g., arterials) and other modes of communication (e.g., intelligent transportation systems, highway advisory radio). However, absent any existing model of DIO and the lack of empirical data upon which to develop a model, it would be unrealistic to address such diverse applications under an initial project of limited scale. The goal of developing guidelines for the range of freeway applications was itself an ambitious target of real practical significance.

In order to achieve this final objective, the project incorporated a number of intermediate goals. These included identifying driver information-processing needs and problems related to freeway guide signing; understanding current traffic engineering concerns and practice related to information overload; incorporating driver and roadway factors into a useful conceptual model of driver information load; refining the model through research experiments; and developing a practical tool for traffic and safety professionals based on the model.

It should be noted that this project dealt specifically with the problem of *information overload*, and not with other issues related to signing practice. A number of important signing problems can, like information overload, lead to driver confusion, operational problems, and safety concerns. However, these are beyond the scope of the present project, and should be explicitly distinguished from information overload. These issues include information deficiencies, confusing sign content, use of route names or numbers for guidance, selection of destinations to show on signs, sign placement to avoid obstruction, and detailed design aspects for variable message signs. While all of these are worthy issues, this project focused on DIO, which concerns the ability of drivers to handle information within time/distance constraints.

OVERVIEW OF PROJECT TASKS AND RELATION TO NCHRP PROJECT 3-50

A series of tasks were undertaken to accomplish the project objectives. These efforts represent an extension of the work begun under NCHRP Project 3-50. In the earlier project, there was a review of the technical literature pertinent to DIO. This included research on sign perception, visual search, information processing, models of driver behavior, and general models of human information processing. A preliminary conceptual model of DIO was then developed. Two experiments (one laboratory and one on-road) were conducted to begin refinement and quantification of the conceptual model. This preliminary work essentially was completed in 1997 (an interim report was delivered in 1998). Based on the promise of the initial findings, the present project began in late 1999 to continue development of this line of work. Project NCHRP 3-50(2) included the following major tasks:

- Update the literature review of NCHRP Project 3-50 and determine if any recent research has implications for the information load model or the planned research experiments.
- Conduct new experiments to provide an empirical basis for the proposed information load model.
- Revise and refine the model based on the research findings.
- Implement the model in computerized form; exercise and evaluate the model.
- Formulate the model into a practical user tool for traffic and safety applications.
- Provide guidelines for freeway sign use that would address DIO.

The sections that follow describe these project efforts and their findings. Key activities and findings from the earlier project (NCHRP Project 3-50) are incorporated into the discussion, where appropriate.

CHAPTER **2**

LITERATURE REVIEW

A detailed literature review was conducted to summarize the current understanding of how drivers handle roadway information, particularly when there are constraints on the time or distance available for a decision. The full literature review was conducted under NCHRP Project 3-50. It was presented as an interim project report under that project (*3*) and was updated for the present project.

INITIAL REVIEW OF LITERATURE

The initial review of literature took place under NCHRP 3-50 and was conducted in 1995. This literature review first considered the findings related to how people notice and attend to signs. A sign or other traffic control device (TCD) will not impose any information load on a driver if it is not "noticed" or attended to. However, this is not an all-or-none process. Rather, highway information sources can be processed to varying degrees and have varying amounts of attention directed at them. The information load is, therefore, not a direct function of the amount of information in the sign, but of the degree to which the driver processes that information. Most of the research on the ability of signs to capture attention and force information processing ("conspicuity") comes from research on warning or regulatory signs, rather than guide signing. Attributes of the sign, its location in the visual field, legibility, background complexity, competing information elements (relation to "noise" elements), and driver expectancy have all been shown to be important determinants of whether, when, and to what degree signs will be processed. Because this literature primarily dealt with warning or regulatory signing, it was of limited use for quantifying driver behavior related to freeway guide sign use.

The literature review next considered models of the visual search process. Visual search processes can be defined in terms of three elements: (1) target characteristics, (2) search field characteristics, and (3) search strategies. Strategies are often classified in terms of how the eye covers the search field. The broad distinction is between visual search schemes that are controlled by the features of the objects in the visual field and schemes that are controlled by the knowledge and beliefs that the viewer brings to the situation. In some situations, the manner in which the visual field is scanned is largely determined by what is in that field: salient objects and their spatial relationships influence the way the eye scans the field. This is referred to as an "exogenous" search strategy. In other situations, the manner in which the visual field is scanned is largely determined by a systematic plan, or "cognitive strategy." This is referred to as an "endogenous" search strategy, and researchers in this field have distinguished a variety of types of endogenous search strategies. In many real world situations, a combination of strategies may be used. Research on visual search in highway driving, particularly the work of Theeuwes (*4*), has highlighted the importance of endogenous strategies that are specifically related to people's expectancies about roadways and signs. In other words, drivers will scan a roadway scene differently than they would scan a similarly structured scene that was not a driven roadway. The way the eye scans is based on people's knowledge of what typically occurs. This is an efficient search strategy when the expectancies are accurate. However, when signs occur in locations that violate driver expectations, there can be considerable delays in detecting those signs.

The literature review next covered the findings related to how people process the information in signs, given they have directed sufficient attention to the signs. Eye movement studies found that most signs receive at least some glances, even when the situation is complex. Although most signs were "read" (if not fully comprehended), this proportion drops when vehicle interactions become more demanding. Much of the pioneering work concerning where and when drivers look for information has been done by Rockwell and Bhise (*5*), although important advancement in modeling this process has been disappointingly limited since that time. Also, much of the work on sign processing has involved warning or regulatory signs, rather than freeway guide signing. Rockwell's work has defined a number of important factors that influence when the initial glance to a sign occurs, how much attention the sign receives, what portion of the available viewing time it draws, and how attention gets distributed among competing features. One finding of note is that when drivers are unfamiliar with the road and confused about the path, they often begin sign-reading late, use a low proportion of the available legibility distance, concentrate their attention on signs during critical periods, and continue reading as late as possible. Drivers who are more familiar with the route and less stressed do not exhibit these characteristics.

The research on noticing signs, directing attention, and processing sign information emphasizes the notion that the human information processor is not a passive receiver of information. He/she has various strategies for seeking or ignoring different sources of information. When information load is high, the driver does not simply accept the overload, but invokes strategies for dealing with it.

The literature review also addressed models of the driver related to information use. These included the positive guidance model (*6*), DHESS Design and Evaluation of Highway Signing Model (*7*), and work by the Texas Transportation Institute on guidance related to real-time (changeable message sign) information display (*8*). None of these models was directly usable for determining driver information load, but all were useful for approaching the topic. Positive guidance, in particular, provided a simple model that was adaptable to the problem. In addition to these models of driver behavior, the literature review also described the general development of information processing models from academic theory and other domains of application.

In summary, the literature review indicated that there has been a considerable amount of research on how drivers may perceive or respond to signs and other TCDs, but relatively little study has directly addressed the specific issue of driver information overload (DIO). There are many aspects to how a driver handles roadway information, but the literature is very fragmented. For example, most of the research on how a sign gets noticed has been based on studies of warning signs, while other research on message formats may be specific to guide signs or variable message signs. The literature does not provide a coherent basis for integrating detailed knowledge about all of the component perceptual and cognitive processes that together determine how much effort is needed to process information in a given situation.

Several key themes emerge from the literature reviewed here, and should be noted:

1. The information load imposed by a given array of information is not simply a function of the total number of "bits" of information contained within the array. The tasks the driver is engaged in, the roadway situation, and the attributes of the driver are essential, interacting factors. A specific sign will impose a load dependent upon its meaning to the driver, driver expectancy, driver experience, driver familiarity with the roadway, and individual differences in performance capabilities. The presence of interacting traffic, roadway geometry and navigational choice points, and other TCD and information sources are critical. The ability of the driver to "shed" irrelevant or lower priority information is an important attribute, as are the perceptual search and processing strategies used to organize and analyze a scene. Because sign processing is not simply mechanistic, it is not sufficient to simply assign a given sign some fixed value in terms of the load it imposes on a driver. If a meaningful model of driver information load is to be developed, it apparently will have to incorporate explicit assumptions about a particular driving scenario: the driver, the task, familiarity and expectancy, environment, and so forth.
2. There is little common ground between current, applied models of driver information handling and basic models and applications for processing cognitive information. Models used for traffic engineering applications have the advantages of being relatively simple and of directly incorporating traffic engineering concepts and variables. However, their simplicity and mechanistic nature make them questionable as reasonable models of driver information processing. Current theoretical and empirical work in human information processing provides more sophisticated models, but they are complex and difficult to work with, and do not deal very directly with highway concepts. Such theories have been incorporated into network models for military design applications (e.g., helicopter displays), but the level of analysis, effort, and expertise involved in applying these models is likely prohibitive for normal traffic engineering applications.
3. Previous research on highway signs has focused predominantly on individual elements of information displays, rather than on the influence of broader arrays of information incorporating multiple TCD and spatiotemporal aspects of information distribution. There is substantial information, for example, on when a given sign may become legible or on how the perception-reaction time may be characterized. There is much less information on how driver performance will be influenced by sequences and arrays of signs of various types, in various locations, competing with one another for attention.
4. Existing research has revealed a variety of important concepts and relationships, but often these are at a qualitative level. There may not be a solid empirical basis for incorporating these factors into a sophisticated, quantitative model of information load, driver performance, or other higher-order description.

In summary then, as of 1995 the literature showed many factors related to driver information load and clearly indicated that a method or model for computing this load cannot be simply a mechanistic addition of the number of information elements in a display. At the same time, there were serious limitations of empirical data and current models that restricted the ability to quantify DIO.

LITERATURE UPDATE

As an initial step in the continuation of this line of research, the literature review was updated. This limited search was sharply focused on work that had been published or conducted since the initial review, and that had direct relevance for modeling DIO or for the methodology of researching the problem. The search specifically covered the time period 1994 to 1999 and was conducted in October to November 1999. The search effort included published, unpublished, and ongoing research, including foreign and domestic sources.

A variety of search activities were undertaken, including the following:

- Primary database automated keyword search;
- Key journal/proceedings scans;
- Internet search;
- Contacts with key experts; and
- Contract with technical committees and professional societies.

Although a great many articles were initially targeted by the keyword searches and other techniques, a subsequent scan of abstracts limited this set to about 36 titles requiring direct consideration. Upon obtaining these documents, each was scanned for actual relevance. Most turned out not to be directly related to the issue of DIO as related to highway signage. Even several major research efforts of which we were aware, and which sounded superficially as though they would be relevant, turned out to offer little of real benefit.

The general impression that emerged from all of this review was that there has been very little recent activity in related areas, with the exception of research on driver workload related to in-vehicle information systems (IVIS). This focus on in-vehicle technologies is part of the broader effort that has been directed at intelligent transportation systems (ITS). The types of ITS tasks investigated included things such as moving map displays, cellular phone use, or on-board display of information on points of interest.

While the present project is focused on roadway signing, it would seem that research on parallel issues for in-vehicle displays might provide some useful insights. However, this was rarely the case because this ITS work provides very little in terms of theory or models that we can draw on. Rather, there are very specific empirical evaluations regarding the ability of a driver to engage in a certain information-intensive task while driving. There are minimal means to generalize these findings. Typical questions might be whether a given item is more effectively presented as an auditory or a visual message, or whether a particular visual message works best as a text, chart, or icon display, or whether using a cellular phone disrupts vehicle control. None of this was very useful for extension to external roadway sign practices.

Another line of research that was not pursued in this search had to do with improvements to the legibility of highway sign alphabets. To the extent that legibility distances can be improved, drivers may derive a benefit in having more time to process that information. For example, Garvey and Pietrucha (*9*) describe a new type font called “Clearview,” which they report resulted in a 22% increase in legibility distance for older drivers at night. The researchers did not find font legibility research to be directly relevant to model development, except to highlight the fact that, to the extent that sign legibility distance is used in any design tool built around a model, the analyst should be cognizant of any unique fonts that might significantly modify the estimated legibility distances.

While none of the more recent research had major implications for the continuation of the driver information load project, several studies were of some interest and raised various points worth noting. The research programs or research articles considered in detail included the following:

- An FHWA project on *In-Vehicle Information Systems Behavioral Model and Design Support* (*10*);
- An NHTSA project on *Heavy Vehicle Driver Workload Assessment* (*11*);
- A laboratory study of time-of-day effects on processing sign information (*12*);
- Ontario Ministry of Transport research on tourist sign information (*13*);
- Texas Transportation Institute research on workload effects associated with aspects of highway design (*14, 15*);
- An “in situ” study of driving workload during extended commuting trips (*16*); and
- A minimum required legibility distance model of sign placement for rural two-lane roads (*17*).

Detailed discussion of each of these sources, and the implications for DIO research or modeling, are provided in Appendix A.

While there are items of interest in the above sources, nothing in the recent technical literature directly affected the basic approach to the driver information load model as initially developed under NCHRP Project 3-50 and discussed in Chapter 3. There are some interesting alternative or complementary approaches to dealing with the problem, but they are not very mature and offer no obvious advantages to the current approach. There is little in the way of either empirical data or conceptual approaches that may be of immediate use for the current application.

A number of approaches seen in other work share a general conception of the problem with the present approach as outlined in Chapter 3. That is, they assume an attention-sharing model with limited attentional resources, competing demands from informational tasks and transient factors as well as general driving/vehicle control tasks, and additive processes for integrating these demands (e.g., Hankey [*10*]; Woolridge [*14*]; Kiger et al. [*11*]; Zeitlin [*16*]).

There were some methodological points raised by some of the reviewed literature, and these influenced some details of the on-road research conducted in this project. However, these are in the manner of methodological refinements, rather than basic changes, as follows:

- The use of brake activations as a supplemental performance measure of driver workload;
- The need to control for time-of-day effects in experimental design; and
- Consideration of potential driver expectancy violations in the interpretation of findings.

CHAPTER **3**

GENERAL APPROACH TO MODELING DRIVER INFORMATION LOAD

The motivation for developing a model of driver information load was to derive a basis for a practical tool for analyzing potential overload situations and to provide improved engineering guidance for freeway signing practice. The eventual users of this model and its associated products are seen to be traffic engineers and safety professionals. This objective helped guide the selection of a general approach to a model, the assumptions that underlie the model, and the conceptual model that ultimately was carried forward into the research phase. The model needs to be able to (a) rely on sign and roadway factors as the primary input, and (b) produce some sort of quantitative index of problem magnitude as output. The model is not an attempt to describe or replicate the complex perceptual and cognitive processes taking place within the driver.

CHOICE OF GENERAL APPROACH

A variety of approaches to modeling driver information load are possible as options. The literature review provided in Chapter 2 revealed a number of these. Broadly, these might be categorized as rather simplistic driver behavior models based on traffic engineering variables, more complex models of driver eye movement, and visual sampling based on the structure of the visual scene and the driving task, or complex cognitive models of human information processing in multitask environments. Originally, it was felt that the optimal approach might be a hybrid of several types of models. However, it soon became apparent that the type of information required for realistic cognitive modeling would place undue demands on the analyst for a traffic engineering application. In order to be a useful tool, the model should require mainly traffic engineering variables as inputs, with the complex underlying perceptual and cognitive processes transparent to the user. Many of the complexities could be dealt with by means of worst-case assumptions or the use of look-up tables rather than computations.

The general approach selected took advantage of the Positive Guidance model (*6*, *18*) as a convenient starting point. The Positive Guidance model is a systematized means of incorporating driver capabilities and behavior into the design or evaluation of highways, integrating human factors and highway engineering. It has the virtue of being an established and familiar resource in traffic engineering. The information load profile is a key part of the Positive Guidance approach that possesses a number of parallels with the modeling requirements of this project. It provided a useful conceptual approach for constructing a means of incorporating a range of information-processing demands on the driver. However, the information load profile technique also has a number of limitations or unrealistic assumptions for the present application, and so serves only as a conceptual starting point.

The Positive Guidance model, in common with a variety of other models of driver behavior, views the demands of the driving task as composed of three levels of task requirements. In Positive Guidance, these are viewed as a pyramid of three interrelated levels of performance: control, guidance, and navigation, with each level representing increasing complexity and a decreasing scale of priority, or "primacy." *Control tasks* are related to the driver interaction with the vehicle, controlling speed, path, and direction. Information at this level is provided by feedback from movement of the vehicle and from vehicle displays. The *guidance level of performance* is defined as those tasks related to a driver's selection and maintenance of safe speed and path. Guidance tasks require a driver to make decisions using judgments, estimates, and predictions. Information at this level is provided by highway characteristics, traffic, and traffic control devices. *Navigation tasks* involve the planning and execution of a trip from beginning to end. Decisions such as lane choice or speed are made at choice points along the route. Information sources may include prior experience, maps, signs, and landmarks. As one progresses through the levels of the Positive Guidance Pyramid, the tasks have less primacy and become more complex; drivers require more time to acquire information from signs and process information. When information sources compete for attention, lower primacy information tends to be discarded or delayed from consideration. The important implication of this conceptualization for the purposes of modeling driver information load from freeway signage is that the model must incorporate the demands of other aspects of the driving task as well as just the information present within a sign array. The ability to deal with sign information must be viewed in the context of the current driving task.

An important component of the Positive Guidance approach is the "information load profile." The information load profile schematizes the demands placed on the driver as a function of the number of significant roadway items competing for a driver's attention. Schematically, each item is represented by a horizontal bar along an axis that corresponds to its location on the road. Each bar begins at the point in the road where the item first becomes visible or legible and continues until the item is passed. The bars for the various items are "stacked" as they overlap on these schematic diagrams. The information load at any point is determined by the height of the stack at that point. Excessive loading at a given point is seen as increasing the probability of a crash. While the present project attempts to model the problem of coping with sign information, rather than specifically with crash effects, the concept of using some additive model to integrate all of the demands on the driver at a particular location is appealing. However, while the information load profile technique from Positive Guidance provides an interesting analogy, it has a number of limitations for application to the present problem. Briefly, these include:

- All roadway items, from lane lines to geometric features to signage, have identical contributions to total load;
- The impact of a given element is mapped on the basis of the section of the roadway over which it is viewable; this may not be the same as the region over which it is likely to influence the driver;
- The summation of multiple elements to achieve a total information load is based on simple addition, but actual rules may be more complex;
- Applications of Positive Guidance have focused mainly on safety issues relating geometric design and traffic control devices to driver performance demands; there has not been as much consideration of navigation-related tasks. As a result,
  - The approach provides a more "micro" approach to roadway geometry and roadside features than may be desirable for the present application, and
  - The approach does not distinguish well among complex navigational sign messages and arrays of signs.

Thus, something conceptually analogous to the information load profile provides a useful general framework from which to develop a model of driver information overload (DIO) for freeway guide signing, but it is only a starting point. A number of changes or refinements are required in order to achieve a useful quantitative model.

ASSUMPTIONS INCORPORATED IN THE MODEL

A set of assumptions related to the general modeling approach was explicitly set forth before conducting the research experiments and more detailed modeling efforts. These assumptions included the following items.

Driver and Task

One of the complicating factors in modeling information load is that the load is not simply a function of the sign content, but also the driver's knowledge, abilities, and task. A different information load could be computed for every driver encountering a sign array. To simplify this situation, the model is assumed to involve a "design driver," who typifies those most likely to experience problems dealing with the information load, within reasonable limits. The following design driver characteristics are assumed:

- **Familiarity.** The driver is assumed not to be familiar with the particular site.
- **Navigation Task.** It is assumed the driver needs to actively navigate in order to reach his destination, and that the signing contains information relevant to that decision.
- **Age and Experience.** The design driver is assumed to be an older driver or an inexperienced driver. These represent groups most likely to experience difficulty. Older drivers are less able to perceive and rapidly process sign information. Inexperienced drivers devote relatively more of their attention to the lower-level driving tasks (control and guidance levels) and are less effective in their attention-sharing strategies.
- **Impairment.** It is assumed that the design driver is *not* impaired by alcohol, drugs, or excessive fatigue.
- **Literacy.** It is assumed that the design driver is English-literate.

Roadway Type and Traffic

The model is confined to freeway and expressway signing. Within these categories of roadway, there are still meaningful differences in the demand that the roadway will place on the motorist, exclusive of the navigational signing issues. The model should therefore include some means of reflecting a range of roadway demand. However, the degree of traffic congestion (level of service) is not a variable that needs to be incorporated into the modeling. Based on analyses done under NCHRP Project 3-50, the problem of DIO did not appear to be experienced during the stop-and-go conditions of peak periods because there was more time to process the information. The sense of information overload was greatest during moderately heavy but rapidly moving traffic. Therefore, this is the condition for which navigational signing systems must be designed and evaluated. The model need not be complicated by incorporating the level of service because the interest is not in the range of conditions at a site but rather with the design condition of moderately heavy but at-speed traffic.

Sign Type

The focus of interest is on signing relevant to the navigation task. This includes guide signing, motorist service signing, and recreational and cultural interest signing. For purposes of determining DIO situations, it is assumed that warning and regulatory signing can be ignored in this model. This assumption is based on the literature on driver eye movement, which suggests that where an unfamiliar driver is in an undecided navigational situation, the information from other sources can be "shed." This assumption may not be appropriate for arterial roadways, where control and guidance tasks require closer attention to traffic control devices at many points. However, because the interest here is specifically with freeways and expressways, the model can reasonably exclude traffic control devices other than guide signing, motorist service signing, and recreational and cultural interest signing.

Sign Set

Interest is specific to normal freeway signing, as typified by the signs defined in Sections 2E, 2F, and 2H of the *Manual on Uniform Traffic Control Devices* (*19*). This reasonable assumption provides a very important advantage for the model. It allows us to assume a fairly large, but finite, universe of possible signs. This means that the "information load" of a given sign can be directly determined from a look-up table, rather than needing to be computed based on a set of general characteristics of the sign (size, color, contrast, font, wording, diagrams, complexity, organization, message length, expectancies regarding content, etc.). It would take considerable research and development effort to develop a reasonable algorithm for translating general sign characteristics into an estimate of information load, and the resulting estimate would likely not be as accurate as one could achieve through a direct evaluation of the sign itself. Therefore, the information load model is not based around component sign physical characteristics, but is based upon matching a given sign to an exemplar from a structured universe of freeway signs.

GENERAL CONCEPTUAL MODEL

A general conceptual model of driver information load, consistent with the points of previous sections, was developed under NCHRP Project 3-50 and provided a starting point for the present project. This model is described as "conceptual" because it defines the various component elements of the model but is not formalized or quantitative in dealing with them. The research described in Chapter 4 was intended to provide a basis for a more refined and quantitative implementation of this general model.

The primary objective of the model is to define the information load associated with a given sign array within its roadway context. The term "sign array" is intended to refer to a set of individual sign panels that are co-located with one another at a given point on the roadway. Thus for example, three individual sign panels located on an overhead mast would constitute a single sign array. The model of driver information load is based on a process of determining the demand placed on the driver by sign arrays and by the driving task, and then summing these in an appropriate manner to derive a total demand placed on the driver's information-processing capabilities. In considering the demand on the driver in dealing with the information present in a given sign array, the model needs to incorporate: (a) the information content and format of the signs of interest; (b) the local information context in which those signs are placed; and (c) the demands of the driving task concurrent with the sign information processing task.

Figure 1 presents a high-level overview of the model. The model breaks the driving task into two major categories, Information Search Demand (ISD) and Driving Task Demand (DTD). Together these categories draw on the attention of the driver. The driver's ability to devote attention to these demands is dependent in part upon various characteristics of the driver, as shown in the illustration. As discussed above, the model uses a "design driver" concept so that individual driver characteristics do not need to be considered. The design driver assumes a locally unfamiliar driver involved in navigating at an approaching choice point. The driver is assumed to be older (e.g., age 65 or older) or inexperienced, English-literate, and not impaired.

The two categories of the driving task, ISD and DTD, are related to the three levels of driver performance of the Positive Guidance model. The lower-level demands of the guidance and control tasks are combined into a single category, DTD, encompassing the general characteristics of the roadway segment and choice points. ISD is analogous to the navigation task as defined by Positive Guidance. Both of these demands, as defined within the DIO framework, compete for available attention resources of the target driver. For purposes of this model, additional demands on driver attention from in-vehicle sources and tasks are not a consideration. Information sources are primarily visual and external to the vehicle.

The driver information load is determined by computing the DTD and the ISD and summing these to derive a total demand, in the same manner as information elements are "stacked" in the Positive Guidance information load profile. DTD and ISD are themselves each composed of component factors that are also summed to determine the overall DTD or ISD values. The DTD is conceptualized in the model as having two components, a demand associated with the roadway segment and a demand associated with the interchange and its proximity. The ISD is conceptualized as having a specific sign array component and a local information density component. Thus the overall information load on the driver represents some additive process of four general sources of

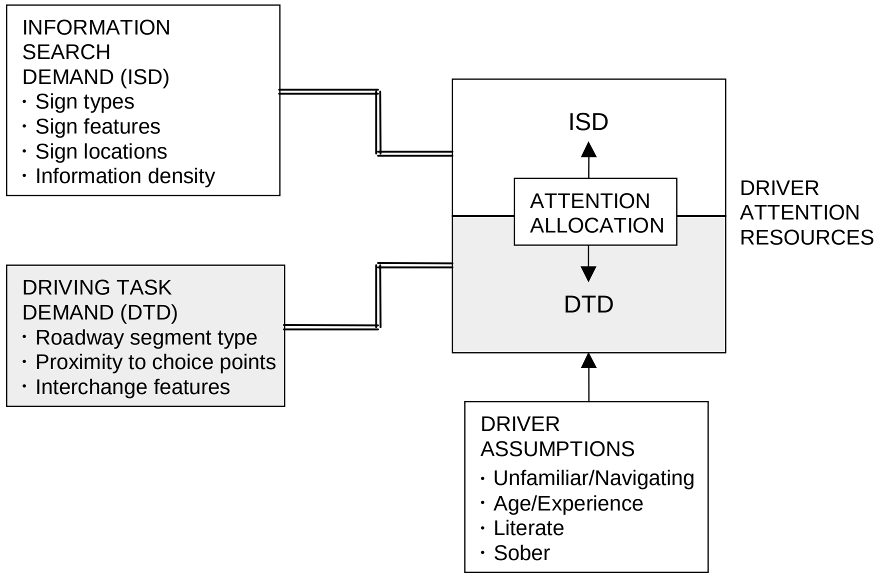

Figure 1. Driver information load model components.

demand for attentional resources: the general roadway, the proximity to maneuver points, the particular array of sign panels at a given location, and the more extended set of informational sources in the general vicinity around the particular sign array. The model presumes that as the total information load approaches higher levels, the driver begins to experience more difficulty in dealing with the information. At some point, the difficulty is severe enough to generate safety or operational problems, defining an "information overload" level. The sections that follow first discuss the DTD portion of the model, then the ISD portion, and finally the combination of all elements to derive the total demand.

Components of Driving Task Demand

The DTD is presumed to be a function of two factors: the roadway baseline requirement and the proximity to the navigation choice point.

The roadway baseline requirement is a general level of attentional demand requirement that is viewed as being more or less uniform over a section of freeway. It is determined by the nature of the roadway and its features. The initial means of addressing this factor was to simply categorize freeways in terms of a three-factor scheme: (1) distance between exits; (2) ADT/lanes each direction; and (3) level of service. However, this categorization scheme did not work particularly well for the on-road experiment of the present project. The preferred means of determining a value for the roadway baseline requirement was based on the set of particular geometric features present (as will be discussed further in Chapter 4). However operationalized, conceptually this factor should be viewed as the general demand imposed upon the driver over an extended segment of freeway based on the geometric, operational, and environmental characteristics of the roadway.

Although the baseline demand of a given freeway is treated as constant over an extended section of roadway, it is necessary for the model to recognize an increased demand as the vehicle approaches a navigational choice point that requires a driving maneuver. Models of driver behavior, including Positive Guidance, typically recognize features such as exit areas as imposing additional load, and the empirical findings of the initial (NCHRP Project 3-50) on-road rating experiment (and confirmed in the subsequent research of this project) identified a factor that clearly "ramped up" as the choice area was approached. The reasons for this increased load may have to do with the perceptual and control demands required to monitor conflicting traffic, find gaps, determine the appropriate lane, determine the appropriate speed, execute lane changes, and adjust speed. It might also be related to increasingly urgent cognitive or emotional factors associated with resolving uncertainty. The precise form of this maneuver proximity ramping function is an issue for model development, and it is dealt with further in Chapter 4.

Figure 2 illustrates the conceptual load diagram for DTD. The X-axis represents distance along the roadway, from some point upstream of the exit maneuver point to the gore point for the freeway exit. The information load imposed upon the driver by the roadway is shown on the Y-axis. Part of the DTD is due to the characteristics of the section of the roadway and is treated as fixed over the course of the road segment. This is labeled "Roadway Baseline." Superimposed on this baseline is the "Maneuver Proximity" function, which begins to ramp up at some distance from the exit point and reaches a peak

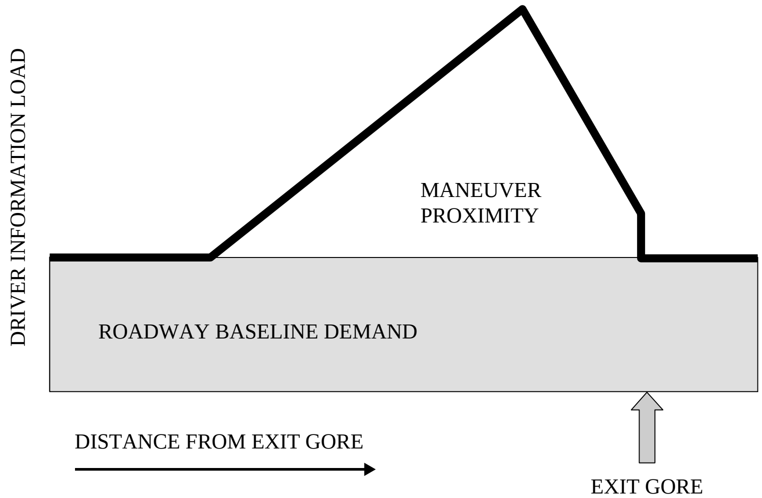

Figure 2. Information load conceptual diagram for driving task demand.

somewhere near the exit point. Taken together, these factors define a DTD profile, upon which the ISD profile is stacked.

Components of Information Search Demand

Conceptually, ISD is the demand imposed upon the driver by the effort of searching the formal information sources provided on the roadway and processing the information so as to support navigational decision-making. There are several aspects to this. First, each sign panel that the driver encounters has to be dealt with to some degree. However, the demand associated with a given sign panel depends in part on the information context in which that sign occurs. One aspect of this context is the other sign panels with which the sign may be co-located, that is, the sign *array*. There is no *a priori* reason to assume that the degree to which a given sign contributes to the overall information demand is identical whether that sign occurs in isolation or together with other signs. For example, consider three individual signs, A, B, and C. If presented alone, each of these signs may have some information demand level associated with processing it. Does this mean that if the motorist now encounters a sign array comprised of three sign panels, A, B, and C, the associated information demand for dealing with the array simply will be equivalent to summing the demands for the individual signs? This appears unlikely for a variety of reasons (search strategies, temporal constraints). Because the modeling approach selected here begins with determining the information demand associated with specific freeway sign types, some rule must be found for combining the associated demands for individual signs that comprise a sign array.

A given sign array will exert its effect over some span of distance and time, so that successive sign arrays may influence one another if they are in close enough proximity. Obviously, the demand on a driver would be greater if two complex sign arrays occurred in close succession as opposed to being spaced far apart. Therefore, the demands of dealing with the information in one particular sign array is influenced by the presence of other signs in the area. This is what is referred to in the model as the local information context. Somehow the model must be able to reflect the interaction of successive sign arrays. The initial modeling efforts under NCHRP Project 3-50 attempted to do this through defining an "envelope" of information demand in the region surrounding a given sign array, and then summing the overlapping portions of the envelopes for successive sign arrays. Figure 3, taken from the NCHRP Project 3-50 report (1) illustrates this concept. The upper panel of the figure (labeled "individual sign loads") shows information load envelopes for six sign arrays located along a roadway. The height of each function at a given point reflects the demand on the driver related to the sign array. The second panel of the figure (labeled "local sign effects") shows how the overlapping functions for individual sign arrays are summed to generate a total information load at each point, one that takes into account all of the sign arrays that may be influencing the driver at that point. However, there were problems with this approach. First, it was difficult to define the appropriate envelope shape, either through the empirical findings or theoretical treatments. Second, in order to yield meaningful results, an additional factor had to be added to the model, one that looked at the density of sign information over the full extent of a roadway site. This factor is shown as the "information density component" load in the bottom portion of the figure. The inclusion of this factor reflected the fact that motorists seemed to be responding to the effects of information that was located beyond the envelope

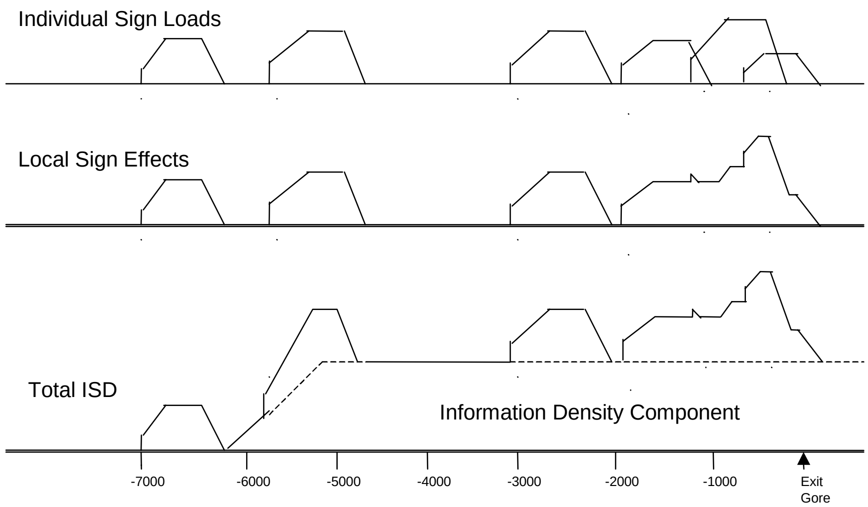

Figure 3. Components of information search demand.

of the sign, based on theoretically assumed envelope shapes. Based on the findings of the research reported in Chapter 4, another approach is provided in the model described later. However treated, it is essential to recognize that a particular sign array occurs in the context of other signage distributed along the site and that this additional signage provides a local information context in which the particular sign array must be dealt with by the motorist.

In summary, the major points with regard to the ISD are as follows: (a) there is some demand associated with a given sign; (b) some rule governs the summation of individual sign loads to determine the demand associated with a given sign array; and (c) other signage in the vicinity of a particular sign array provides a local information context that also contributes to the difficulty of dealing with the target sign array. Figure 4 illustrates this conception of ISD. In contrast to Figure 3, this figure does not attempt to illustrate any particular region over which the information load of a given sign array is experienced; a single point of information load is shown. The need and ability to describe the spatiotemporal aspects of information demand are dealt with further in subsequent sections.

Total Information Load

The total information load represents the ISD value overlaid upon the DTD value. Figure 5 illustrates this conceptualization. The figure shows the summing of the two factors, each composed of its subfactors. The overall height of the function represents the total demand associated with coping with the navigation-related sign information. Some level of this demand defines an "information overload" region. The research and modeling efforts described in the subsequent sections of this report represent an effort to formalize this conceptual scheme and develop a useful engineering tool based around this model.

Although the conceptual model was illustrated diagrammatically in order to illustrate the process of summing component aspects of information load, this does not imply that the ultimate model or related engineering tool needs to be diagrammatic rather than in some other form. Formalization of the conceptual model will be dealt with in subsequent sections of this report. It should also be recognized that this initial effort at modeling is limited in that it does not include all possible factors contributing to information load nor does it attempt to treat each component factor to the greatest level of

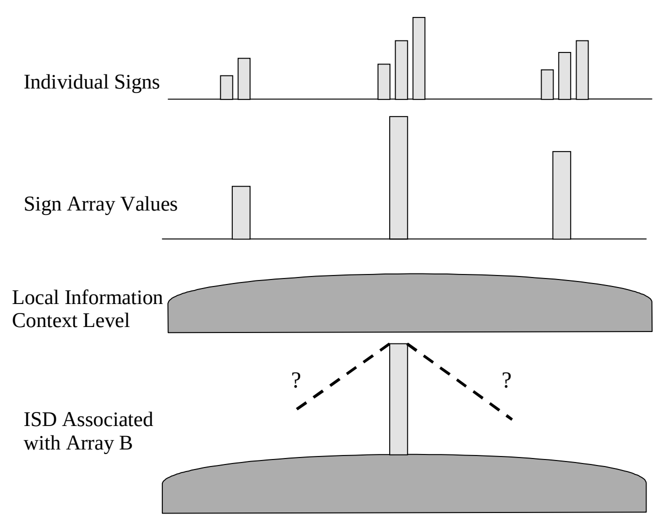

Figure 4. Conceptual scheme for information search demand.

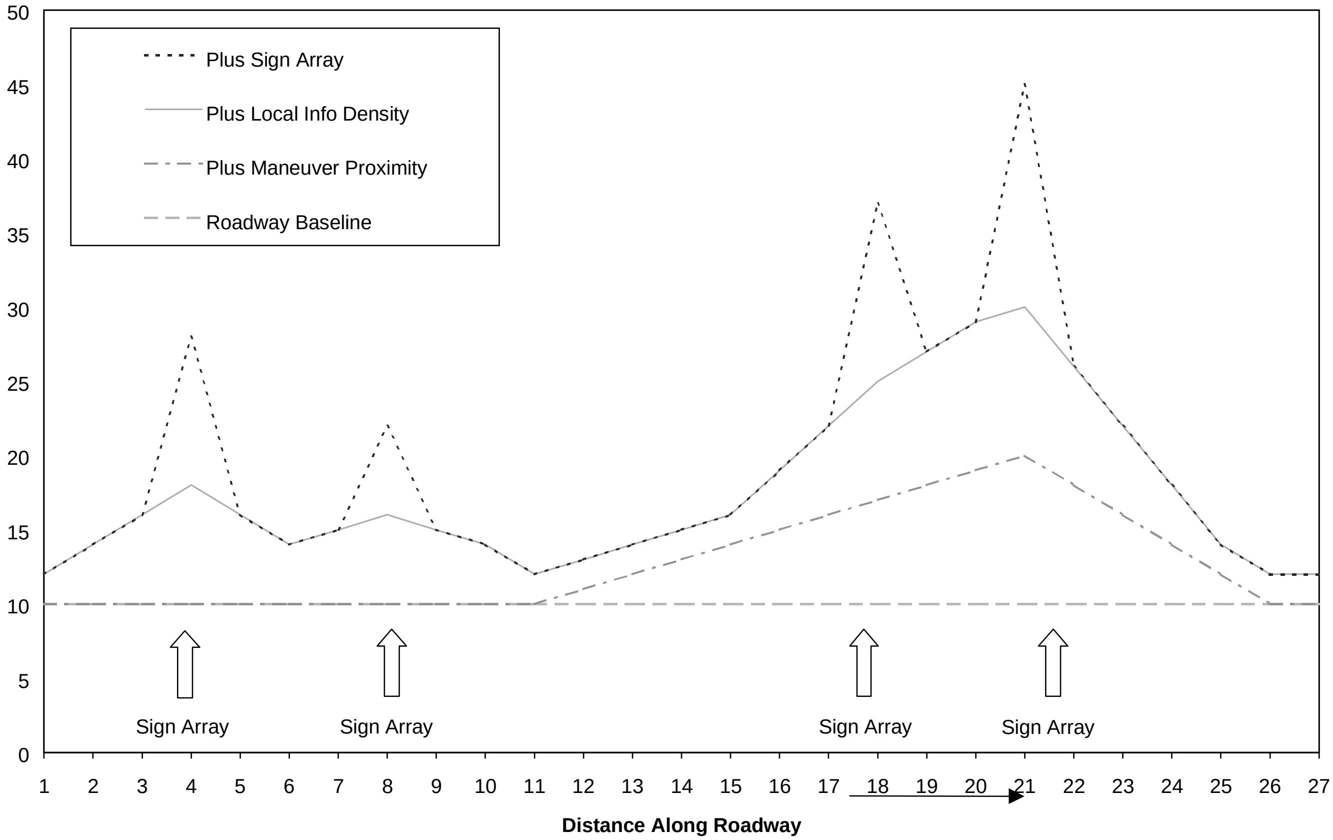

Figure 5. Conceptual scheme for total information load.

detail. For example, off-road signing and distractions are not explicitly treated, nor are transient factors such as obscuration of signs by trucks in the traffic stream. Roadway driving demands could be treated at a much more micro level of analysis (e.g., point-by-point consideration of every roadway element). The model does not address qualitative aspects of the sign message (e.g., is the message ambiguous, are the destination names appropriate?) or fundamental traffic engineering principles (e.g., appropriate legibility and sight distances). Nonetheless, the scope of the problem that is addressed is substantial and provides an opportunity to significantly improve current practice.