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EXPERT SYSTEM FOR RECOMMENDING SPEED LIMITS IN SPEED ZONES

FINAL REPORT

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DISCLAIMER

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ABSTRACT

The idea of controlling vehicle speed evolved from the assumption that reducing speed also reduces crashes. Speed limits are selected to balance travel efficiency versus safety. It can be argued that a rational speed limit is one that is safe, that most people consider appropriate, that will protect the public, and that can be enforced. Previous work has shown that better methods are needed to identify appropriate speed limits especially on urban roads having higher traffic volumes, a mix of road users, and more roadside activity. The objective of this project was to develop a knowledge-based expert system for recommending speed limits in speed zones that are considered to be credible and enforceable.

The expert system (hereafter referred to as USLIMITS2) was developed based on results from previous research, responses from practitioners to hypothetical case studies as part of two web-based surveys, input from experts from three panel meetings, and lessons learned from the current USLIMITS program developed by the Australian Road Research Board for FHWA. The expert system developed as a result of this research is accessed through the Internet and has been designed to address the establishment of speed limits in speed zones on all types of roadways, from rural two-lane segments to urban freeway segments. The types of speed limits not addressed by the system include statutory limits such as maximum limits set by State legislatures for Interstates and other roadways, temporary or part-time speed limits such as limits posted in work zones and school zones, and variable speed limits that are raised or lowered based on traffic, weather, and other conditions.

Based on input from the user, the expert system employs a decision algorithm to advise the user of the speed limit for the specific road section of interest. Appropriate warnings are also provided in a summary report that may suggest that additional information and/or action is necessary to address areas of concern. The system is meant to assist the user in making the speed limit decision for a road segment, but will not make the decision for him or her.

This report documents the research effort that was used to develop the expert system. For those primarily interested in applying the expert system to assist in setting speed limits on roads and streets in their area, a User Guide is provided in Appendix L, and flow charts illustrating the decision rules are provided in Appendix K.

EXECUTIVE SUMMARY

Speed limits are selected to balance travel efficiency versus safety. The optimal balance depends on the type of road and the environment in which it exists. Roads in areas such as residential subdivisions provide access, while collector roads distribute local traffic between neighborhoods and arterial street systems. On local roads, low operating speeds are desired to accommodate pedestrians and bicyclists and to provide access to residences and businesses. On arterial streets where the function of the road is to carry traffic and provide access to businesses, the goal of speed management is to maintain mobility and capacity while increasing safety. On limited access roads built to the highest standards, there is greater emphasis on reducing travel times without comprising safety.

It may be argued that a rational speed limit is one that is safe, that most people consider appropriate, that will protect the public, and that can be enforced. Artificially low speed limits can lead to poor compliance as well as large variations in speed within the traffic stream. Increased speed variance can also create more conflicts and passing maneuvers that can lead to more crashes.

The objective of this project was to develop a knowledge-based expert system for recommending speed limits in speed zones that are considered to be credible and enforceable. The expert system is accessible through the Internet and has been designed to address the establishment of speed zones on all types of roadways, from rural two-lane segments to urban freeway segments. The types of speed limits not addressed by the system include statutory limits such as maximum limits set by State legislatures for Interstates and other roadways, temporary or part-time speed limits such as limits posted in work zones and school zones, and variable speed limits that change as a function of traffic, weather, and other conditions.

A brief overview of the technical approach that was followed in this study is given below along with the conclusions:

Review of Previous Work. A review of the literature was conducted to identify relevant work in this area. The review focused on the several topics including the impact of speed limit changes, relationship between site characteristics and operating speeds, motorist compliance with existing speed limits, and factors and methods used to set speed limits.

Survey of USLIMITS Users. USLIMITS is an expert system developed for FHWA by the Australian Road Research Board based on several years of experience in developing expert systems for many provinces in Australia and New Zealand. The objective of the survey was to get feedback on several aspects of the program including: the ease of use, problems encountered, and the potential utility of the USLIMITS program. The intent of the survey was to determine the weaknesses of the current USLIMITS program (if any) and use that information to develop USLIMITS2.

Identification of Expert Panel. The knowledge base and decision making processes used in expert systems were drawn from experts with a background and experience in the area of interest. Members of the expert panel chosen to provide input for the expert system were selected from a comprehensive list of persons engaged in setting, enforcing, or adjudicating speed limits in speed zones.

User Needs and System Requirements. Based on input provided by the expert panel, user needs were developed and subsequently used to develop the system requirements.

Development of the Decision Rules. The decision rules for the expert system were developed using the information obtained from several face to face meetings and surveys of the expert panel, the NCHRP panel, and lessons learned from the use of the current USLIMITS program.

Conclusions. The following conclusions are based on the results of this research:

- Most previous studies suggest that the increase in posted speed limits on interstate roads in 1987 and 1995 resulted in more fatalities. Very little work has been conducted to study the effect of changes in speed limits on crash frequency and severity in non-limited access speed zones in this country.

- The survey of USLIMITS users revealed that most respondents felt that the speed limit recommended by USLIMITS was reasonable. Some felt that the USLIMITS program should provide more information regarding the decision rules and the factors used/not used in developing the final recommendation.

- In order to provide easy access to many practitioners, the expert system needs to be a web-based application.

- When developing an expert system, care should be taken to ensure that the system does not require extensive data collection that is beyond the scope of data now collected and maintained by an agency. The system’s interface should be intuitive and provide explanation of each step and the consequences of each decision made by the user.

- There is consensus that operating speed is a critical factor in determining an appropriate speed limit for a speed zone. Other factors identified as being critical included interchange spacing (in limited access freeways), roadside development, presence of pedestrian and bicycle activities, presence/absence of medians, roadside hazards, and crash and injury statistics.

- On road sections in rural areas where crash risk is typically not very high, many experts recommend posting the speed limit at the 5 mph multiple closest to the 85th percentile speed (the 85th percentile speed is the speed at or below which 85 percent of motorists drive on a given road). In urban areas with high pedestrian and bicycle activity, many experts recommend selecting the 5 mph multiple closest to the 50th percentile speed (the 50th percentile speed is the speed at or below which 50 percent of motorists drive on a given road) as the speed limit.

- Most experts agree that on road sections with high crash rates, a detailed crash analysis needs to be conducted to identify the contributing factors for all crashes. Countermeasures for reducing crashes should be selected based on identified causal factors; which can include measures other than the posted speed limit.

- To create widespread use of the product and truly have an effect on how speed limits are set, there is a need to promote the expert system and train potential users.

CHAPTER 1

BACKGROUND AND INTRODUCTION

The idea of controlling speed evolved from the assumption that reducing speed also reduces crashes, and indeed, speed is related to crash occurrence in three ways (*1*, *2*). First, speed influences the amount of time needed to respond to vehicles, pedestrians, or other objects in the roadway and to either stop or avoid the problem. Second, the difference in speed between vehicles on the roadway, or between vehicles and roadside objects such as parked cars or obstructions directly influences the probability of crashes. Third, greater speed influences the severity of injuries and property damage when crashes do occur.

Speed limits are selected to balance travel efficiency versus safety. The optimal balance depends on the type of road. Roads in areas such as residential subdivisions provide access, while collector roads distribute local traffic between neighborhoods and arterial street systems. On these roads, low operating speeds are desired to accommodate pedestrians and bicyclists and provide local access. On arterial streets where the primary function of the road is to carry traffic, the goal of speed management is to maintain mobility and capacity while increasing safety (*1*, *2*). On limited access roads built to the highest standards, there may be greater emphasis on reducing travel times without comprising safety.

It can be argued that a rational speed limit is one that is safe, that most people consider appropriate, that will protect the public, and that can be enforced. Even if a majority of motorists feel that they can make reasonable judgments about their driving speeds, posted speed limits are still essential, because:

1) Excessive speed selected by a particular driver who may have a higher tolerance for risk imposes significant risks on other drivers,
2) Some motorists are unable to correctly judge the capabilities of their vehicles, and/or unable to anticipate roadway geometry and roadside conditions sufficiently to determine appropriate driving speeds, and
3) Some motorists tend to underestimate or misjudge the effects of speed on crash probability and severity (*3*).

Artificially low speed limits can lead to poor compliance as well as large variations in speed within the traffic stream. Increased speed variance creates more conflicts and passing maneuvers, which can lead to more crashes (*4*, *5*). Some have argued that as a general proposition, speed limits should be set at levels that are self-enforcing so that law enforcement officials can concentrate their efforts on the worst offenders. "When speed limits are set artificially low and enforcement action cannot be directed at all the violators, the enforcement officer has too much discretion in selecting the motorists to be penalized" (*6*).

NEED FOR EXPERT SYSTEMS

The Manual of Uniform Traffic Control Devices (MUTCD 2003 Edition) notes that "when a speed limit is to be posted, it should be within 10 km/h or 5 mph of the 85th percentile speed of free-flowing traffic". However, the MUTCD also indicates that the following factors may be considered in addition to the 85th percentile speed when establishing speed limits, but does not provide specifics on how to account for these variables:

- Road characteristics, shoulder condition, grade alignment, and sight distance;
- The pace speed;
- Roadside development and environment;
- Parking practices and pedestrian activity;
- Reported crash experience for at least a 12 month period.

Due to lack of specific guidance and procedures from the MUTCD and other documents, engineers often rely on their experience and judgment in considering other factors apart from the operating speed while deciding on the appropriate speed limit in a speed zone. This sometimes leads to inconsistencies in how speed limits are set in different jurisdictions and can be confusing to the driver. An expert system is one approach that can be used to identify the appropriate speed limit for a speed zone. TRB Special Report 254 (*3*) argues that "the expert system approach deserved consideration because it provides a systematic and consistent method of examining and weighing factors other than vehicle operating speeds in determining an appropriate speed limit".

Expert systems aim to mimic an expert's thought process in solving complex problems. The original expert system (VLIMITS) developed by the Australian Road Research Board (ARRB) for Victoria, was a DOS-based program (*7*). Development of VLIMITS began with field measurements at over 60 locations. The data collected from the field were reviewed by a panel of experts who used this information to come up with decision rules for appropriate speed limits for different types of roads and traffic conditions. This information was reduced to a computer program. In this program, users were prompted to respond to a series of questions, and the system responds with a recommended speed limit. VLIMITS was updated in 1992 (*3*). Since then, programs have been developed for all Australian state roads authorities and for New Zealand. These include NLIMITS (for New South Wales), SALIMITS (for South Australia), WALIMITS (for Western Australia), QLIMITS (for Queensland), TLIMITS (for Tasmania), and NZLIMITS (for New Zealand). Collectively, these are called XLIMITS. It is important to note that the logic in these systems is hard coded, and the system does not learn with previous experience, as some expert systems do.

The most recent version of XLIMITS takes the user through a five-step process before recommending a speed limit (*3*). The first step deals with the type of area, rural, urban, urban fringe, or rural fringe. The next step deals with roadway and roadside characteristics such as number of lanes, access control, type of road, and median width. Using the information entered in these two steps, the system develops a first approximation for the speed limit. In the next two steps this speed limit may be modified based on other factors such as schools, accidents, alignment, and the 85th percentile speed. The final outcome is the recommended speed limit with warnings about specific factors that need to be studied further.

USLIMITS is the next generation in this series and was specifically developed by ARRB for application in the U.S. This application was developed for the Federal Highway Administration based on the logic used in the XLIMITS programs, but with changes made to suit the conditions in this country. One change was to force the recommended speed limits to be within the 50 to 85th percentile range. The logic and decision rules used in developing USLIMITS are not available to the user. Hence, it is not clear which variables affect the final recommendation and to what extent. Based on the research team's experience in using this system with several case studies, the area type, roadway characteristics, abutting development, and the operating speed do seem to affect the recommended speed limit. However, other factors such as accident counts, adjacent limits, and presence/absence of adverse alignment do not seem to affect the recommended speed limit, but the information on these factors are considered while providing warnings along with the recommended speed limit at the end of the program. USLIMITS can be accessed through the Internet (www.uslimits.com), but a username and password are required.

This project has developed a second generation expert system based on knowledge gained from experts in the United States (hereafter called USLIMITS2). Similar to USLIMITS, this program is accessed through the Internet (www2.uslimits.org). Unlike, USLIMITS, the user can create their own username and password, and the decision rules used to develop the system are documented in the form of flow charts, which are available to the user along with a User Guide.

STUDY OBJECTIVE AND SCOPE

The objective of this project was to develop a knowledge-based expert system for recommending speed limits in speed zones that are considered to be credible and enforceable. Credibility must be achieved in the eyes of multiple audiences including, but not limited to:

- Practitioners using the system and applying the results.
- Elected officials and public policy makers that must respond to the community.
- Drivers who are directly impacted by the limits established and whose behavior is a direct reflection of the effectiveness of the system.
- Judges and magistrates who must often address the "reasonableness" rule within their courts.
- Enforcement officials who need a more objective means of separating the egregious violators from the rest of the driving population.

The system has been designed to address the establishment of speed zones on all types of roadways, from rural two-lane segments to urban freeway segments. The types of speed limits not addressed by the system include statutory limits such as maximum limits set by State legislatures for Interstates and other roadways, temporary or part-time speed limits such as work zones and school zones, and variable speed limits that may change as a function of traffic, weather, and other conditions.

OVERVIEW OF THE APPROACH

Following is a brief overview of the approach (i.e., the steps) that was followed in this study:

Review of Previous Work

A review of the literature was conducted to identify relevant work in this area. The review focused on the following topics

- Impact of speed limit changes
- Relationship between site characteristics and operating speeds
- Motorist compliance with existing speed limits
- Factors and methods used to set speed limits
- Agencies/personnel involved in making speed limit decisions

Chapter 2 provides a brief summary of the literature review. The complete review is provided in Appendix A.

Survey of USLIMITS Users

A survey was sent in December 2003 to 55 individuals who had an account for using the current USLIMITS program. The objective of the survey was to get feedback on several aspects of the program including: the ease of use, problems encountered, and the potential utility of the USLIMITS program. The intent of the survey was to determine the weaknesses of the current USLIMITS program (if any) and use that information to develop USLIMITS2. A brief overview of the results from this survey is presented in Chapter 3. Appendix B has the detailed summary of the results.

Identification of Expert Panel

The knowledge base and decision making processes used in expert systems are drawn from experts with a background and significant experience in the area of interest. Members of the expert panel chosen to provide input for the expert speed limit system were selected from a comprehensive list of persons engaged in setting, enforcing, or adjudicating speed limits in speed zones, and persons with significant research experience in this area. Chapter 4 discusses the approach that was used in selecting the expert panel, and the list of members who attended the expert panel meetings.

User Needs and System Requirements

Chapter 5 outlines the user needs and system requirements of the expert system developed by the research team. The user needs were discussed at the expert panel meeting in June 2004, and subsequently used to define the system requirements.

Development of the Decision Rules

The decision rules for the expert system were developed using the information obtained from several face to face meetings and surveys of the expert panel, the NCHRP panel, and previous research. Chapter 6 gives a detailed discussion of the approach followed in the developing the decision rules for the expert system, and also presents an overview of the decision rules. Flow charts illustrating the decision rules are presented in Appendix K. A user guide is presented in Appendix L. The decision rules and the user guide are also available to the user from the expert system (www2.uslimits.org).

Long-Term Management Strategy

Chapter 7 discusses the issues related to the management of the product once the development contract ends, including site administration, upgrade cycle, and marketing.

Conclusions and Future Research

Chapter 8 provides a summary of the conclusions from this study and directions for future research.

CHAPTER 2

REVIEW OF PREVIOUS WORK

This chapter provides a brief summary of the literature review. The complete review is provided in Appendix A. The review is summarized in the following categories:

- Impact of speed limit changes
- Relationship between site characteristics and operating speeds
- Motorist compliance with existing speed limits
- Factors and methods used to set speed limits
- Agencies/personnel involved in making speed limit decisions

IMPACT OF SPEED LIMIT CHANGES

Effect on Average Speeds and Speed Dispersion

Several studies have tried to assess the effect of changes in speed limits on average speeds and speed dispersion. In many studies, speed dispersion is expressed as the difference between the 85th percentile speed and the average speed, which is approximately equal to the standard deviation (i.e., square root of the variance).

Effect of System-Wide Changes in Speed Limits

Most of the work in the United States has focused on studying the effect of system-wide changes in speed limits in Interstate highways. In 1974, the maximum speed limit was reduced to 55 mph; in 1987, maximum speed limits on rural interstates were increased to 65 mph; in 1995, the authority to set speed limits was given back to the individual States. The 1974 legislation was effective for some time in reducing average speeds due to the oil crises and because drivers understood that lower speeds were associated with less fuel consumption. When gas became more easily available, speeds started creeping up. Following the increase in the speed limits in 1987 from 55 to 65 mph on rural Interstate highways, average speeds increased between 1 and 5 mph. However, there is very little consensus on the relationship between changes in speed limits and speed dispersion.

Effect of Changes in Speed Limits in Speed Zones

In contrast to the large number of studies in the United States that have tried to examine the effect of changes in system-wide speed limits in Interstate highways, very few studies have looked at the effect of changes in speed limits in speed zones. Parker (*8*), in a landmark study, collected speed and crash data from 100 experimental sites where speed limits were increased or decreased and 83 comparison sites where speed limit was not altered. Overall, the study found very little evidence of a relationship between posted speed limits and speed distributions.

Effect on Safety

Speed is directly related to the severity of crash injury. It can also be argued that lower speeds lead to safer driving, based on at least 3 reasons. At lower speeds the vehicle travels a shorter distance during the fixed period of time that it takes for the driver to perceive and react to a problem. Second, the distance required to stop the vehicle decreases with a decrease in speed. Third, lower speeds reduce the chances of a vehicle running off the road while negotiating a horizontal curve.

Effect of System-Wide Changes in Speed Limits

Again, most studies have focused on the effect of *system-wide* changes in speed limits on safety. In general, most studies have concluded that the decrease in Interstate speed limits in 1974 was associated with a significant reduction in fatal crashes, and the increase in speed limits in 1987 and 1995 were associated with an increase in fatal crashes. Charles Lave from the University of California at Irvine has challenged these results indicating that the methodologies used in these studies are flawed and did not consider changes in enforcement and shifts in traffic from less safe non-Interstate roads to safe Interstate roads following the increase in speed limits in 1987. Recently, NCHRP (through Project 17-23) sponsored a study to look at the safety impacts of changes in speed limits on high-speed roads (*9*). This study concluded that an increase in speed limit from 55 to 65 mph can lead to a 28% increase in fatal crashes; and, an increase in speed limit from 65 to 75 mph can lead to a 13% increase in fatal crashes.

Effect of Changes in Speed Limits in Speed Zones

Regarding the effect of changes in speed limits on non-limited access speed zones, studies conducted by Parker (*10*) and Parker (*8*) are notable. Both studies used before-after designs with a comparison group to study this issue. A group of roadway sections had their speed limit increased or decreased (treatment group) while for another group of roadway sections, the speed limit was not altered (comparison group). Both the studies concluded that changes in speed limit had very little effect on the frequency and severity of crashes.

More recently, Elvik and Vaa (*11*) conducted a meta-analysis of the results from 52 studies between 1966 and 1995 that had studied the effect of changes in speed limits. It is not clear how many of these studies had looked at system-wide changes in speed limits and how many looked at changes in speed limits in speed zones. The meta-analysis showed that overall, reduction in the speed limit was associated with a reduction in fatal and injury crashes; fatal crashes were reduced more than injury crashes. For example, a 10 km/h (6 mph) reduction in the speed limit was associated with approximately a 10% reduction in injury crashes and a 20% reduction in fatal crashes; whereas, a 20 km/h (12 mph) reduction in the speed limit was associated with approximately a 20% reduction in injury crashes, and a 40% reduction in fatal crashes.

Effect of Changes in Average Speeds

Elvik (*12*) tried to determine if there is a relationship between average speeds and crashes. Specifically, he tried to assess if the Nilsson power model (*13*) is a reasonable model for the relationship between crashes and average speeds. The power model states that a given change in the mean speed of traffic is associated with a relative change in the number of crashes or number of injuries/fatalities by means of a power function. Elvik (*12*) conducted a meta-analysis based on a detailed review of 97 studies that provided 460 estimates of the relationship between changes in the average speed and changes in the number of crashes/injuries/fatalities, and concluded that in general, the power model was a reasonable model. However, Elvik (*12*) also acknowledged that some of its implications are counter-intuitive. For example, the Power model predicts that the effect on fatalities of reducing speed from 80 to 40 km/h is the same as the effect of reducing speed from 10 to 5 km/h. This seems unlikely to be the case. Further work using the same data set is ongoing in NCHRP Project 17-25 to determine if alternative model forms can better explain the relationship between the relative change in crashes and the relative change in mean speed.

RELATIONSHIP BETWEEN SITE CHARACTERISTICS AND OPERATING SPEED

The research team reviewed studies that have tried to study the relationship between site characteristics and operating speed. This review was helpful in identifying the possible factors that may need to be considered in identifying the appropriate speed limit in speed zones. Fitzpatrick et al. (*14*), as part of recently completed NCHRP Project 15-18, conducted a detailed review of the literature on this topic. The review looked at different types of roadways including rural two-lane highways, low-speed urban streets, urban and suburban arterials. Most of the studies used regression type models to relate average speeds with different site characteristics. Some studies included speed limit as one of the independent variables apart from other site characteristics, while others did not include the speed limits. Collectively, the following variables were found to be significant for different types of roads:

Rural two-lane highways: In horizontal curves, degree of curve, length of curve, deflection angle, radius, and grade had some relationship with operating speed. In tangent sections, region of the country, grade, length of the tangent section, and characteristics of preceding and succeeding curves were found to be statistically significant.

Low-speed urban streets: Average curvature, percent of zone with residential land use, percent of zone with parking allowed, roadside hazard rating, and lane width were related to operating speed.

Urban and suburban arterials: Deflection angle (in horizontal curves), access density, presence and type of median, lane width (in straight segments), and roadside characteristics were found to be related to operating speed.

MOTORIST COMPLIANCE WITH SPEED LIMITS IN SPEED ZONES

Many studies have reported that the posted speed limit is usually significantly lower than the measured 85th percentile value. For example, Parker (*8*) found that, in general, posted speed limits were set at the 45th percentile value on non-limited access roads. ITE (*15*) found that for roadways with posted speed limits of 45 mph and below, most of the measured speeds are higher than the posted speed limit. When the posted speed limit is 55 mph or more, about half of the measured speeds are above the posted speed limit. Collectively, these studies indicate that there is very little motorist compliance with existing speed limits.

FACTORS AND METHODS USED FOR SETTING SPEED LIMITS

Setting System-Wide Speed Limits

Statutory limits are one-way of setting system-wide speed limits. These limits are established by legislation at the national, state, or municipal level. The National Maximum Speed Limit (NMSL) of 55 mph that was established in 1974 during the oil crisis is one example. Typically statutory limits apply to a category of highways. Other statutory limits apply to vehicle categories. Differential limits for cars vs. trucks on Interstates in many States are examples of such. Usually, with statutory limits, the trade-off between safety, travel time, and other objectives is determined politically, and hence the limits can sometimes not be appropriate for a section of road.

Another approach to setting system-wide speed limits is setting optimum speed limits. Initially proposed in the 1960's (*16*), this approach is based on the argument that the speeds selected by drivers do not take into account risks imposed on other drivers and society. In order to apply this approach, there is a need to estimate the relationship between speed limits and parameters such as travel time, vehicle operating costs, crashes, comfort, and convenience. Although this approach has conceptual appeal, there is no universal consensus on the relationship between speed limit and the other parameters, making it difficult to implement in practice.

Setting Speed Limits in Speed Zones

The most common approach to setting speed limits is based on an engineering study, which requires collecting data on operating speeds, crash frequency and severity, and other site characteristics such as roadway geometry, traffic characteristics, and roadside characteristics. The MUTCD recommends that the speed limit *should* be set at the 85th percentile speed, but adds that other factors including crash statistics, roadway cross section, pace speed, roadside development, and parking and pedestrian activities, *may* be considered.

ITE (*15*) conducted a survey to determine the factors that are being used to set speed limits in speed zones. The 85th percentile speed, roadway geometry, and accident experience, were always or usually considered by over 90% of the responding agencies. The survey revealed that roadway geometry, accident experience, and politics were the three most common reasons why a number other than the 85th percentile speed was used when setting the speed limit. Some survey responses stated that the "85th percentile does not work and a better method is needed".

It is clear that better methods are needed to identify appropriate speed limits, especially in urban roads having higher traffic volumes, a mix of road users, and more roadside activity. Practitioners have to use their experience and judgment in considering these factors. A knowledge-based expert system provides a valuable opportunity for improving the decision making process.

Expert systems for recommending speed limits have been used in Australia for more than a decade starting the late 1980's (*7*). USLIMITS, an expert system for recommending speed limits for speed zones in the USA, was developed based on the experience in developing and using the expert systems in Australia, but with changes made to suit the conditions in this country. The USLIMITS system asks the user to enter data for the following factors before recommending a speed limit:

- roadway and roadside characteristics,
- abutting development,
- nature of road user activity,
- operating speeds,
- traffic volume, and
- speed limits in adjacent sections
- presence of adverse alignment
- crash statistics
- special situations

Information about some of these factors is used by the system to provide warnings at the end of the program. USLIMITS can be accessed through the Internet, but a username and password are required, which can be obtained from the Federal Highway Administration.

AGENCIES/PERSONNEL INVOLVED IN SPEED LIMIT DECISIONS IN SPEED ZONES

Most state and local agencies base their decision to raise or lower a speed limit in a speed zone on the results of an engineering and traffic investigation. Agencies and persons frequently involved in speed limit decisions are included, but not limited to, the following groups:

- Practitioners conducting the speed studies and interpreting the results.
- Elected officials and public policy makers that respond to community affairs.
- Drivers whose behavior is a direct reflection the effectiveness of the system.
- Citizens living or working in the area who are directly impacted by the traffic flow.
- Judges and magistrates who must address the 'reasonableness' of the limit in their court decisions.
- Enforcement officials who need an objective means of separating the egregious violators from the rest of the driving population.

CONCLUSIONS

The following conclusions can be made based on this review:

- Consistent speed limits are essential even if a majority of motorists feel that they can make reasonable judgments about their driving speeds

Conclusions regarding changes to system-wide speed limits

- Increase in speed limits on interstate roads in 1987 and 1995 seem to be followed by an increase in average speeds, although the increase in average speeds was typically less than the increase in the speed limit. Effect of the increase in speed limits on speed dispersion is not very clear.

- Most researchers argue that the increase in speed limits on interstate roads in 1987 and 1995 resulted in more fatalities.

Conclusions regarding changes to speed limits in speed zones

- Very little work has been conducted to study the effect of changes in speed limits on average speeds on non-limited access speed zones.

- Very little work has been conducted to study the effect of changes in speed limits on crash frequency and severity in non-limited access speed zones. Parker (*10*) and Parker (*8*) in their work on non-limited access roads did not find any significant associations between speed limits and crash frequency/severity.

- Many studies have tried to find relationships between site characteristics and operating speed. Depending on the type of road under consideration and whether tangent sections or horizontal curves are being considered, several factors including degree of curve, deflection angle, radius, grade, lane width, presence/absence of parking, roadside hazard rating, access density, presence and type of median, pedestrian activity, and roadside characteristics, seem to be associated with operating speeds.

- In general, there is limited motorist compliance to existing speed limits.

- It is clear that posted speed limits in speed zones should be credible and enforceable. It is also clear that better methods are needed to identify appropriate speed limits especially in urban roads having higher traffic volumes, a mix of road users, and more roadside activity. Practitioners have to use their experience and judgment in considering these factors. A knowledge-based expert system provides a better opportunity of improving the decision making process.

CHAPTER 3

SURVEY OF USLIMITS USERS

A survey was sent in December 2003 to 55 individuals who had an account for using USLIMITS. The objective of the survey was to get feedback on several aspects of the program including: the ease of use, problems encountered, and the potential utility of the USLIMITS program. Fifteen individuals responded to the survey. Three had used the product for establishing speed limits, 11 had explored the application (not actually used it to set speed limits), and 1 had not used USLIMITS.

A brief summary of the results is provided here. Further details about the survey and the response are available in Appendix B. The questions asked in the survey were as follows:

1. Have you or your agency explored or applied the USLIMITS program for the purpose of setting speed limits?
2. Enter the number of speed zoning projects in each roadway type for which you have applied USLIMITS.
3. Apart from using USLIMITS, describe how you currently set speed limits, e.g., do you have established or written guidelines (this question applies to only those agencies that have authority to set speed limits).
4. Please rate the overall Ease of Use of the USLIMITS program. Indicate how the ease of use can be improved.
5. Please comment on the clarity and completeness of the input screens, on-line help, and the Users Manual.
6. The data collection form in the USLIMITS program asks the user to input information on several variables/factors. Based on your knowledge and experience, please indicate whether you feel each of these factors are of "primary importance", "secondary importance", or "not important" (the variables are described in the USLIMITS user manual). In addition, also list additional factors that need to be considered, and indicate whether they are of primary or secondary importance.
7. Please describe problems and annoyances encountered in using USLIMITS. If you have a specific recommended solution to a problem, please provide that as well.
8. Was USLIMITS useful in assisting with your speed zoning decision? Explain.
9. Would you say that speed limits recommended by USLIMITS are reasonable based on your knowledge and experience? If No, please explain. For example, are the recommended speed limits higher or lower than what you would have recommended for certain types of roads, areas, or conditions?
10. Please comment on the content, completeness, and flexibility of the USLIMITS output report.
11. Does the USLIMITS output report provide all the relevant information that you need? What changes would you suggest?

Eleven respondents felt that USLIMITS was easy to use; two felt that it was not easy to use (question 4). Eleven respondents felt that the speed limit recommended by USLIMITS was reasonable; two felt that the speed limit recommended by USLIMITS was not reasonable (question 9).

Twelve individuals responded to question 6, which asked the user to rate the importance of factors currently used by USLIMITS to develop its recommended speed limit. Road length, road function, number of accesses, number of lanes, whether the section is a freeway (or not a freeway), traffic volume, operating speeds, presence/absence of adverse alignment, presence/absence of signals or unprotected pedestrian crossings, special activities, and crash rate, were selected as of 'primary importance' by more than half the respondents (i.e., at least 7 of the respondents): operating speeds and adverse alignment were identified by 11 respondents, road function was identified by 10 respondents, and crash rate was identified by 9 respondents to be of primary importance.

Some respondents provided detailed comments on different features of USLIMITS. Here is a summary of the some of the problems that the users faced, their recommendations for improvement, and actions taken by the research team to avoid these problems in the second generation expert system:

- The program should provide more information about the logic that it uses and the factors that are used/not used in developing the final recommendation. One respondent pointed out that the system is not sensitive to a lot of variables that are required to be input.
    - It is possible that the lack of information about the decision rules used in USLIMITS reduces the confidence in the potential users. The decision rules used to develop the second generation expert system (USLIMITS2) is documented and available to the user.

- Some respondents felt that it would be easier to have a single long form to enter most of the data rather than waiting for different screens to load. The program should allow easier navigation among the input windows.
    - The USLIMITS program has several windows with one window allocated for each factor. USLIMITS2 allows users to enter most of the site characteristics (except crash data) in one screen, and hence reduces the time it takes to go through the program.

- Definitions should be provided for some of the variables such as access, access types, street classifications, shoulder, and density of surrounding development.
    - In USLIMITS2, by clicking on the More Info link, the user can obtain further information about each variable. Users also have access to the User Guide that provides more information about each variable.

- A couple of respondents felt that the tool is probably geared only towards high speed facilities and not very useful for lower speed urban situations.
    - Since the decision rules used to develop USLIMITS is not available to the user, it is hard to know if this is true or not. In USLIMTS2, decision rules have been developed to deal with different types of roads including high speed facilities and lower speed urban situations.

- Improve the output to make it easier to read. The output should also include information about the input data that was entered by the user.
    - In USLIMITS2, users can download the output in a MS Word file, and this file provides information on the input data entered by the user.

CHAPTER 4

IDENTIFICATION OF THE EXPERT PANEL

The knowledge base and decision making processes used in expert systems are drawn from experts with background and experience in the area of interest. The success or failure of an expert system is dependent upon the selection of an appropriate group of experts with knowledge, experience, and interest in the subject area. Members of the expert panel chosen to provide input for the expert system were selected from a comprehensive list of persons engaged in setting, enforcing, or adjudicating speed limits in speed zones, and individuals with significant research experience in this area. The process used to identify the panel members is outlined in this section.

SELECTION OF EXPERT PANEL MEMBERS

The expert panel for this study was involved in all areas of product development, starting with the planning stage, continuing with development of the decision rules, and concluding with the evaluation of the prototype expert system. The expert panel provided expertise in how speed limits are set and enforced; identified the level of skill, needs, and requirements of the user community; determined the variables to be considered; provided data on how problems and issues are addressed in practice; and advised on how the system must function to be accepted by users.

In order to fulfill the general data and other needs of the project, the research team identified a comprehensive list of individuals involved in the speed limit setting process. The list was further refined to identify candidates who would attend the expert panel meetings in Washington, DC. This group is hereafter referred to as the Expert Panel. All other candidates (hereafter referred to as the expanded panel) were retained on a second list and were contacted by email, telephone, mail, etc. to provide input on specific topics.

Development of the Comprehensive List of Potential Candidates

The initial selection of candidates to provide input for this project was based on identifying individuals whose responsibility included, but was not limited to, the following speed management-related areas:

- Highway engineer.
- Traffic operations administrator.
- Traffic engineers who analyze speed and other data and recommend a posted speed limit. (Engineers from a cross-section of States were solicited. The group also included engineers from local jurisdictions, i.e., cities, counties, etc.)
- Traffic operations/safety systems computer analyst.
- Public policy and political issues specialist and elected officials.
- Traffic enforcement administrator.
- Traffic patrol officer.

- Judicial administrative representative.
- Researchers with significant experience in speed studies.

After identifying the areas of specific expertise, the next step in the selection process was to select individuals for each of the categories mentioned above. To initiate this process, the research team examined a wide variety of membership lists including, but not limited to, the following organizations and events:

- State Department of Transportation members as well as practitioners with cities, counties, and other local highway agencies.
- Presenters and attendees at the Speed Management Workshops that were held in Washington, DC on January 9, 2000; Dallas, Texas on March 6, 2000; Jacksonville, Florida on June 12, 2002; and at the Institute of Transportation Engineers (ITE) annual meeting in Philadelphia, Pennsylvania on August 4, 2002 http://safety.fhwa.dot.gov/fourthlevel/flspeedwkshp.htm, [Accessed 11/8/2002].
- Members of the AASHTO Traffic Engineering Subcommittee.
- ITE Traffic Engineering Council and Safety County Committee members.
- Member of ITE Committees 4M-25, Speed Zoning Guidelines, and TENC 97-12, Survey of Speed Zoning Practices.
- Participants in the TRB Committee that developed TRB Special Report 254, Managing Speed – Review of Current Practice for Setting and Enforcing Speed Limits.
- Members of the FHWA Scanning Program Study Tour for Speed Management and Enforcement Technology (http://ntl.bts.gov/DOCS/speed06.html), [Accessed 11/6/2002]
- Participants in the ongoing Cooperative Agreements on Speed Setting and Enforcement Projects in Connecticut, Mississippi, etc.
- Members of the U.S. DOT Speed Management Team, which includes sponsors from FHWA, NHTSA, and FMCSA.
- Members of NCHRP Project 3-67 Panel who would be willing to provide their knowledge and expertise.
- Persons who had obtained a username and password to examine the beta version of USLIMITS.

Contact information for persons identified through the above sources was placed in a spreadsheet for further analysis. Over 100 individuals were initially placed on the master list.

Selection of Potential Candidates

As previously noted, the Expert Panel consisted of individuals who were willing to attend panel meetings in Washington, DC. In selecting the Expert Panel, the following general criteria were used:

- Individuals were identified with the following expertise:

    - Enforcement
    - Judicial
    - Traffic Engineering

    - Other including research, public policy, elected officials, etc.

- In accordance with the travel budget allocated for this activity, a maximum of eight candidates were selected from outside the greater Washington, DC area. Other candidates were selected within Washington, DC area.

- For each expertise and within the travel constraints listed above, candidates were selected from different geographic regions as well as from states, cities, and other jurisdictions ranging from rural to large urban centers.

Based on the selection criteria, individuals from the master list were chosen as candidates to be on one of the two panels. Prior to contacting the persons on the Expert Panel list to determine their availability, the meeting group list and the contract group list was sent to the NCHRP 3-67 Panel for review and comment. In written comments received from the Panel, eight additions and one deletion were suggested for the Expert Panel proposed to meet in Washington, DC. In addition, eight additions and one deletion were suggested for the Expanded Panel.

Following input from the NCHRP Panel, the revised list of candidates for the Expert Panel was further refined. The selection process consisted of sending or directly contacting the person and asking the questions shown in Table 1. Based on the responses to the questions, each person was placed on either the Expert Panel list or the Expanded Panel list. Some of the individuals were not available for travel, and three candidates did not respond to the inquiry. Of the persons who were available to meet, the list was further refined to only include eight persons from outside the greater Washington, DC. The criterion used in this refinement was primarily based on the experience and involvement of the candidate in setting speed limits in speed zones.

The list of Expert Panel members who were invited to the June 10 and 11, 2004 meeting in Washington, DC is shown in Table 2. The list of members who attended at the December 2005 expert panel meeting is shown in Table 3.

The persons who were either not selected or were not available to attend the Washington, DC meeting were placed in the Expanded Panel except for those who noted that they could not participate (see Appendix C for the Expanded Panel). It should be noted that persons attending the meeting were also periodically contacted and asked to provide specific expertise needed to complete the knowledge base and/or logic for the expert speed limit system.

Through two meetings in Washington, DC (one held on June 10-11, 2004 and the other in December 2005) and through the use of regular mail, e-mail, and telephone, the expert and expanded panels provided information and feedback in the following project areas:

- Expert System Planning – What should the system do? Who are the end users? Who should administer and maintain the site?
- Speed Management Knowledge – Knowledge of user needs, user requirements, variables and factors considered, problems encountered in setting and enforcing speed limits and solutions, etc.

- Expert System Development – Breakpoints for critical variables and factors, decision rules, and logic flow.
- System Validating and Evaluation – Reviewed and critiqued the beta version, provided recommendations for system modifications, etc.

Table 1: Questions for Potential Expert Panel Candidates

NCHRP 03-67
Expert System for Recommending Speed Limits in Speed Zones

1. Are you directly involved in setting speed limits for roads and streets in your jurisdiction?

2. Please describe your experience with speed limits, including years of experience?

3. Have you heard of USLIMITS, an advisory program used to set speed limits?

4. Do you have an interest in our project?

5. Would you be interested in traveling to Washington, DC to serve on an expert panel?

6. Are you available for travel to Washington, DC on June 10 and 11 and again next year (date to be determined)? Reimbursement is available for travel costs only.

7. Would you be interested in being a member of our expert advisory group which does not require travel to Washington, D.C.?

Table 2. Attendees at the Expert Panel Meeting in Washington, DC (June 10-11, 2004)

Out of Town Attendees

Bruce Ward, Traffic Engineer, Town of Gilbert, AZ
Cpl. Michael Caldwell, Traffic Bureau, Taylor Police Department
Michael J. Cynecki, Traffic Engineering Supervisor, City of Phoenix
George W. Black, Jr., Senior Civil Engineer/National Resource Specialist, National Transportation Safety Board
Michael K. Curtit, Technical Support Engineer, Missouri Department of Transportation
Robert S. Ciolek, Magistrate, City of Taylor, MI
Harold T. Thompson, National Safety Council
William Taylor, Michigan State University, NCHRP 3-67 Panel Member

Washington, DC Area Attendees

Lt. Dennis R. O'Neill, Police Officer, Fairfax County Police Department
Davey Warren, FHWA Office of Safety Programs, NCHRP 3-67 Panel Member
Mena Lockwood, Virginia DOT
David Snyder, Falls Church, VA City Council
Ron Lipps, Traffic Engineer, Maryland State Highway Administration

Table 3 Attendees at the Expert Panel Meeting in Washington, DC (December 2005)

Name	**Affiliation**
Joseph Durkee	Arlington County, VA
Michael Caldwell	Taylor Police Dept, Michigan
Dennis O'Neill	Fairfax County Police
Martin Bretherton	Gwinnett County, Georgia
Bruce Ward	City of Gilbert, Arizona
Larry Caldwell	Virginia DOT
Ron Lipps	Maryland DOT
Bill Finger	City of Charlotte, NC
William Taylor	Michigan State University, NCHRP 3-67 Panel Member
Davey Warren	FHWA, NCHRP 3-67 Panel Member
David Synder	American Insurance Association; City Council Member – Falls Church, VA

CHAPTER 5

USER NEEDS, SYSTEM REQUIREMENTS, AND HARDWARE/SOFTWARE REQUIREMENTS

USER NEEDS AND SYSTEM REQUIREMENTS

The identification of user needs and system requirements for the expert speed limit system was accomplished via a two-step process. First, the research team developed a preliminary set of user needs and system requirements based on extensive experience and contacts with agencies and persons involved in setting and enforcing speed limits at the state and local level throughout the United States. In the second step, this preliminary set of needs and requirements was refined by the Expert Panel at the meeting in June 2004, and the NCHRP Panel during the Interim Meeting in August 2004. The refined needs and requirements were used in developing the hardware, software, and interface requirements which were used as the basic building blocks for developing the expert system. In addition, the fundamental user needs were used to evaluate the effectiveness of the completed system, e.g. is the system user-friendly, do users accept the system, is the system maintainable, etc.

User Needs

Based on years of experience working with state and local highway and law enforcement officials and public officials involved in speed management, the following user characteristics were identified:

- Most State and larger urban jurisdictions have computer networks connected to the Internet. Most of the users have been trained and are experienced Internet users. Web applications are accepted practice for interactive problem solving, and the results are widely accepted by administrators, politicians, and the public.

- Some small jurisdictions may or may not have Internet access. As computer prices and Internet access has become commonplace across the county, most localities will have Internet connections in the near future. In addition, affordable high-speed Internet access is becoming available in many areas.

- The basic requirements of an engineering and traffic study, which is conducted to set speed limits in speed zones, typically consists of a large number of geometric, vehicle characteristics and volumes, land use, non-motorized user information, crash statistics, and operating speed data. In some cases, much of this data is often not used effectively because of the absence of guidelines in how the information should be considered in speed limit decisions.

- Engineers and other practitioners that may use this system are typically very busy and do not have time to learn new systems or continually refer to manuals on how to use a software product. Hence, the expert system should require no formal classroom training. Not only should the interface be intuitive, it should provide explanation at each step of what is happening and the consequences of each decision made by the user.

- While context sensitive self-help features are one means of addressing user needs, some users are not satisfied until they have their questions addressed by a site monitor. Responses to questions from users must be provided in a reasonable amount of time and should be specific enough to address the user's concerns.

- Practitioners are frequently faced with political influences that encroach on speed limit decisions.

System Requirements

Based on the experiences of the research team, the results of the literature review, and the user needs described above, the following general system requirements were identified:

- The system should be a web-based application; however, as mentioned earlier, some users in small communities and rural areas may not have access to the Internet.

- When developing the expert system, the type of variables and amount of data collected or that can be collected by the agency must be taken into consideration. Care should be taken to insure that the system does not require extensive data collection that is beyond the scope of data now collected and maintained by the agency. In other words, the system needs to be data-driven but not data-intensive.

- The user interface and method of interacting with the user should be compatible with the expectations of the user and the physical realities of the road or street being examined. For example, the user should not be asked to input the number of driveways on limited-access highways.

- The system data needs and decision-making process should be self-explanatory. Convenient electronic assistance should be provided.

- Training requirements for a new user should be minimal with sufficient help provided to assist with the terms or processes used.

Expert Panel Feedback

The preliminary set of user needs and requirements were summarized and presented at the Expert Panel meeting held in Washington, DC on June 10-11, 2004. Panel members were asked to comment on, remove, add to, or modify the preliminary list of user needs. The panel agreed with the needs and requirements identified, but emphasized the following two issues:

Access of the Expert System through Internet versus CD

Some members of the expert panel indicated that some jurisdictions still do not have access to the Internet and others have filters that prevent them from accessing certain sites. Hence, a CD product would be useful. Other members argued that jurisdictions that do not have access to Internet are unlikely to use a tool such as an expert system to set speed limits. Since developing a CD version of the product in addition to the Internet version incurs additional costs, this issue was discussed further with the NCHRP Panel at the Interim Meeting. The NCHRP Panel felt that the development of the CD product was not worth the additional cost.

Information about the Decision Rules

In order for the decision maker to use the tool effectively, information about the factors considered by the system and the decision rules should be available to the user.

APPLICATION DESIGN AND HARDWARE/SOFTWARE REQUIREMENTS

Application Platform

There are a variety of tools that could be used in the development of the expert system. The tools can be divided into two categories: programming languages and expert system shells. Programming languages that have been used by project team members for expert advisor systems range from Microsoft Excel for the selection of appropriate signal timing plans to Allaire's ColdFusion for a web-based system that allows one to select the most appropriate countermeasures for pedestrian safety.

Expert system shells (e.g., EXSYS, CLIPS, Nexpert-Object, VP Expert) are specifically designed so that their modular development allows for additions and changes as the defined knowledge base grows. One has to be careful in selecting an appropriate expert shell that can not only provide the programming robustness required to meet the functional specifications, but also be applicable in a web-based environment. In addition, the cost of the development tool is a consideration.

For this project, the research team used a traditional programming backed by a database rather than the use of an expert system shell. The research team felt that while there are shells on the market that allow for non-programmers to create and maintain the necessary code, these options limit the overall functionality of the system. The final product is envisioned to be a robust and versatile web application that is best created and maintained with an equally robust and versatile programming language. Furthermore, by storing the variables and valid values in a database, and structuring the code accordingly, future updates or modifications will only require the modification of the database, and not the code. Maintaining a database is much easier, less costly, and safer that editing code.

Product Medium

The primary product developed in this effort is a web-based application. Subsequently, the discussion that follows pertains to the hardware and software requirements for such.

End-User Hardware, Software, and Interface Requirements

With a web-based product, the user is only required to have a computer with web-browsing software connected to the internet. Any web browser version developed in 2003 or later would be sufficient. Examples include Netscape (Version 6.0 or later), MS Explorer (Version 5.5 or later), and Firefox (Version 0.8 or later). The final results are output to the user's computer screen. Users will not need any special skills to access and use the system.

Server Hardware, Software, and Interface Requirements

The system host configuration includes a web server, an application server, and a database server. The host machine should be server-grade, with sufficient memory and disk space to accommodate the selected server software. The server, operating system, web server, and application server are an integrated package. The minimum requirements for the application installed in a UNIX server are as follows:

- Processor: UltraSPARC IIIi
- Memory: 2048 MB
- Disk Subsystem: SCSI or RAID

The minimum requirements for a WINDOWS server are:

- Processor: Pentium IV 2.8 GHz
- Memory: 1024 MB
- Disk Subsystem: SCSI or SATA

Product Development Software

In creating numerous web applications over the years, the research team has found ColdFusion MX and Oracle to be the best overall programming language and database structure for building powerful applications, and hence used to develop the expert system. While other options did exist (such as ASP and PHP) when the decision was made to use ColdFusion, ASP and PHP had limitations that the research team felt would be detrimental to this application.

ColdFusion is a server-side solution for creating interactive, database-driven Web sites. It works in conjunction with a Web server to deliver dynamic, rather than static, Web pages. In other words, the web page content varies according to user input. Web pages are built including special tags, which must be hosted on an application server that supports ColdFusion. When a

Web browser requests one of those pages, the application server first interprets the special tags, replaces those tags with the results of whatever calculations or database queries are specified, and then sends the completed page to the Web server, which then sends it to the browser.

ColdFusion uses a tag-based language—normal HTML tags are mingled with those of ColdFusion Markup Language (CFML). CFML includes tags for querying databases and outputting text, and interacting with other Web services such as email. Instead of ending the filenames with .htm or .html, the .cfm extension is used.

CHAPTER 6

DEVELOPMENT OF THE DECISION RULES

The decision rules were developed using information obtained from several meetings/conference calls with the expert panel and the NCHRP Panel, and surveys of practitioners around the country. The following list outlines the meetings, surveys, and other steps that were undertaken:

- Expert Panel Meeting (June 2004)
- Interim Meeting with the NCHRP 3-67 Panel (August 2004)
- Survey of NCHRP Panel and Expert Panel (Fall and Winter 2004)
- Web-Based Pilot Tests (Spring and Summer 2005)
- Final Round of Web-Based Case Studies (Fall 2005)
- Expert Panel Meeting (December 2005)
- Development of Draft Decision Rules (January 2006)
- Develop of Expert System Prototype (March and April 2006)
- Conference Call to Discuss Draft Decision Rules and the Prototype (May 2006)
- Final Decision Rules and Expert System for Panel Review (August 2006)

Further details about each of these steps are discussed below.

EXPERT PANEL MEETING IN JUNE 2004

This section provides an overview of the activities at the expert panel meeting in June 2004 that were used to identify critical factors and gives insight to how the information may be considered in the decision making process when determining a recommended speed limit in a speed zone. The critical factors and elementary decision logic were identified via a review of the literature and through case studies presented during the meeting.

One of the first steps in developing an expert speed limit system is to identify critical factors that need to be included. *Critical factors* are factors and variables that are considered by experts to be essential to formulating a speed limit recommendation. Without a critical factor or default value supplied by the system, it is not possible to make a speed limit decision.

Prior to the June 2004 meeting, the members of the expert panel were sent the following materials for review:

- Tentative Agenda for the two-day meeting
- Draft version of the Literature Review (Appendix A has the updated version)
- Results of the Survey of USLIMITS Users (Appendix B)
- Preliminary List of Variables and Factors (Appendix D)

In addition, prior to the meeting, the research team developed a series of case studies, which consisted of photographs and supporting speed, crash, geometric, and other data. Each case study was a section of road or street in southeastern Michigan where speed, crash, and other data were recently collected in order to determine the appropriate speed limit for the speed zone. The Expert Panel was not furnished with the case studies prior to the meeting.

The primary objective of the meeting was to use the knowledge and experience of the group to identify the critical factors and variables needed to make a speed limit decision. In addition, once the major factors were identified, the second major objective was to obtain a preliminary understanding of how the variables were evaluated and used in making the speed limit decision.

At the beginning of the meeting, the research team presented an overview of the project, a brief demonstration of the current USLIMITS program, and described the meeting objectives. The research team then made a presentation on user needs and requirements and obtained feedback from the Expert Panel. Following a break, the reminder of the day and most of the following day was devoted to identifying the critical variables.

The session on critical variables began with a PowerPoint introduction of the preliminary list of variables. The variables were presented for the following roadway types:

- Rural interstate highways
- Urban interstate highways
- Rural high-speed two-lane and multi-lane highways
- Urban and suburban multi-lane and two-lane roads
- Rural lower speed two-lane roads
- Urban residential streets

Some members of the expert panel felt that the distinction between rural and urban was sometimes ambiguous and the distinction between high speed/low speed roads should be made based on factors such as operating speed/design speed. There was a general consensus that the roads could be categorized into freeway, multi-lane, and two-lane, for undeveloped and developed areas.

Case Studies

Up to this point in the meeting the Panel members were provided with the list of variables based on the literature review and the experience of others. While this information may have introduced some bias either for or against a particular variable, the research team did not make the assumption that all of the variables described in the literature were actually used in practice to make speed limit decisions. To identify which variables the Expert Panel felt were critical to the decision making process, a series of case studies were introduced through photographs, and the attendees were asked to tell the research team which variables they felt were critical for the particular road section under study. Thus, the Panel members had to examine the photographs, which were projected on the screen for all members to review, and then decide what information, or variables they needed to determine the speed limit for the section.

To initiate the use of case studies and to set the stage for having the Panel members identify critical variables based on their experiences, the research team made a presentation that is summarized on the next two pages in Figure 1. The purpose of the presentation was to provide a general overview of the process that would be used by the panel to identify critical variables. The presentation consisted of eight slides taken at various road and street locations in southeastern Michigan. A broad cross section of roads was used which included the road types identified during the literature review. As shown on the next two pages, only general titles, such as Rural two-lane, Urban with on-street parking, etc. was used to describe the sections. No other information, such as operating speeds, traffic volumes, etc., was supplied. Throughout the presentation, the Panel was asked to think about what variables they would need to determine the speed limit on the section if the road was in their jurisdiction.

During the two-day meeting, a total of six case studies were presented to the Expert Panel. To illustrate the process used to identify the critical variables, one of the case studies, a rural two-lane road, is presented in this section.

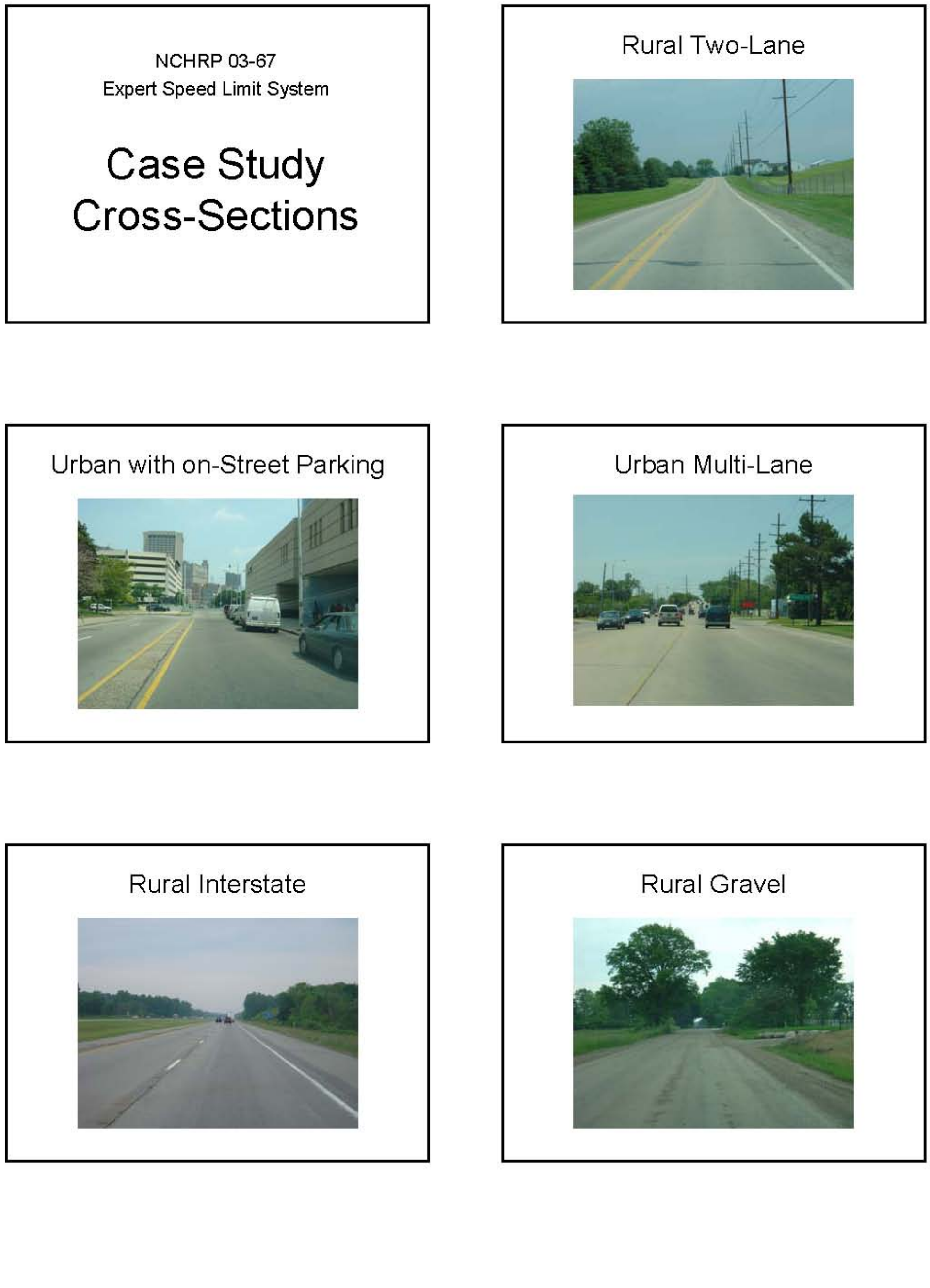
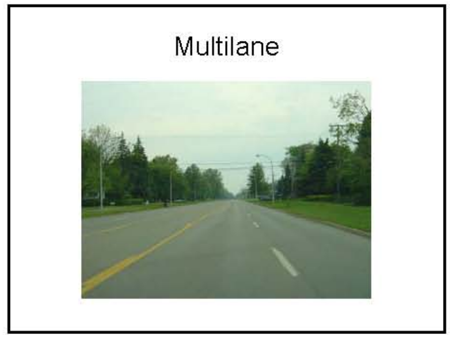


Figure 1. Typical cross-sections for the case studies used in the Expert Panel meeting.



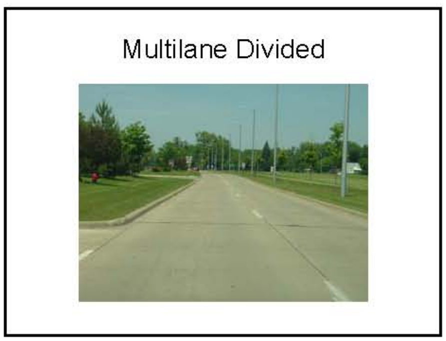


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Figure 1 (con't). Typical cross-sections for the case studies used in the Expert Panel meeting.

Case Study Example (Rural Two-Lane Road)

As shown on Figure 2, photographs of representative cross sections of a rural two-lane road in southeastern Michigan were shown to the Panel on the screen. The members were asked to review the photographs and determine the variables they would use to determine the appropriate speed limit for the section. A general or broad list of variables was not permitted, because this is not reflective of general practice, i.e., speed limit decisions are usually based on collecting just the amount and type of information needed to make the decision. The collection of other variables may be desirable; however, it is not routinely done due to personnel and budget limitations.

The following variables were requested by the Panel for this road segment. The information presented below is based on the data that was actually collected at the site prior to the meeting.

- Section length = Two miles.
- Speed data
  - 85^{th} percentile speed ranges from 53 to 55 miles per hour.
  - Average speed ranges from 47 to 49 miles per hour.
  - Pace ranges from 47 to 56 with approximately 72 percent of the vehicles in the pace.
- Posted speed Limit = 40 miles per hour
- Speed limits on the adjacent sections = 55 and 35 mph. The 35 mph section is in a small town.
- ADT = 1,200 vehicles per day.
- Reason for the study = Request to raise the speed limit.
- Crash experience was extremely low (4 crashes in 3 years with 1 injury crash).
- Little pedestrian or bike traffic observed on the section.
- The shoulder width is variable.
- There are no schools in the area.
- The roadside development consists of a few residential farmhouses, i.e., low density.
- There are no public road intersections within the segment.

After identifying the critical variables for each case study similar to the process described above, the Panel was subdivided into break-out groups and asked to categorize each variable by high, medium, or low importance. Each breakout group was presented with photographs of different types of roadway segments and asked to develop the list of factors for which data would be necessary in order to identify the appropriate speed limit for a particular roadway section.

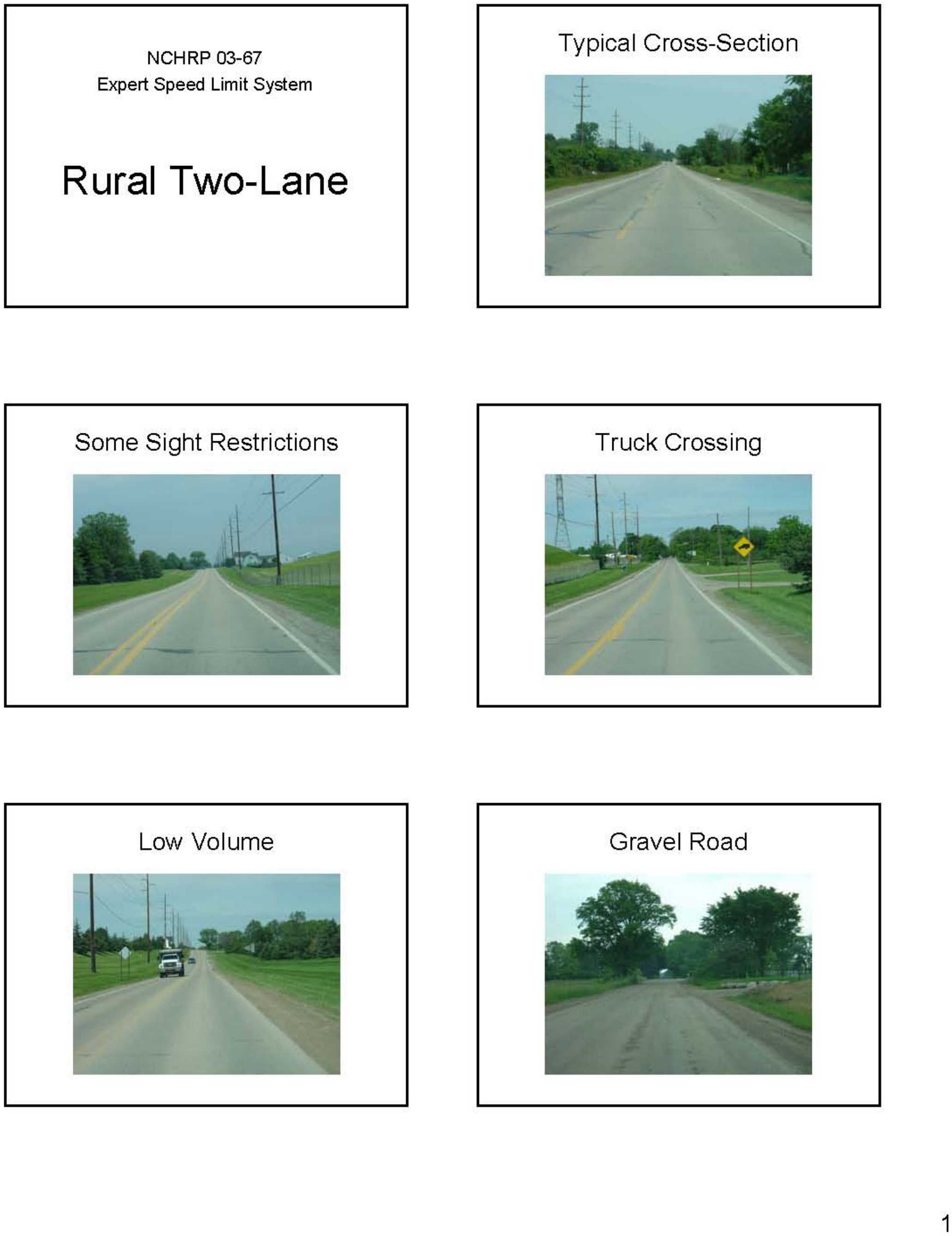

Figure 2. Images used in the Expert Panel meeting for the Rural Two-Lane case study.

In subsequent exercises, the Panel was asked to consider the quantitative information for each section (e.g., operating speeds, crash statistics, etc.) and to recommend a speed limit for the section. This was done to examine the decision logic used by the experts to arrive at the recommended speed limit. Generally, using the data the Panel requested, the majority of the panel members recommended a speed limit within 5 miles per hour of each other for a particular road segment. Most members felt that the operating speed was an important factor in obtaining an initial speed limit, but there were differences on how the other variables should be considered in the decision making process.

Critical Variables

The panel identified the following variables as critical for the three different roadway types (Table 4):

Variable	Freeway	Multi-lane	Two-lane
Operating Speed	X	X	X
Roadway Geometrics (more critical if operating speeds are not available)	X	X	X
Cross-section (includes clear zone)	X	X	X
Crash statistics	X	X	X
Roadside friction		X	X
Major intersection/interchange spacing	X	X	X
Ped/Bike activity		X	X
Road classification		X	X
Proximity to a School Zone		X	X

Table 4: Critical variables for the three different roadway types

Conclusions from the June 2004 Expert Panel Meeting

The processes used to identify the decision rules used to determine the numerical value of the posted speed limit for a section of road included utilizing the experience of the research team and the knowledge and experience of the Expert Panel. The list of critical variables and a preliminary understanding of the logic used to recommend a speed limit in a speed zone was obtained at the Expert Panel meeting. However, it was recognized that to further develop the decision rules, more work was needed including input from the Expanded Panel of experts listed in Appendix C.

The following conclusions were made following the expert panel meeting:

- Operating speed is a critical factor in all types of roads. Based on the speed limit provided by the individual members of the expert panel for the different case studies, it is clear that the speed limit should not exceed the 85^{th} percentile speed. Some members of the expert panel felt that average speed, median speed, and pace, should be considered in addition to the 85^{th} percentile speed, although it was not clear how exactly the supplemental speed measures were being applied to the decision.

- Crash statistics were also considered a critical factor by the members of the expert panel. A three year crash history, as a minimum, was felt necessary by the panel. A road with a poor crash history might need input requiring road features, while a section with a below average crash history would not require this additional information. For some members of the expert panel, information on the 85^{th} percentile speeds and crash statistics was sufficient for them to identify the appropriate speed limit. In addition, some members of the Expert Panel felt that on road sections with a higher-than-average crash rate, the expert system should call for a safety investigation to identify the problem and determine the appropriate course of action, which may or may not include changing the posted speed limit.

- Number of access points, available clear zone, roadside friction, extent of ped/bicycle activity, and road classification were variables considered critical by many members of the expert panel for non-limited-access roads.

- For many members of the expert panel, operating speed and crash statistics were the two most critical factors. In other words, if operating speed and crash statistics are available, the other factors become supplemental. If operating speed and crash statistics are not available, these other factors become surrogates and therefore are more critical. There were exceptions, e.g., some members in the expert panel felt that speed limits in two-lane residential streets should be limited regardless of crash statistics and operating speeds.

- Many members of the expert panel felt that there should be a clear distinction between new/reconstructed roads and existing roads. New roads (either in the design or construction phase) will have no speed or crash data. Reconstructed roads may have been altered to the point that any historical data on speed and crashes no longer represent the existing conditions. This issue was discussed further at the Interim Meeting with the NCHRP Panel.

- Ideally, the variables used in the expert system must be objective and measurable. Ease of measurement should be considered.

- The system must be able to provide default values for factors when data are missing or not available.

- In formulating a decision, it must be determined under what conditions an advisory limit effects a speed limit in a speed zone.

- In most cases, knowledge of the statutory speed limit will be necessary in developing a speed limit recommendation.

INTERIM MEETING WITH THE NCHRP 3-67 PANEL (AUGUST 2004)

The Interim Meeting involved a detailed discussion of several issues including the critical factors identified at the June 2004 Expert Panel and the options for developing the decision rules for the expert system. Here is a summary of these discussions.

Discussion of Critical Factors

As discussed in the beginning of Chapter 6, the expert panel identified critical factors for freeways, multi-lane roads, and two-lane roads that need to be included in the development of the expert system. Following is further discussion of issues and questions with respect to the individual critical factors:

Operating Speed

Although there was general agreement among the expert panel that the 85^{th} percentile speed is an important parameter, and the speed limit should not exceed the 85^{th} percentile value, some panel members wanted to know the median speed, the pace speed, and the percentage of vehicles in the pace, before they made the decision about the appropriate speed limit. However, it was not clear how exactly these parameters were used. Some questions that need to be answered include:

- Can the recommended speed limit be lower than the median speed? If yes, what are the conditions/roadway types where this should be (or should not be) an option?
- How should the pace, and the percentage of vehicles in the pace, influence the recommended speed limit, or provide an upper/lower bound for the recommended speed limit?
- Should the system provide guidelines on where speed data should be collected, e.g., in tangent sections, middle of a horizontal curve, etc.?

Crash Statistics

Part of the concern is that the crashes experienced on a roadway section may be totally unrelated to operating speed or speed limits, and the problem cannot be resolved by simply lowering the speed limit. A roadway section may have a high crash rate because of poor design, irregular pavement surface, insufficient sight distance, and a host of other factors. However, many of the NCHRP panel members felt that a system that would exclude safety would not be well accepted by the users. Most of the NCHRP panel members felt that the system should require the user to obtain and input crash data. How safety should be incorporated in the expert system should be determined based on expert knowledge.

Roadway Geometry

In this context, roadway geometry includes the frequency/severity of horizontal and vertical curves, and adverse alignment. Previous research has shown that there is a relationship between roadway geometry and operating speeds (see Appendix A under the section entitled "Relationship between site characteristics and operating speed"). Hence, if reliable operating speeds are available and roadway geometry is uniform over the segment, roadway geometry is less critical. However, if information on operating speed is not available and the section includes adverse alignment, then geometry can become more critical. With adverse alignment, it is necessary to decide if advisory speeds are sufficient, or if the speed limit for the whole section needs to be reduced.

Cross-section

In some ways, issues regarding cross section parameters are similar to the issues associated with roadway geometry. Relationships between cross section characteristics and operating speeds are available in the literature (see Appendix A under the section entitled "Relationship between site characteristics and operating speed"). Again, if reliable operating speeds are available and section characteristics are uniform over the segment, cross section characteristics are probably not critical. However, if information on operating speed is not available, and the section includes design exceptions (such as narrow lanes), then, cross-section characteristics can become more critical. Examples of questions that need to be addressed here include:

- How should road design exceptions, such as narrow lanes (e.g., 10 foot lanes) affect the speed limit?
- If a median is installed on an undivided multi-lane road, should that lead to a change in the speed limit? Should type of median have an impact on the posted speed limit?
- If a roadway segment has a limited clear zone (e.g., due to trees and utility poles), should that result in a reduction in the speed limit?

Roadside Friction

This refers to number of access points, parking activity, and surrounding land use. This variable is applicable only for multi-lane and two-lane roads. Although there is some evidence in the literature about the relationship between roadside friction and operating speeds and safety, few studies have examined this association. The question here is how to quantify the individual and combined effects of these factors on speed limits. Examples of questions include:

- How should the effect of parking activity quantified?
- Should the number of access points affect the speed limit decision?
- Should the type of adjacent land-use (i.e., residential, commercial, and industrial) influence the speed limit decision?

Number of MajorIntersections/Interchanges

Number of major intersections/interchanges increases the interaction between slow and fast moving traffic, and can have an effect on safety and operating speeds. Again, the question is how to quantify the effect on this variable. Examples of questions include:

- How should the number of intersections in a section used in the speed limit decision?
- Should the volume of turning and cross street traffic be considered in the system? Is it reasonable to expect users to obtain detailed turning and cross street traffic information?

Ped/Bike Activity

Again, this variable is applicable only for multi-lane and two-lane roads. One could argue that some measure of activity, i.e., number of pedestrian and bicycle crossings during a certain period and the presence/absence of unprotected crossings needs to be considered. There is a need to be able to quantify the effect of the different levels of these factors. Examples of questions to be addressed include:

- How should the presence/number of uncontrolled pedestrian crossings affect the speed limit?
- Should the system consider exposure information on the number of pedestrians/bicycles? Is it reasonable to expect the user to have this information?
- Should the system recommend lower speed limits if school-age children are present or because the section is located adjacent to a school zone?

Road Classification

One way to classify multi-lane and two-lane roads is to classify them as *through* and *local*. The goal here would be an attempt to separate those roadways with primarily commuter traffic and those comprised of local residents. Using traffic volume (i.e., AADT), one may be able to roughly distinguish between through and local. For example, through roads would be expected to carry a higher traffic volume than local roads. By itself, road classification may not affect the speed limit. However, in combination with other variables such as roadside friction and ped/bike activity, a reduction in the speed limit may be appropriate. Examples of questions to be addressed include:

- Is there a specific definition for through versus a local street that should be provided to the user of the expert system?
- How should the presence of traffic calming influence the recommended speed limit? Should the system try to differentiate between different types of traffic calming devices?

Roadway Segments Near School Zones

Setting speed limits specifically for school zones is outside the scope of this application. However, some members of the expert panel indicated that roadway segments near school zones where school-age children may be crossing may need to have a speed limit reduction. One way to address this issue is by introducing a level in the Ped/Bike Activity variable that will account for the presence of school-age children.

Residential Subdivision Streets

The NCHRP Panel felt that the expert system should recommend that residential (or subdivision streets) be posted at the statutory speed.

New and Reconstructed Roads

The NCHRP Panel felt that the expert system should recommend that the statutory speed be posted on new roads until such time that reliable data on operating speed, crashes, and other factors can be collected.

Different Approaches for the Development of the Decision Rules for the Expert System

Following the discussion of the critical variables, the research team presented three options that could be used to complete the development of the decisions rules for the expert system and answer the questions raised earlier. Following is a brief discussion of these options.

Option A

In this approach, a comprehensive set of real-world case studies providing all necessary combinations of the relevant levels/values of the critical factors will be assembled. Examples utilizing this approach were presented at the Expert Panel meeting in June 2004. A large number of case studies will be required in order to cover all the relevant levels/values of the critical factors. This will possibly require extensive field data collection in order to obtain the values for these critical factors. After these case studies are compiled, the expanded panel of experts will be asked to provide the recommended speed limit for each case study. By estimating a regression type model with the recommended speed limit as the dependent variable and the levels of the critical factors as the independent variables, it will be possible to determine if a particular critical factor is significantly related to the recommended speed limit. The results of this model will be used to develop the decision rules.

Option B

In Option B, the experience and knowledge of the research team and results of previous work (including the June 2004 expert panel meeting) will be used to develop draft decision rules for the expert system. The draft decision rules will be tested internally by the research team through case studies to ensure that it appears reasonable. In the third step, the draft decision rules will be sent to the expanded panel for their review and comments. The fourth step will incorporate the comments and recommendations from the expanded panel to refine the decision rules.

Option C

Option C, similar to Option A also relies on case studies to develop the decision rules. However, instead of compiling data from a large number of real-world case studies, this approach will rely on hypothetical case studies. Each case study will consist of series of scenarios. In each scenario, the value (or level) of one critical factor will be altered while keeping the values (and levels) of the other critical factors constant. The expanded panel of experts will be asked to provide the recommended speed limit for each scenario. Regression type models will be estimated with the recommended speed limit as the dependent variable and the levels of the critical factors as the independent variables. The results of this model will be used to develop the decision rules.

Following the discussion of the three options at the Interim Meeting, the NCHRP panel felt that Option C will be the best approach for this project. Many members of the panel felt that Option B would not make use of expert knowledge to the required degree, and Option A would be too expensive.

SURVEY OF NCHRP PANEL AND EXPERT PANEL (FALL AND WINTER 2004)

Before developing the case studies (following Option C), the research team felt that it is important to determine the appropriate categories/levels/ranges for the different critical variables. In order to get feedback from the NCHRP panel and the expert panel regarding the categories and levels for the critical variables, a survey was developed and distributed. In this survey, for each roadway type (i.e., limited access freeways, multilane roads, and two lane roads) variables were presented along with the proposed categories, levels, and the range of appropriate values to be considered. The respondents were asked to indicate if they agree/disagree with the proposed categories/levels. If they did not agree, they were asked to suggest an alternative set of categories and levels for that variable and/or alternative ways of considering that variable.

The results of the survey are presented in Appendix E. Eight individuals filled out the survey. In addition, two individuals made some general comments about the survey.

WEB-BASED PILOT TESTS (SPRING AND SUMMER 2005)

During the Interim Meeting in August, the NCHRP panel had suggested that a limited set of case studies and scenarios be developed in order to pilot test the methodology and the format in which the case studies and scenarios can be presented to the experts. The research team developed 14 case studies with 56 scenarios for the Pilot Tests (see Appendix F). Each case study had between 3 and 7 scenarios. Within each case study, one or two factors were modified while keeping other factors constant. The changing factors were highlighted. These case studies were implemented over the web (http://www.pedbikeinfo.org/speedlimits/pilot/). Each potential respondent was asked to select a link. Once they selected this link, they were asked to fill out a brief survey indicating their affiliation and experience in setting speed limits. They were then provided the background and instructions for filling out the survey. For each scenario, respondents were asked to:

- State what speed limit (in mph) they would select for each scenario, or indicate that 'not enough information' is available for making the decision,
- Indicate which critical factors were used for making your decision, and
- Identify other data/factors that they feel are critical and need to be provided to make a speed limit recommendation for that scenario.

For the Pilot Tests, the following assumptions were made:

- Sections are in urban/suburban areas
- Sections are multi-lane
- The crash rate for the sections under consideration is below average, compared to similar sections
- There is no adverse alignment in these sections

Respondents were able to access these case studies through a link to a website. Several members of this expert panel responded to these case studies.

The following factors are included in the case studies for the pilot tests:

- 85^{th} percentile speed
- Median speed
- Roadside hazard rating
- Presence and type of median
- Number of traffic signals in the section
- Total length of section
- Roadside development
- Pedestrian and bicycle activity
- On-street parking

The link to the survey was forwarded to the NCHRP panel, the expert panel, and selected members of the expanded panel. A total of 23 individuals accessed the link to fill out the survey. Out of these, 20 actually completed the survey, while 3 individuals completed only the first two case studies.

The results from the pilot web survey were used to construct a regression model to relate the speed limit with the site characteristics. Here is a brief discussion of the findings. More detailed results are available in Appendix F.

- Operating speed (85^{th} percentile and 50^{th} percentile speed) was the most important factor that was considered by the participants.

- More signals per mile is associated with lower speed limits, although this factor was only marginally significant in the regression analysis (p value was approximately 0.2).
- The regression analysis indicated that compared to Hazard level 7 (the most hazardous roadside condition), hazard levels 1 through 5 were usually assigned higher speed limits by the participants.
- In general, undivided roads were associated with lower speed limits compared to divided roads. The participants did not treat TWLTL and divided roads in a significantly different way.
- In general, participants assigned higher speed limits for low/medium ped/bike conditions compared to the high ped/bike condition.
- Compared to on-street parking on two sides, the participants assigned higher speed limits for roads with no parking. The participants in the survey treated parking on one-side and two-sides in a similar way.

FINAL ROUND OF WEB-BASED CASE STUDIES (FALL 2005)

Using the results of the pilot case studies, the research team developed case studies for five different roadway types. These case studies included more variables compared to the pilot case studies. Links to these case studies were sent to 148 individuals that included traffic engineers, enforcement personnel, and researchers. This included the NCHRP 3-67 and the expert panel. These 148 individuals were divided into five groups corresponding to the five roadway types (freeway, two-lane undeveloped, multilane undeveloped, two-lane developed, multilane developed). State DOT personnel were primarily assigned to the freeway group. City engineers and practitioners were assigned to the developed roadway types. County engineers and practitioners were assigned to either the developed or the undeveloped roadway types. Enforcement personnel and researchers were randomly assigned to one of the roadway types. Here is the link to the case studies that were developed for the five roadway types (the case studies and scenarios used in the final round of web-based case studies are presented in Appendix G):

Freeway
http://www.pedbikeinfo.org/speedlimits/speed2/fway.cfm

Two-lane Undeveloped Roads
http://www.pedbikeinfo.org/speedlimits/speed2/twolan_undv.cfm

Multilane Undeveloped Roads
http://www.pedbikeinfo.org/speedlimits/speed2/multilan_undv.cfm

Two-lane Developed Roads
http://www.pedbikeinfo.org/speedlimits/speed2/twolan_dv.cfm

Multilane Developed Roads
http://www.pedbikeinfo.org/speedlimits/speed2/multilan_dv.cfm

After filling out the case studies for the roadway type that they were assigned to, all respondents were encouraged to fill out the case studies for the other four roadway types.

Here is the number of experts who completed the case studies for the five different roadway types:

Freeway – 8
Two-lane Undeveloped – 8
Multilane Undeveloped – 12
Two-lane Developed – 9
Multilane Developed – 7

In addition, there were some individuals who started responding to the case studies, but did not complete them. One researcher completed the case studies for three roadway types. Four individuals completed the case studies for two roadway types.

In order to determine the effect of individual factors in the recommended speed limit for a facility, the research team analyzed the responses to the web survey in a couple of ways. The first approach was to calculate the average value of the speed limit recommended by the different experts for each scenario. In addition, for each scenario, the minimum speed limit, the maximum speed limit, and standard deviation of the speed limit were recorded for each scenario – this provided some indication of the extent to which the experts agreed or disagreed with each other in providing the recommended speed limit. Since, within each case study, one variable was modified while keeping the other variables a constant, by comparing the average speed limit for a particular scenario with the average speed limit for another scenario within a case study, it was possible to make a preliminary assessment of the effect on that variable (which was modified in that case study) on the speed limit.

A second approach used regression analysis to assess the effect of different factors was linear regression. In this approach, the recommended speed limit was included as a dependent variable, and the site characteristics were included as independent variables. The results of these analyses (discussed in Appendixes H and I) were used to develop preliminary decision rules for the expert system for review at the expert panel meeting in December 2005.

EXPERT PANEL MEETING (DECEMBER 2005)

The objective of the expert panel meeting was to review the results of the web survey and determine how these results could be used to determine the decision rules for the expert system. The first part of the meeting focused on the project objectives, scope, and status. This was followed by a discussion of the results of the web-based survey. In general, many of the panel members did not agree with the coefficients and factors generated by the regression models (discussed in Appendix H), although some agreed with the final speed limit recommended by the regression model for a particular situation. They recommended that the results of the regression models should not be used as the basis for developing the decision rules. Many of the panel members were surprised that the participants to the survey gave importance to adjacent speed limits even for relatively long sections. Some panel members felt that crash statistics (i.e., injury rates and rates of speed-related injury crashes) should have been given much more importance compared to adjacent speed limits.

Following the discussion of the results of the web survey, there was a detailed discussion about how each critical variable should be used in coming up with the recommended speed limit for a situation. The final session of the expert panel meeting on Friday, December 16, 2005, was used for discussing 6 case studies, which included alternate scenarios within each case study. In this session, each expert was asked to select the recommended speed limit for a condition and indicate why they made that decision. The majority of the experts agreed on the same speed limit for most of the scenarios that were presented on December 16, 2005. However, there was disagreement among the experts when one of the following two conditions occurred:

1. Undivided roads in high-speed rural areas with high crash rates. About half the experts who were present at the meeting chose the rounded_down_50^{th}_speed (rounded-down_50^{th} is obtained by rounding down the 50^{th} percentile speed to the nearest 5 mph multiple) as the speed limit under these conditions. However, the others did not want to choose anything lower than the closest_50^{th}_speed (Closest_50^{th} is the 5 mph multiple that is closest to the 50^{th} percentile speed) as the speed limit under these conditions.

2. Urban roads with significant ped-bike activity and high crash rates. Again, half the experts who were present at the meeting chose the rounded_down_50^{th}_speed as the speed limit under these conditions. However, the others chose the closest_50^{th}_speed as the speed limit under these conditions.

Even those members of the expert panel who were willing to recommend the rounded_down_50^{th}_speed as the speed limit, indicated that a detailed crash investigation should be conducted and other traffic and geometric measures should be considered before the speed limit is lowered.

A report summarizing the discussions at the expert panel meeting is presented in Appendix J.

DEVELOPMENT OF DRAFT DECISION RULES AND THE PROTOTYPE

The draft decision rules were developed based on the information obtained from previous research, expert panel meeting in June 2004, web-based pilot survey in Spring 2005, web-based pilot survey in Fall 2005, expert panel meeting in December 2005, and the judgment of the research team. The decision rules for the expert system were developed, documented in the form of flow-charts, and forwarded to the HSRC programmer for development of the prototype of the expert system. The HSRC programmer implemented the decision rules and developed a prototype expert system. This prototype, along with flow-charts describing the expert system were sent the expert panel, the NCHRP panel, and practitioners around the country for beta-testing. The panel members and practitioners were asked to review the decision rules document, the prototype expert system, and comment on various aspects of the system. The intent was to use the responses from the panel members and the practitioners to verify, evaluate, and validate the system. The panel members and practitioners were asked to answer the following questions:

- Is the system user-friendly?
- Do users accept the system? Are there any bugs in the system?
- Will you make use of the recommendations from this system to set speed limits?
- Are the recommendations from the system consistent with your knowledge and experience?
- Based on your opinion, what percentage of recommendations from the system is correct?
- Do you feel the recommendations from the system are more or less accurate for certain types of roads or areas?
- Do you feel that the system takes into account all critical factors? If no, what other factors should be considered?
- Do you feel that the logic used in this system is appropriate? If no, how should it be modified?

Six panel members and practitioners provided written comments on the decision rules and prototype for the expert system. The research team provided a written response to these comments.

CONFERENCE CALL TO DISCUSS DRAFT DECISION RULES AND THE PROTOTYPE

A web conference was held on May 17, 2006, to discuss the decision rules, the prototype, and the written comments provided by the panel members and practitioners to the prototype. Here is a summary of the discussion during the conference call:

- Prior to the meeting, one of the reviewers of the prototype was concerned that the crash and injury rates from HSIS may not be representative of data for city streets. The panel members at the web conference did confirm that average rates do need to be provided as default since some users may not have access to these values in their jurisdictions. The panel members suggested that it may be worthwhile to explore the possibility of comparing crash data complied by the South East Michigan Council of Governments (SEMCOG) and from Charlotte, North Carolina, with the HSIS data to examine the applicability of using the HSIS data as a baseline for city streets. Subsequent to the meeting, the research team contacted the City of Charlotte and also tried to obtain data from SEMCOG. However, the research team was not successful in obtaining crash and injury rates for different roadway types and AADT categories from these agencies.

- There was some concern that the program does not provide definitions for mountainous roads. The research team was asked to look into the information provided by AASHTO concerning terrain and horizontal and vertical curvature that can be used to provide some guidance to the user.

- The panel members indicated that minimum section length needs to be considered in developing the decision rules. One approach is to provide a warning if the section length is shorter than the minimum section length.

- Some panel members were concerned that the information currently provided to distinguish between roads in Developed and Undeveloped areas is not sufficient and more qualifiers need to be added. Some thought that these qualifiers can include population, population density, and level of roadside activity. They also suggested that the access to the definitions and photographs should be improved to eliminate the long user delay in downloading this information.

- There was considerable discussion about whether the rounded-down 50^{th} percentile speed is too low for the recommended speed limit. There was disagreement among the panel members on whether this was too low. However, most of the panel members agreed that the rounded-down 50^{th} percentile was too low when crash data were not available and the speed limit is calculated based on surrogates. Panel members also agreed that if crash rates are high, the program should suggest a detailed crash study to determine the causes and possible solutions.

- The panel members felt that more information needs to be provided to the user about procedures for collecting and analyzing speed data.

- In the prototype expert system, the speed limit for road sections in undeveloped areas had a lower bound of 45 mph. Most panel members felt that when there is adverse alignment in a section, the lower bound of 45 mph for undeveloped roads is not appropriate. Here again, the location where the speed data are collected was identified as an important factor.

- In the prototype expert system, residential subdivision streets were considered a separate roadway type apart from road sections in developed areas. Some panel members suggested that residential subdivision streets could be combined with the developed roadway section. However, there was not a clear consensus on how to treat this roadway type.

- Most panel members agreed that if the recommended speed limit was higher than the statutory limit, then a warning will be useful. There was less agreement about how to deal with the absolute maximum speed limit in a particular State.

DECISION RULES AND EXPERT SYSTEM FOR PANEL REVIEW

Changes were made to the draft decision rules and the prototype expert system based on the comments received from the panel members and the practitioners as part of the beta testing process. Here is a summary of the changes that were made:

- A user guide was developed and provided as a link to the expert system. In the prototype expert system, the more info links provided access to photographs describing different area types. Since some users experienced significant delays while accessing the photographs that were available as part of the more info link in the prototype, the photographs were moved to the user guide.

- A warning was introduced if the length of a section was below the minimum length. Minimum lengths from the current USLIMITS program were used for guidance.

- The help screens were modified to include more information to help the user understand the meaning of the different factors and variables, including guidance for collecting speed data, further information to distinguish between road sections in undeveloped and developed areas, information to distinguish between mountainous, flat, and rolling terrain.

- The flow charts representing the modified decision rules from the expert system are available in Appendix K. The user guide is documented in Appendix L. The expert system can be accessed through the following link: http://www2.uslimits.org

DESCRIPTION OF THE DECISION RULES

Here is a brief overview of the logic flow and the decision rules that are used in the expert system (further details are provided in Appendix K and L). After entering the location of the project, the user is asked to indicate whether the road is a limited access freeway, road section in an undeveloped area, or a road section in a developed area. Here is a definition of the three roadway types. Photographs illustrating the different roadway types are available in the User Guide (see Appendix L).

***Limited Access Freeway* –** This route type includes U.S. and state numbered freeways and expressways and Interstate routes where access to and from the facility is limited to interchanges with grade separations. These high-speed routes typically have posted speed limits ranging from 55 mph in urban areas to 75 mph in some rural areas. Some urban areas may have short segments directly connecting the freeway to surface streets where the posted speed limit is as low as 35 mph. In rural western Texas, an 80 mph limit has recently been posted on selected segments of I-10 and I-20. As of September 2006, this is the highest posted speed limit on a freeway segment in the United States. This expert system will not recommend speed limits higher than 75 mph for limited access freeways.

***Road Section in Undeveloped Area* –** An undeveloped area is generally an area where the human population is low and the roadside primarily consists of the natural environment. Access is not restricted and posted speed limits are typically in the 40 mph to 65 mph range depending upon terrain and road design features. Road sections with lower speed limits usually have narrower pavement widths, little or no shoulders, and horizontal and vertical curvature that limits driver speeds. Road sections with higher speed limits usually have 12-foot lanes, 8-foot or greater shoulders which may be paved, and horizontal and vertical curvature that supports higher speed travel. This expert system will not recommend speed limits higher than 65 mph for road sections in undeveloped areas.

***Road Section in Developed Area* –** A developed or built-up area is an area where the human-built environment has generally replaced most of the natural environment. Access is not restricted and posted speed limits are usually in the 25 mph to 50 mph range depending on the degree of human activity that interacts with vehicular travel, the road design, and degree of traffic control used. Road sections with lower speed limits are found in downtown and residential areas with considerable pedestrian and other non-motorized movements and on-street parking activity. Road sections with higher speed limits have little pedestrian activity, no on-street parking, and traffic control which favors through traffic movement. In this expert system, the maximum speed limit for road sections in developed areas is 50 mph. Roads in developed areas are further subdivided into residential subdivision/neighborhood street, residential collector street, commercial street, and a street serving a large complex such as a large shopping mall:

> ***Residential Subdivision/Neighborhood Street* –** A residential neighborhood street is a public street located within a subdivision or group of homes that serves the motorized and non-motorized activities of residents. Posted speed limits generally range from 25 to 35 mph. Two-way traffic operations are permitted along with on-street parking on both sides of the road, however, the pavement width is usually too narrow to allow unimpeded bidirectional traffic and on-street parking. Accordingly, painted centerlines are not typically used on these facilities. These streets do not carry through traffic. Commercial development is not permitted in the area.
>
> ***Residential Collector Street* –** A residential collector street carries both through traffic from residential neighborhoods and local traffic generated by residents who live along the corridor. Posted speed limits generally range from 25 mph to 45 mph. The pavement widths permit full time operation of bidirectional traffic. On-street parking on one or both sides may or may not be permitted. Painted centerlines are typically found on these facilities. Development along the street is primarily single- and multi-family homes. Typically, there are more than 30 residential driveways per mile. The corridor may contain a small amount of commercial development; usually convenience stores at major intersections.
>
> ***Commercial Street* –** A commercial street is a street that serves both through traffic and local shopping needs. Development along the corridor is primarily commercial with more than 30 business driveways per mile. Posted speed limits generally range from 25 mph to 45 mph. The streets usually tend to be multilane and on-street parking on one or both sides may or may not be permitted.
>
> ***Street Serving Large Complexes* –** Large area business developments typically include shopping malls, office buildings and industrial complexes. Streets that serve large complexes generally are designed to carry large volumes of traffic to and from the complex and typically are designed to manage access to carry through volumes. The streets tend to be multilane facilities and the number of access driveways is usually less than 30 per mile. Posted speed limits range from 35 mph to 50 mph.

After the user selects the roadway type, they are taken to a window where they are asked to enter the site characteristics. For each route type, users are asked to enter the following site characteristics:

Limited Access Freeway

- Operating Speed: 85^{th} percentile speed and 50^{th} percentile speed
- Presence/absence of adverse alignment (if adverse alignment is present, a warning is provided to the user in the end; by itself, this variable does not affect the recommended speed limit)
- Is this section transitioning to a non-limited access highway? (this is used to determine if a particular operating speed that is entered is too low; by itself, this variable does not affect the speed limit)
- Section Length
- Current statutory limit for this type of road (if the recommended speed limit is higher than the statutory limit, a warning is provided to the user in the end; there was some discussion on whether the speed limit recommended by the expert system can exceed the statutory limit. Some members of the expert panel indicated that in some States the posted limit can exceed the statutory limit if it can be justified by an engineering study)
- The terrain (the maximum speed limit in mountainous terrain is 70 mph)
- Annual Average Daily Traffic
- Number of Interchanges within this section
- Crash Statistics (if available)

Road Sections in Undeveloped Areas

- Operating Speed: 85^{th} percentile speed and 50^{th} percentile speed
- Presence/absence of adverse alignment (if adverse alignment is present, a warning is provided to the user in the end; by itself, this variable does not affect the recommended speed limit)
- Is this section transitioning to a road section in a developed area? (this is used to determine if a particular operating speed that is entered is too low; by itself, this variable does not affect the speed limit)
- Current statutory limit for this type of road (if the recommended speed limit is higher than the statutory limit, a warning is provided to the user in the end; there was some discussion on whether the speed limit recommended by the expert system can exceed the statutory limit. Some members of the expert panel indicated that in some States the posted limit can exceed the statutory limit if it can be justified by an engineering study)
- Annual Average Daily Traffic
- Roadside Hazard Rating (based on Zegeer et al., *18*)
- Number of lanes and presence/type of median
- Crash Statistics (if available)

Road Sections in Developed Areas

- Operating Speed: 85^{th} percentile speed and 50^{th} percentile speed

- Current statutory limit for this type of road (if the recommended speed limit is higher than the statutory limit, a warning is provided to the user in the end; there was some discussion on whether the speed limit recommended by the expert system can exceed the statutory limit. Some members of the expert panel indicated that in some States the posted limit can exceed the statutory limit if it can be justified by an engineering study)
- Annual Average Daily Traffic
- Presence/absence of adverse alignment (if adverse alignment is present, a warning is provided to the user in the end; by itself, this variable does not affect the recommended speed limit)
- Area type
- Number of driveways and unsignalized intersections in the section
- Number of traffic signals within the section
- Presence/usage of on-street parking
- Extent of ped/bike activity
- Crash Statistics (if available)

For each project, the program calculates a speed limit based on two approaches:

Approach 1 - Based on operating speeds and other site characteristics (also called safety surrogates).

The surrogates were chosen based on input from the expert panel and evidence (based on previous research) of a relationship between these surrogates and crash statistics. For freeways, safety surrogates include interchange spacing and AADT. Based on the research team's judgment in interpreting the results of the recent work of Bared et al. (*17*), if AADT is higher than 180,000 and the average interchange spacing is between 0.5 and 1 mile, the recommended speed limit from this approach will be the 5 mph multiple obtained by rounding-down the 85^{th} percentile speed; if AADT is higher than 180,000 and the average interchange spacing is less than 0.5 mile, the recommended speed limit is the 5 mph multiple closest to the 50^{th} percentile speed. For other situations in freeways, the recommended speed limit from this approach will be the 5 mph multiple closest to the 85^{th} percentile speed.

For road sections in undeveloped areas, the roadside hazard rating (*18*) was selected as the safety surrogate. For roadside hazard ratings of 1, 2, or 3, the recommended speed limit is the 5 mph multiple closest to the 85^{th} percentile speed. For roadside hazard ratings of 4 or 5, the recommended speed limit is the 5 mph multiple obtained by rounding down the 85^{th} percentile speed. For roadside hazard ratings of 6 or 7, the speed limit is the 5 mph multiple closest to the 50^{th} percentile speed.

For road sections in developed areas, extent of pedestrian/bicycle activity, presence/usage of on-street parking, number of traffic signals, and the number of driveways and unsignalized access points, were selected as surrogates. Based on the results from FHWA's work on the Safety Impacts of Access Management (http://ops.fhwa.dot.gov/access_mgmt/docs/benefits_am_trifold.htm), and the opinions of the expert panel, the following rules are used to calculate the recommended speed limit for road sections in developed areas:

If <u>at least one of the following is true</u>, the speed limit is the 5 mph multiple closest to the 50^{th}:

> Signals_per_mile > 4
> Ped_bike activity is High (definitions are available in the user manual)
> Parking activity is High (definitions are available in the user manual)
> Driveways_per_mile > 60

If the following is true, the speed limit is the 5 mph multiple obtained by rounding down the 85^{th}:

> Driveways_per_mile > 40 and <=60, and Signals per mile > 3, and Area Type is (commercial or residential-collector)

All other conditions, the speed limit is the 5 mph multiple closest to the 85^{th} percentile speed

Approach 2 - Based on operating speeds and results from the crash module.

In the crash module, the user is asked to enter the total number of crashes and total number of injury crashes. In addition, the user is also asked to enter the average crash rate and the average rate of injury and fatal crashes for similar sections in the same jurisdiction. If data on average rates are not available, the program makes use of average rates calculated with data from 8 States that are part of the Highway Safety Information System (HSIS). Using the average crash rate and the average rate of injury and fatal crashes, the program calculates the critical crash rate and critical injury rate (*70*).

$$R_C = R_a + K\sqrt{\frac{R_a}{M}} + \frac{1}{2M}$$

Where:

R_C = critical rate for a given road type
R_a = average rate for a given road type
K = constant associated with the confidence level (1.645 for 95% confidence)
M = 100 million vehicle miles

If the crash or injury rate is higher than the corresponding critical rates or at least 30% higher than the corresponding average rates, the user is asked to indicate if traffic and geometric measures can reduce the crash and/or injury rate in this section. If the user answers Yes to this question, the recommended speed limit from this module will be the 5 mph multiple closest to the 85^{th} percentile speed. If the user answers No or Unknown, the recommended speed limit from this module will be the 5 mph increment obtained by rounding-down the 85th percentile speed (if crash or injury rate is at least 30% higher than the average rate) or closest to the 50th (if the crash or injury rate is higher than the critical rate).

The lower value of the calculated speed limits from Approaches 1 and 2 is reported as the recommended speed limit in the output window. The expert system does not recommend speed limits higher than the 5 mph multiple closest to the 85th percentile speed; it also does not recommend speed limits lower than the 5 mph multiple closest to the 50th percentile speed. The system also provides warnings if the 85th percentile speed entered by the user is unusually low or high for a particular roadway type.

At the output window, the program provides the recommended speed limit, and some additional warnings depending on the site characteristics that were entered by the user. For example, warnings are provided if the following conditions occur:

- If the length of the section is shorter than the minimum section length for the recommended speed limit. The guidelines regarding minimum section length are based on the information available in the current USLIMITS program.

- The final recommended speed limit is higher than the statutory limit for that type of road

- There is adverse alignment in the section

- If the crash rate is higher than the critical crash rate or at least 30% higher than the average crash rate.

- The rate of injury and fatal crashes is higher than the critical injury rate or at least 30% higher than the average injury rate.

- The 85th percentile speed is higher than 52 mph for road sections in developed areas, higher than 67 mph for road sections in undeveloped areas, or higher than 77 mph for limited access freeways.

CHAPTER 7

LONG-TERM MANAGEMENT OF THE EXPERT SYSTEM

For this product to be widely implemented and continue to be upgraded, a long-term strategy must be developed for administering and maintaining it. As previously discussed, this product is a web-based application. The specific issues addressed in developing a long-term management strategy include:

- Capability and responsibility for hosting the application.
- Administrator assignment and responsibilities.
- Maintenance and troubleshooting.
- Upgrade cycle.
- Marketing (including training and outreach).
- Long-term needs (e.g., planning for future data sources or analysis needs).

The proposed strategy below discusses each of these issues and provides specific recommendations for consideration by the panel and those agencies that may be involved in promoting and managing the application.

APPLICATION HOST

This application requires a host. HSRC has offered to host the application for up to one year following the end date of the contract, and provide some administrative support to ensure that the site is running and accessible to users. This effort is undertaken as a short-term solution until a decision is made with respect to where the application should reside. When the application is moved to another host, the users will be informed about these changes through electronic mail.

SITE ADMINISTRATION

Irrespective of where the application is hosted, a site administrator will be required to perform a variety of tasks, including:

- Monitoring the site to ensure that it is running and accessible to users.
- Handling inquiries from users – may include specific technical issues related to the web site as well as questions related to the logic or merits of the application itself.
- Working with the server administrator to address any technical problems of the site.
- Working with a web application programmer to address any bugs in the application.

The research team communicated with individuals in ITE, AASHTO, and FHWA, through phone and email to understand their willingness in hosting the expert system after it is completed. Each agency was provided a one page summary of the project before the phone call that included an overview of NCHRP Project 3-67, hardware and software requirements for hosting the expert system, and responsibilities of the site administrator. The research team spoke with ITE staff Tom Brahms, Executive Director, and Phil Caruso, Deputy Executive Director.

The research team gave an overview of the project, presented the system hardware, software, and interface requirements, and the issues associated with administering the site. ITE staff indicated that they will be interested in hosting the expert system as long as it is a user-friendly product, and ITE will not be flooded with questions from users, and the benefit of hosting the expert system (to its membership) exceed the costs. The research team assured ITE that the product will be user friendly.

Then, the research team spoke with AASHTO staff Ken Kobetsky, Director of Engineering, and David Dubov, Web Business Manager. Both Ken and David indicated that AASHTO was interested in hosting the expert system. In addition to discussing the system hardware and software issues, David Dubov also wondered if the States would like to have the option of refining the decision rules and the logic flow to suit their regulations and conditions.

Following this, research team had email exchanges with Davey Warren (Office of Safety Programs, FHWA), and Carl Shea (IT Policy and Infrastructure Team Leader, FHWA) regarding this issue. FHWA also expressed an interest earlier in hosting the product.

In summary, all the three agencies (ITE, AASHTO, and FHWA) showed an interest in hosting the expert system after it is completed. However, they would all prefer to host it in a Windows system. ITE and AASHTO do not own currently own UNIX workstations, and do not intend to purchase one. HSRC programmers had suggested that a UNIX environment because they consider UNIX to be more secure and robust. In theory, an application developed using Coldfusion in a UNIX environment, should work in a WINDOWS environment without any problems. However, in practice, there may be a need to make some minor changes to the application to ensure that it runs properly in a Windows environment. It is important to note that the prototype expert system that was evaluated by the expert and NCHRP panel in April and early May of 2006 was initially installed in a WINDOWS environment. The expert system has since been moved to an UNIX server, and it is working properly.

UPGRADE CYCLE

Traditionally in the field of transportation engineering, the upgrading of “guidance” products took decades. The Highway Capacity Manual is one example that was in place 20 years (1965 to 1985) before a major upgrade. Other documents such as the AASHTO Green Book and the MUTCD were also upgraded once in several years. In recent years, however, there has been a shift toward more frequent upgrades, which means that the most recent research and best practices are being disseminated to practitioners more quickly. With the Internet now a major source of many guidance documents and application tools, the ability to upgrade products can be more frequent since there is no publication expense. In addition, there is a greater expectation on the part of the user that anything on the web be the latest information available.

Given that the expert system is now and will continue to be a web-based product, it will be important for credibility reasons to keep it up to date. As shown in the life-cycle graphic in Figure 3, the development of this product can be divided into two distinct components – the application itself, which includes the decision-making algorithm, and the platform (server) specifications and development. These two components are interlinked, as the decisions made for each affect the other. Combining these two elements results in the implementation of the final product, that should be tested and evaluated on a continual or periodic basis. The product is then released and marketed, and followed by practitioners using the application. Over time, there will be a need for users to acquire technical support.

The components in this life-cycle graphic that serve as immediate feedback mechanisms to the development components are the users and technical support personnel. Issues identified by either should be documented. Critical issues, i.e., those that prevent one from using the application, need to be addressed immediately by changes in the application and/or platform. Such changes may range from simply providing a clarifying statement on the site related to a variable to fixing a bug in the application to changing a hardware component on the server. Non-critical issues and recommendations need to be archived for consideration of future changes in the product. How often these non-critical changes need to be considered is a key question. It is recommended that they be considered at the same time as incorporating the latest research results and upgrading the hardware/software (discussed below).

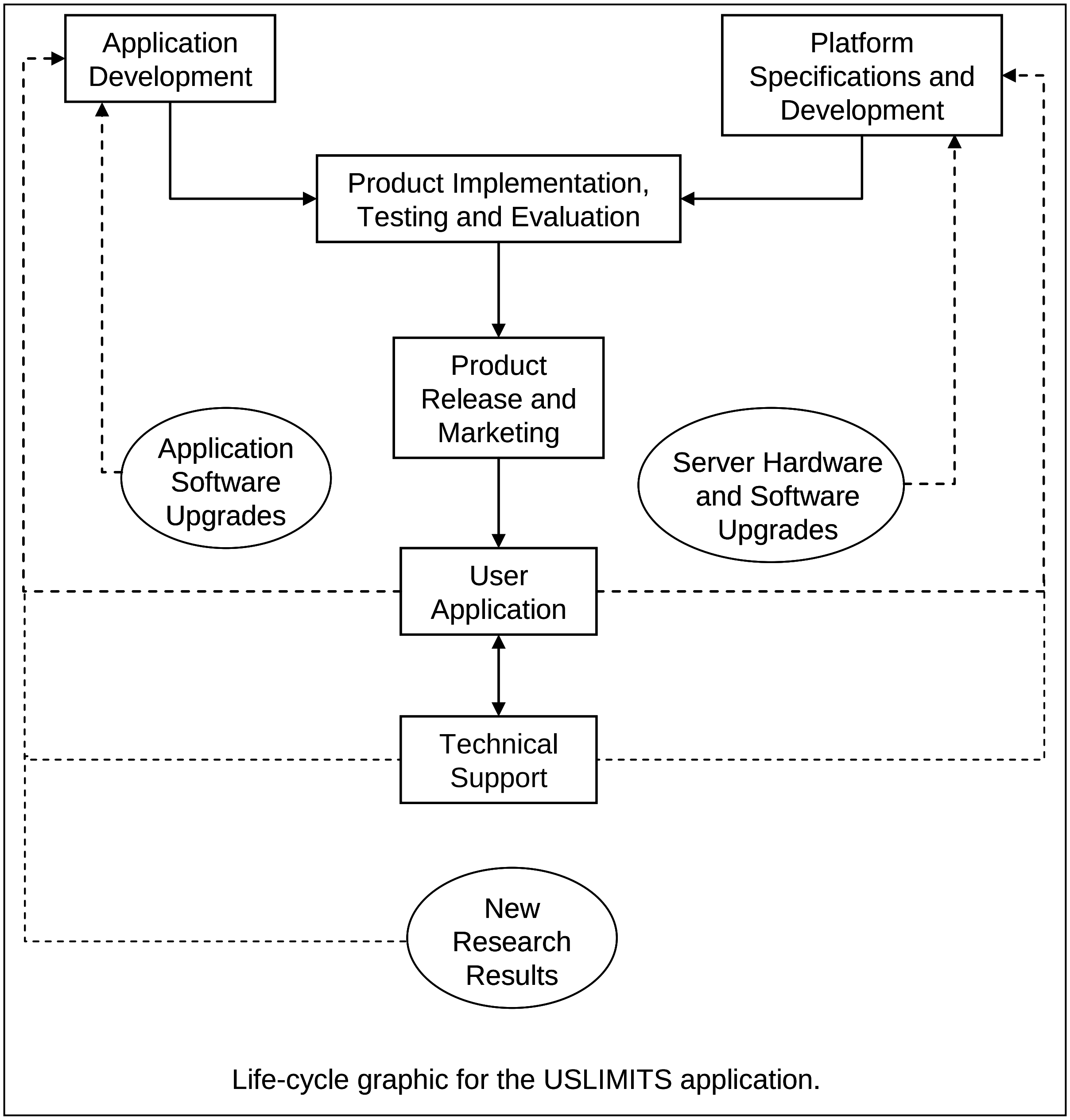

Figure 3: Life-cycle graphic for the speed limit expert system

Other elements that will impact the decisions to upgrade the product are also shown on the graphic and include new research results, application and database software upgrades, and server hardware and software upgrades. Generally, most application, database and server software packages are upgraded about every 2 years. Similarly, server hardware has been in a cycle of upgrading every 18 to 24 months over the past decade or so. It has been our experience that there is no need to keep pace with each generation of hardware and software. The changes are usually not substantive enough to warrant making such a monetary investment. The recommendation is to skip a generation at a minimum. Given the current development cycle for hardware and software, this would require a review of the advantages and costs about every 3 years.

With respect to new research results, the goal should be to monitor the research for information that could be used to improve the knowledge base in the application and specifically the decision rules in the algorithm. The question then becomes how often to critically review such results for possible changes in the application. Generally, research studies require 2 to 4 years to complete. Therefore, a comprehensive review of the literature every 3 years would seem to be a reasonable cycle. In addition to the review itself, other more substantive techniques should also be considered at the same time. Examples of three such techniques are described below.

Meta-Analysis

A meta-analysis of results such as those conducted by Elvik and Vaa (*11*), where statistical techniques are used to combine the independent estimates from separate studies by weighting each individual estimate according to its variance.

Reanalysis of Data from Prior Studies

Reanalysis of existing data is another way to identify critical variables and factors and their relationship to operating speed, posted speed limits, and crashes. As per the discussion in McCarthy (*19*), many before-after studies on speed limits "generally used univariate classification procedures, regression analysis, or ARIMA time-series models, and multivariate classification models are rarely used". Also, "among simple regression models, there is often a surprising lack of diagnostics and correction for common statistical problems" and very "little work has been done on developing and estimating simultaneous frameworks to capture the interaction" between different factors.

Based on several years of research on speed limits, several data sets are available. Examples of the more recent ones include: Kockelman et al., (*9*), Fitzpatrick et al., (*14*), and Stokes et al., (*20*). Examples of other data sets that may be available include Parker (*8*) and Poe and Mason (*21*).

Development and Analysis of New Data Sets

Limited analysis of new data sets can provide useful insights into the relationship between operating speed, posted speed limit, design speed, crashes, and site characteristics. One option is to consider the use of the Highway Safety Information System (HSIS), which has data on roadway inventories and detailed data on crash statistics from 9 states. These data will have to be combined with data on operating speeds from State DOTs. If such data can be acquired, the advantage in using HSIS is the ability to explicitly study the relationship between operating speed and crashes, posted speed, and other site characteristics.

MARKETING

The development of the expert systems product is the required first step. However, to create widespread use of the product and truly have an effect on how speed limits are set, there is a need to promote the application and to train potential users. FHWA has recently executed a contract to begin this process for the current USLIMITS system. Members of the research team are in the process of developing brochures and other materials to promote that product. Members of the research team also conducted a web-based training course in July 2006 to educate different stakeholders about the capabilities and limitations of the current USLIMITS system. A similar marketing effort is necessary to make potential users aware of the expert system (USLIMITS2) from this project. This type of effort needs to be coordinated by the FHWA/NHTSA Speed Management Team as it cuts across a number of disciplines.

DESIGN IMPLICATIONS OF LONG-TERM NEEDS

This system will function as an expert advisory system that uses pre-defined decision rules. It has not been developed as a "true expert system" that makes use of output measures and constantly revises the algorithm on the basis of inputs and subsequent performance measures. Based on discussions with the NCHRP panel, the expert panel, and other practitioners, it is not clear if the long-term goal is to develop a true expert system. Given that there are still some disagreements among practitioners on what the appropriate speed limits should be under certain situations, any changes to the algorithm should be based on results from evaluations that are methodologically and statistically defensible. One example of such an evaluation is a before-after study that will require collecting several years of crash data before and after a new speed limit is posted, and applying state of the art techniques such as the empirical Bayes approach to account for regression-to-the-mean, trends in crashes, and changes in exposure and other site characteristics over time. We suggest that this be addressed as part of periodic upgrades.

One other possible long-term need that has been raised is the ability to retrieve and archive the input data for the projects created in the system for the purposes of research. At the first panel meeting in August 2004, some of the panel members believed the system should be an open public site that allows anyone to use the system (without an account). The projects created in this case would be downloaded and stored on the individual user's computer and then uploaded again when needed. However, subsequently, it was decided that it is necessary to store the projects in a server that can be retrieved for purposes of research in the future. In USLIMITS2, each user creates an account (with a username and password) and will have access to projects that are created in that account. The site administrator can access the projects created by all the users.

CONCLUSIONS REGARDING THE LONG-TERM MANAGEMENT OF THE EXPERT SYSTEM

- This application requires a host. HSRC will host the application for one year on its site (www2.uslimits.org) following the completion of the project. After this period, an appropriate host needs to be identified. ITE, AASHTO, and FHWA, are possible hosts, and have shown interest in hosting the product.

- Irrespective of where the application is hosted, a site administrator will be required to perform a variety of tasks, including monitoring the site to ensure that it is running and accessible to users, handling inquiries from users, working with the server administrator to address any technical problems of the site, and working with a web application programmer to address any issues with the application.

- Given that the expert system is now and will continue to be a web-based product, it will be important for credibility reasons to keep it up to date. It is important that the results of new research are used to improve the knowledge base and refine the decision rules of the algorithm. A comprehensive review of the literature at least every 3 years is recommended followed by appropriate updates in the algorithm as necessary.

- To create widespread use of the product and truly have an effect on how speed limits are set, there is a need to promote the application and to train potential users.

CHAPTER 8

CONCLUSIONS AND FUTURE RESEARCH

CONCLUSIONS

Here are the major conclusions based on this study

Conclusions based on previous work

- Posted speed limits, consistent for similar road features, are essential even if a majority of motorists feel that they can make reasonable judgments about their driving speeds.

- The increase in speed limits on interstate roads in 1987 and 1995 seem to be followed by an increase in average speeds, although the increase in average speeds was less than the increase in the speed limit. Effect of the increase in speed limits on speed dispersion is not very clear.

- Most researchers seem to suggest that the increase in speed limits on interstate roads in 1987 and 1995 resulted in an increase in fatalities.

- Very little work has been conducted to study the effect of changes in speed limits on crash frequency and severity in non-limited access speed zones. Parker (*10*) and Parker (*8*) did not find any significant associations between speed limits and crash frequency/severity in their studies on limited access facilities.

- There is a need for guidance to practitioners to help them in identifying appropriate speed limits in speed zones.

Conclusions based on survey of USLIMITS users

- The survey of USLIMITS users revealed that most respondents felt that the speed limit recommended by USLIMITS was reasonable. Some felt that the USLIMITS program should provide more information regarding the decision rules and the factors used/not used in developing the final recommendation.

Conclusions based on the analysis of user needs and requirements

- In order to provide easy access to many practitioners, this program needs to be a web-based application.

- The system should not require extensive data collection that is beyond the scope of data now collected and maintained by the agency.

- Practitioners that are likely to use the expert system are typically very busy and do not have time to learn new systems or continually refer to manuals on how to use a software product. Hence, the system's interface should be intuitive and provide explanation of each step and the consequences of each decision made by the user.

Conclusions based on web surveys and expert panel meetings

- The operating speed was identified as a critical factor in determining an appropriate speed limit. Other factors identified as being critical included interchange spacing (in limited access freeways), roadside development, presence of pedestrian and bicycle activities, presence/absence of medians, roadside hazards, and crash and injury statistics.

- The results of the web surveys and expert panel meetings indicated that in general there is good consensus among experts regarding the appropriate speed limit on road sections where crash rates are not high. Typically, in such situations, experts recommended posting the 5 mph multiple closest to the 85th percentile speed.

- Many experts recommended the 5 mph multiple closest to the 50th percentile speed for urban areas with high pedestrian and bicycle activity.

- There was some disagreement among experts regarding the appropriate speed limit when crash rates are high. However, there is universal agreement that a detailed crash analysis needs to be conducted to identify the contributing factors for all crashes. If crash and/or injury rates are high, this program provides a warning to the user and suggests a detailed crash investigation to identify traffic and engineering measures to reduce the crash and injury rates.

- In the web surveys, some experts seem to consider speed limits in adjacent sections as a critical factor even in relatively long sections. However, the expert panel did not agree that speed limits in adjacent sections should be a critical factor. If the length of the section is below the minimum section for the recommended speed limit, the program gives a warning that the section length is too short for the recommended speed limit, and the user may consider lengthening the speed zone (if that is possible) or using the speed limits from adjacent sections (if they are appropriate for this section).

- To create widespread use of the product and truly have an effect on how speed limits are set, there is a need to promote the application and to train potential users. FHWA has a contract to do this for the current USLIMITS system. A similar marketing effort is necessary to make potential users aware of the expert system from NCHRP Project 3-67 (i.e., USLIMITS2). This type of effort needs to be coordinated by the FHWA/NHTSA Speed Management Team as it cuts across a number of disciplines.

FUTURE RESEARCH DIRECTIONS

Reanalysis of existing data sets

It is important to continuously monitor the research for information that could be used to improve the knowledge base in the application and specifically the decision rules in the algorithm. There may also be some value in reanalyzing existing data to identify critical variables and factors and their relationship to operating speed, posted speed limits, and crashes. As per the discussion in McCarthy (*19*), many before-after studies on speed limits "generally used univariate classification procedures, regression analysis, or ARIMA time-series models, and multivariate classification models are rarely used". Also, "among simple regression models, there is often a surprising lack of diagnostics and correction for common statistical problems" and very "little work has been done on developing and estimating simultaneous frameworks to capture the interaction" between different factors. Based on several years of research on speed limits, several data sets are available. Examples of the more recent ones include: Kockelman et al., (*9*), Fitzpatrick et al., (*14*), and Stokes et al., (*20*). Examples of other data sets that may be available include Parker (*8*) and Poe and Mason (*21*). The recent work by Kockelman et al. (*9*) may be good starting point in this regard – this study used simultaneous equations to study the relationship between speed limit, operating speed, and crash statistics.

Development and Analysis of New Data Sets

Limited analysis of new data sets can provide useful insights into the relationship between operating speed, posted speed limit, design speed, crashes, and site characteristics. One option is to consider the use of the Highway Safety Information System (HSIS), which has data on roadway inventories and detailed data on crash statistics from 9 states. These data will have to be combined with data on operating speeds from State DOTs. If such data can be acquired, the advantage in using HSIS is the ability to explicitly study the relationship between operating speed and crashes, posted speed, and other site characteristics.

Obtaining input from a larger sample of experts

In this study, 44 practitioners and researchers responded to the final round of case studies that tried to assess the critical variables and the logic used by experts while determining the appropriate speed limit for a speed zone. Although the results of the web survey was very useful in determining the decision rules, future research should explore the possibility of obtaining input from a larger group of experts and practitioners.

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