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Development and Evaluation of a Cellular Phone Based Teen Driver Support System

Final Report

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16. Abstract (Limit: 250 words)

Motor vehicle crashes are the leading cause of death for teenagers with speeding, seat belt non-compliance, alcohol involvement, and distractions serving as the primary contributors to this unacceptably high crash rate. In an effort to mitigate this situation, a prototype teen driver support system (TDSS) has been designed and developed. This computer-based system provides real-time feedback to teens regarding speed limit violations and warns of upcoming speed zone changes. A unique feature of this system is that speed limit feedback is relative to the speed limit posted on the roadway on which the teen is driving. By informing teens of speeding behavior, it is hoped that this system will reduce teen crash rates. This project includes a description of the TDSS features and specifications for how the TDSS operates using the Smart Phone technology. A small usability study was completed as part of the project where teen drivers (aged 18-19) drove with and without the system. Overall, the pilot study demonstrated that the TDSS could operate effectively within a vehicle driven by a teen driver. Warnings and messages were presented to the drivers and corresponding text messages were sent when drivers failed to alter their behavior in relation to a warning. The performance data trended in the direction expected, with the TDSS encouraging lower speeds and less speeding overall. The teen participants reported that very little mental effort was required to interact with the TDSS while driving, but they also reported the system increased their perceptions of stress while driving. The second phase of the study proposed the information that should be presented in the real-time text messages and to parents in a weekly report. A potential weekly report format is described. Finally, the project identified the issues associated with using the TDSS as an additional tool to support GDL programs.

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Executive Summary

Forty percent of all teenage deaths are caused by motor vehicle crashes, which are the leading cause of death among teenagers (NCHS, 2005). Inexperience and the propensity to engage in risky behavior or situations are contributing factors that make teenagers dangerous behind the wheel (Mayhew, Simpson, & Pak 2003). The rate of teen traffic fatalities remains high despite the introduction of mandatory driver training programs in many countries over the past few decades (e.g., Engstrom, et al., 2003). Some researchers even suggest that driver education contributes to an increase in crash risk because it allows teenagers to start driving at younger ages (Wiggins, 2005). In contrast to driver training, progress has been made in the reduction of fatal and non-fatal teen accidents over the past 10-12 years with the adoption of graduated driver's licensing (GDL) programs in all 50 states (Ferguson, Teoh & McCartt, 2007). These programs work by restricting teen drivers from known risky situations for specified periods of time while they gain driving experience. GDL programs are difficult to enforce as they rely heavily on parents to impose regulations, but, at the same time, parents can point to the state for why their teen's driving must be regulated in particular ways.

Therefore, a need exists to identify the best ways to support teen driver behavior. The implementation of in-vehicle monitoring systems is gaining ground in the market place, with a number of systems currently in existence (see Appendix A). The use of in-vehicle technology in the form of a Teen Driver Support System (TDSS) that can monitor behavior and identify risky driving as well as monitor adherence to GDL-related licensing provisions could potentially be an effective way to reduce high-risk behaviors and teen crash causal factors. This report reviews the background information that led to the development of the original TDSS and then describes how the TDSS feedback and monitoring functions were implemented in a smart phone. Additionally, this report identifies current and future features of the TDSS system and discusses how they relate to teen driving safety. Finally, this report discusses how TDSS may find a role in monitoring teen drivers' compliance with a GDL Program.

Crash statistics and research related to teen drivers indicate there several specific driving behaviors and situations that are linked to the overrepresentation of teenagers involved in motor vehicle accidents. These include speeding, alcohol abuse, seat belt non-compliance, peer passenger presence, and hazardous driving conditions. The TDSS tries to incorporate feedback and monitoring related to these primary crash factors, but primarily focuses on speed as a main issue.

The TDSS developed for this project expanded on the original TDSS project by moving the system's monitoring functions to a smart-phone to reduce the costs of deploying such a system to the general public. First, a smart phone could adequately replace the computer and cellular modem, as well as competently serve as an in-vehicle processor and display. Second, because most cellular phones are equipped with Bluetooth capabilities, data can be wirelessly transmitted from devices such as seatbelt and alcohol sensors to maximize portability and significantly reduce any peripheral installation that may be required. Third, 75 percent of 15-17 year old teenagers already carry cell phones.

The prototype smart phone TDSS is comprised of a simple hardware configuration. Other than the cellular phone, there are only two other physical pieces of hardware. The first piece is a GPS receiver that wirelessly transmits longitude and latitude data to the phone via Bluetooth at 1

Hz. The second piece is a device that is connected to the vehicle's OBDII port that sends speed data from the vehicle to the phone via Bluetooth at 1.5 Hz. GPS and an on-board map database work together to identify which road the driver is on. Speed limits are then pulled from a speed limit database and compared to the actual speed of the vehicle to identify speeding infractions.

Driver feedback and parental reporting functions were incorporated into the TDSS. The smart-phone TDSS provided real-time auditory and visual feedback to the driver about speed information, weather conditions and curves. The visual messages used on the phone were simple and familiar to drivers (e.g., use of speed sign to depict current speed) to reduce the time drivers needed to interpret a message. The phone was also placed near the steering wheel to improve visibility of the messages. Reporting features were also developed to demonstrate the system's ability to send real-time text messages to parents about infractions and to upload data to an online reporting system for parents.

A small pilot study was conducted using a convenient sample of 16 teen drivers aged 18-19. Overall, the goal of the study was to ensure the smart-phone TDSS software and hardware were running effectively and providing the appropriate information to drivers. Participants drove a 30-minute route twice: once with the TDSS active and once with it inactive. Objective and subjective data were collected during this study. Overall, small reductions in speeding behavior were observed while the TDSS was active compared to when it was not active. However, given the small sample size and the presence of a researcher in the vehicle, it is possible the test subjects felt compelled to adhere to the TDSS messages they were receiving. Feedback about the TDSS was collected from the drivers and indicated that most (80%) felt the system improved driving safety. However, about 50% felt the system made driving more stressful. It was possible this perception of stress was linked to a perception that the auditory messages were annoying as most teens found the audio feedback annoying.

The results of this small-scale pilot study have been taken into consideration for future TDSS implementations and the issues discovered will be examined in more detail in future usability studies.

Another goal of this report was to outline the support that the next-generation TDSS would provide for teen drivers and parents. The proposed requirements are:

- Sensing driving location and time-of-day along with biometric confirmation of the driving teen and supervising adult
- Sensing presence of passengers using low-profile weight sensors in seats. Only passengers (e.g. adults, siblings) pre-screened by parents would be allowed (at the appropriate stage in the GDL) based on biometric confirmation.
- Seat belt compliance using remote sensor switch.
- Restriction of incoming cell phone calls and management of outgoing calls (limited to 911) based on smart phone technology.
- Alcohol detection and ignition interlock if alcohol is detected.
- Sensing speeding events in relation to posted local speed limits and prevailing weather conditions.
- Sensing aggressive driving events in relation to rates of deceleration and acceleration.

- Geofencing to prohibit teens driving at times, locations, and routes other than those specifically approved by parents.
- Monitoring system that automatically notifies parents that their teen has arrived at an approved destination.

Based on these proposed requirements, text message content and parental reporting content for the next version of the TDSS were also identified in this report. In general, text message feedback to parents will include information related to the time of an incident, what type of incident (e.g., speeding), and where the incident occurred. The online parental summary report will include similar information to the text messages, but in aggregate form for a specified time period (e.g., 1 week). The online report design also specified that additional information to help parents mentor their teen's driving be available, such as by providing links to information about teen crash statistics, licensing issues or talking points on safety.

Finally, this report outlines the benefits and limitations of using the TDSS to help support Graduated Driver Licensing (GDL) provisions for teen drivers. Ultimately, the TDSS could be used to monitor behavior specific to GDL provisions (e.g., alcohol use, passenger restrictions, night-time driving restrictions). The report highlights how different entities, such as authorities, third-party providers (e.g., insurance) or parents, could monitor and support GDL provisions using the TDSS. Ultimately, parents are the current intended monitoring entity for the TDSS, but discussion of other possible monitoring entities is important to frame the future potential of the TDSS to provide support for licensing programs.

1 Introduction

Forty percent of all teenage deaths are caused by motor vehicle crashes, which are the leading cause of death among teenagers (NCHS, 2005; see Figure 1-1). Inexperience and the propensity to engage in risky behavior or situations are contributing factors that make teenagers dangerous behind the wheel (Mayhew, Simpson, & Pak 2003). Teenagers continue to have the highest fatal crash rates per vehicle mile traveled (VMT). Figure 1-2 shows the number of fatal crashes per 100 million VMT by driver age. (The 2001-2002 NHTS mileage data was used to calculate the miles travelled by age because it is the last known reliable source that addresses VMT with respect to driver age.) The crash rate for teenagers (11.5 crash fatalities per 100 M VMT) is significantly higher than any of other age groups. In 2006, teen drivers (aged 16-19) accounted for 13.2 percent of all fatal crashes in Minnesota even though they only represented 6.4 percent of the driving population (Minnesota OTS, 2006). The fatality rate per 100,000 licensed drivers in Minnesota is shown in Figure 1-3.

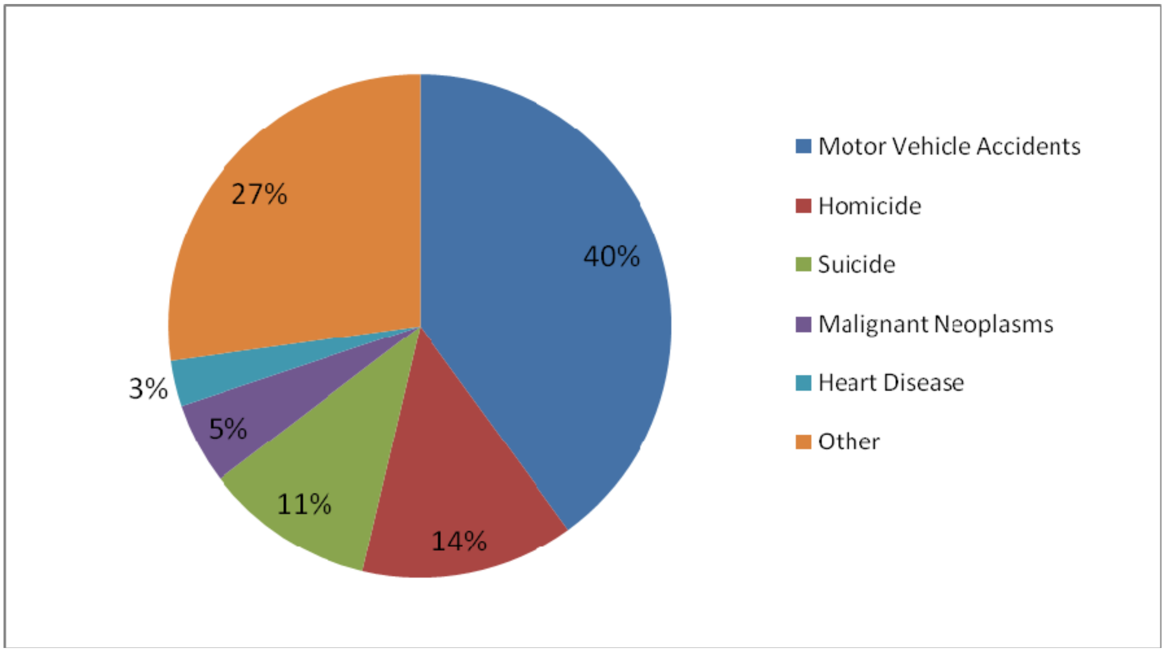


Figure 1-1. Leading causes of death among 15-20 year olds (NCHS, 2005).

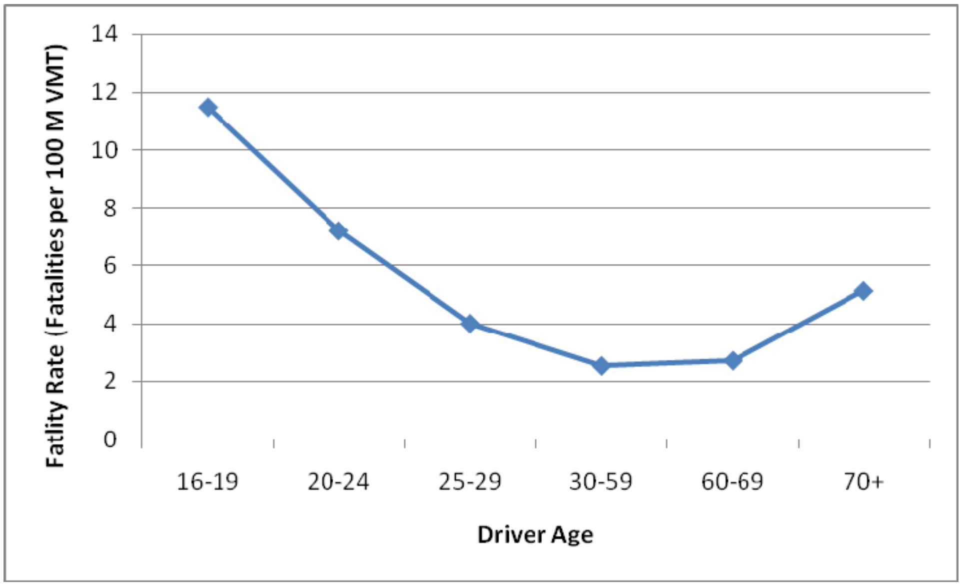


Figure 1-2: 2006 Fatal crash rate per 100 M VMT by age (FARS, 2006).

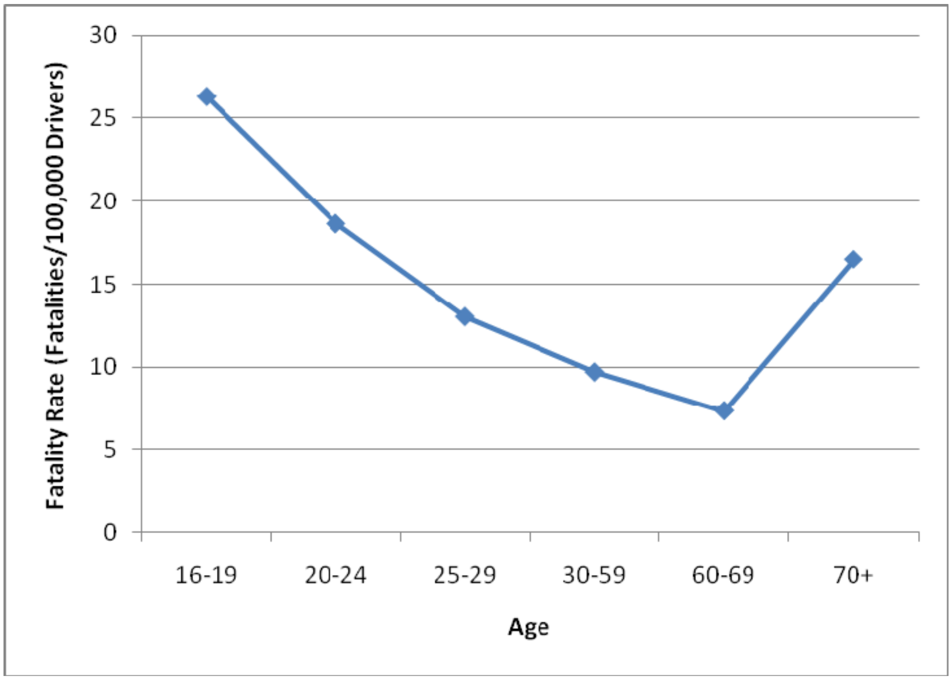


Figure 1-3. 2006 Minnesota driver fatality rate per 100,000 registered drivers by age (Minnesota OTS, 2006).

The rate of teen traffic fatalities remains high despite the introduction of mandatory driver training programs in many countries over the past few decades (e.g., Engstrom, et al., 2003). Some researchers even suggest that driver education contributes to an increase in crash risk because it allows teenagers to start driving at younger ages (Wiggins, 2005). In contrast to driver training, progress has been made in the reduction of fatal and non-fatal teen accidents over the past 10-12 years with the adoption of graduated driver's licensing (GDL) programs in all 50 states (Ferguson, Teoh & McCartt, 2007). These programs work by restricting teen drivers from known risky situations for specified periods of time while they gain driving experience. GDL programs are difficult to enforce as they rely heavily on parents to impose regulations, but, at the same time, parents can point to the state for why their teen's driving must be regulated in particular ways.

Therefore, a need exists to identify the best ways to support teen driver behavior. The implementation of in-vehicle monitoring systems is gaining ground in the market place, with a number of systems currently in existence (see Appendix A). The use of in-vehicle technology in the form of a Teen Driver Support System (TDSS) that can monitor behavior and identify risky driving as well as monitor adherence to GDL provisions could potentially be an effective way to reduce high-risk behaviors and teen crash causal factors.

This report reviews the background information that led to the development of the original TDSS and then describes how the TDSS feedback and monitoring functions were implemented in a smart phone. Additionally, this report identifies current and future features of the TDSS system and discusses how they relate to teen driving safety. Finally, this report discusses how TDSS may find a role in monitoring teen drivers' compliance with a GDL Program.

2 Background: Teen Crash Behaviors and Causal Factors

Crash statistics and research related to teen drivers indicate there a number of specific driving behaviors and situations that are linked to the overrepresentation of teenagers involved in motor vehicle accidents. These include speeding, alcohol abuse, seat belt non-compliance, peer passenger presence, and hazardous driving conditions. The TDSS tries to incorporate feedback and monitoring related to these primary crash factors.

2.1 Speeding

Speeding continues to be a problematic behavior among teen drivers. In 2006, 39 percent of 16 year old drivers involved in a fatal accident were speeding. Similarly, 34 percent of drivers aged 17-19 involved in fatal crashes were speeding (IIHS, 2006). The propensity of teenagers to speed is due to the teenager's inability to accurately recognize the dangers associated with speeding (NHTSA, 2006). The National Young Driver Survey (2005) found that more than half of teenagers do not think they are speeding unless they are traveling in excess of 10 mph over the posted speed limit.

Additionally, speeding can attribute to problems with curve negotiation. In general, teens have problems with curve negotiation, with one study finding novice drivers aged 16-17 to be 3.4 times more likely to be involved in a fatal collision than older drivers aged 30-49 when negotiating a curve (Lerner, et al, 1999). Another study found that teen drivers aged 17-19 were involved in twice the number of crashes while negotiating a curve than older drivers aged 30-49 (Clarke et al., 2006). McKnight and McKnight (2003) found that about 29% of crashes in curves occurring among teen drivers aged 16-19 were due to problems with adjusting their speed.

Speed is currently monitored by the TDSS for both straight roads and curves.

2.2 Alcohol

All 50 states have implemented zero tolerance laws that make it illegal for drivers under the age of 21 to drive with any traces of alcohol (IIHS, 2008). However, the 2006 SADD Teen Today Survey reported that 19 percent of teenagers drive under the influence of alcohol. Furthermore, 25 percent of 15-20 year old drivers who were killed in motor vehicle crashes had a BAC level of .08 g/dL or higher (NHTSA, 2006). Although teenagers drink and drive less often with lower BAC levels than adults, their crash risks are much higher (Williams, 2003). This is attributed to the fact that alcohol impairment is greater among teenagers compared to older age groups because the adolescent body and brain is not fully developed (White, 2001). A study by Keall, Frith, and Patterson (2004) found that teen drivers had five times more crash risk than drivers 30 years and older at all BAC levels.

As with other age groups, the trend in teen alcohol fatality rates has remained static for about the past 15 years (see Figure 2-1). This trend suggests that teen impairment monitoring might be needed to facilitate a reduction in teen drinking and driving. Organizations such as DADSS are already working on new in-vehicle alcohol detection technologies (DADSS, 2008).

Alcohol detection is not currently implemented in the prototype TDSS system discussed in this report, but is a proposed feature of the next version of the TDSS. Appendix B discusses BAC detection technologies.

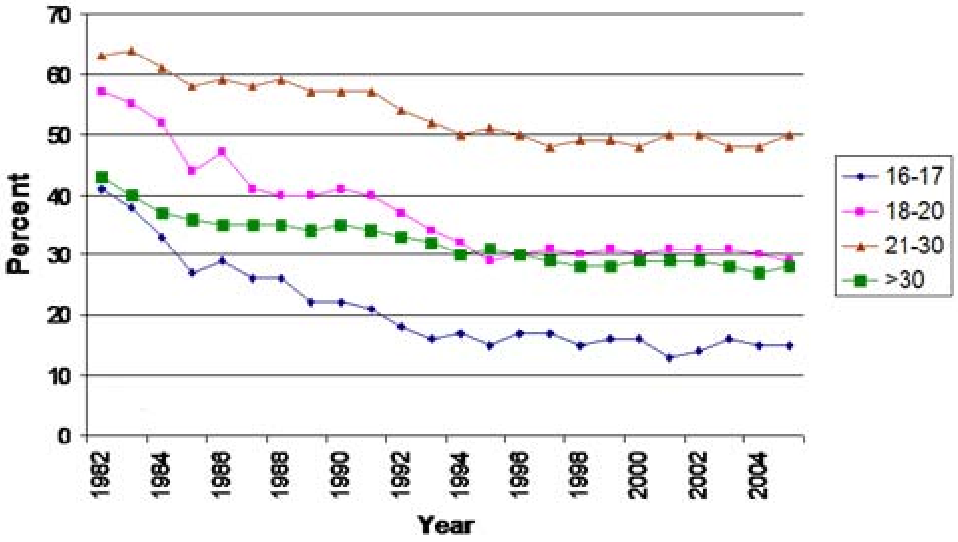


Figure 2-1. Percentage of fatally injured passenger vehicle drivers with BACs greater than 0.08%, 1982-2005 (IIHS, 2006).

2.3 Seatbelt Use

Although seatbelt non-compliance does not directly cause crashes, it heavily influences the severity of injury. In 2006, 58 percent of all 16-20 year olds who died in a motor vehicle accident were not belted (NHTSA 2006). Teenagers continue to have the lowest rate of seatbelt use despite the fact they have the highest crash rates (CDC, 2006). A recent survey conducted by the Centers for Disease Control (2007) found that 11.1 percent of high school students rarely or never wear seatbelts. Additionally, The Utah Department of Health (2006) conducted a statewide observational seatbelt study and found that seatbelt use among teenagers was only 67 percent in comparison to the 88 percent state average for all drivers.

Seatbelt use is not currently monitored by the TDSS prototype, but is a proposed feature for the next version of TDSS.

2.4 Passenger Presence

The effect of peer passengers on teen drivers is well established. Teen drivers often see driving as a way to attain excitement, attract attention, and achieve status (Moller, 2004). As a result, teenage drivers are willing to become involved in risky driving behavior in order to gain the approval of their peers. A study conducted by Simons-Morton et al. (2005) concluded that teenage drivers are far more likely to speed and maintain shorter headways with young passengers in the vehicle.

Passenger risk is also one that is exclusive to the younger age groups. Williams (2003) concluded that teen crash risk increases exponentially with the number of passengers inside the vehicle, whereas older age groups actually showed a reduction in crash risk with an increase in passengers. Williams also concluded that 16 and 17-year-old drivers are four times as likely to crash with three or more passengers present than when no passengers are present. Because of this risk, teen passenger limitations are a critical part of many GDL programs.

The current TDSS prototype does not monitor the presence of passengers in the vehicle, but is a proposed feature of the next TDSS.

2.5 Weather Conditions

Weather conditions are often over looked as a potential teen crash hazard; however, poor weather conditions often present emergency situations that teen drivers are not experienced enough to properly handle. As a result, teenage drivers are more susceptible to crashing in bad weather. Figure 2-2 shows the 2006 driver fatality rate per 100,000 licensed drivers by age filtered to focus on weather (FARS, 2006). The subset of driver fatalities used to calculate the fatality rates were associated with the following weather and road condition factors: rain, snow, fog, smoke, sand, dust, severe crosswinds, ice, slush, water dirt, oil, and wet leaves. The teen driver fatality rate (0.55) is considerably higher than the older age groups. Moreover, the teen fatality rate is more than twice as high as all age groups except the 20-24 age group.

Weather monitoring is currently enabled in the prototype TDSS. Currently, all weather conditions are monitored. Future instances of the TDSS may incorporate only those considered to increase crash risk, such as icy roads or snow.

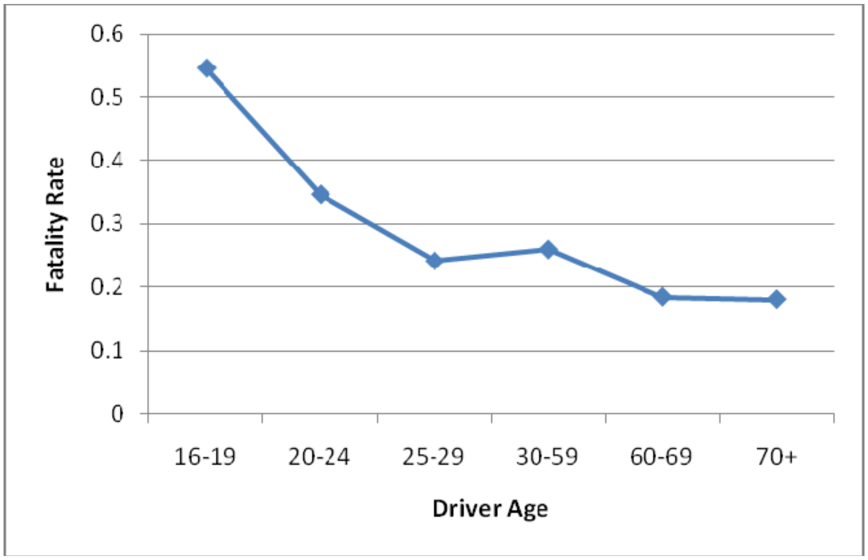


Figure 2-2. Driver fatality rate per 100,000 registered drivers of crashes associated with weather conditions by age (FARS, 2006).

3 Means of Reducing Teen Crash Rates

3.1 Graduated Driver Licensing (GDL)

Teens exhibit the highest crash risk during the first few months of licensure (McCartt et al. 2003). GDL programs are designed to address this issue by providing teenagers with an opportunity to obtain driving experience in a low risk environment by imposing restrictions on when and with whom teens can drive (Simpson, 2003). GDL has proven effective in the reduction of teen crash rates for drivers who adhere to the program's restrictions (Mayhew et al. 2005).

In the United States, GDL programs vary from state to state; however, they all consist of two stages before full licensure (Hedland, 2007). The first stage is a learner's permit that requires driving under the supervision of a licensed adult. During this stage, most states mandate a six month minimum holding period and 30-50 hours (some of these hours may be required at night) of supervised driving (IIHS, 2008). The second stage is a provisional license that permits unsupervised driving with certain provisions that vary from state to state. Most often these provisions include a teen passenger limit and nighttime driving curfew.

Florida was the first state to adopt a GDL program in 1996 (Preusser & Tison 2007). By 2006, all 50 states plus the District of Columbia had enacted GDL legislation. However, the Insurance Institute for Highway Safety (IIHS, 2007) has rated only 30 of these programs as good, 12 as fair and the remainder as marginal. More than 25 published studies have been conducted to evaluate the effectiveness of GDL programs (Hedlund, 2007). Most of the risk reduction among 16-year-old drivers during the GDL period was found in the following categories: nighttime driving, driving with teen passengers, and driving under the influence of alcohol (Ferguson et al., 2007). This is expected considering most of the GDL limitations directly remove novice drivers from these high-risk situations.

Seventeen states along with the District of Columbia have implemented cellular phone limitations as part of GDL (GHSA, 2007), but the effectiveness of such a restriction is in question. A recent study in North Carolina conducted by the IIHS (2008) found that teen driver cell phone use actually increased after the restriction was implemented. Despite the fact that 76 percent of teens and 95 percent of parents approved of such a restriction, only 64 percent of teens and 39 percent of parents surveyed actually knew about the law. Furthermore, only 22 percent of teens and 13 percent of parents felt that the restriction was being enforced. The surveys suggest that the ineffectiveness of the restriction was likely due to a lack of public awareness and enforcement.

Enforcing GDL restrictions is difficult and continues to be a problem for many jurisdictions (Hedlund, 2007). It is a formidable task for law enforcement officers to distinguish GDL violations from normal driving situations (e.g., driving with a passenger) that are perfectly legal for the majority of the population. Often, the burden of monitoring GDL compliance falls directly on parents, which can lead to a conflict of interest. For example, parents are asked to vouch that their teen has acquired the appropriate number of supervised driving hours before a provisional license is issued. Although some parents recognize the increased risk that comes with licensure, many parents want to rid themselves of “chauffeur” responsibilities (Shinar, 2007). Additionally, Foss (2007) notes that poor communication between parents and teens may be a stumbling block to getting parents to enforce teen driving behaviors. For example, a parent may believe they have communicated a certain message about driving well to their teen, but what is actually recorded and interpreted by the teen is something different. Facilitating this communication process could help parents better address GDL restrictions and requirements with their teens.

Certain programs exist that are aimed at helping parents appropriately monitor GDL restrictions. The Checkpoints program is a six-month program that helps parents establish driving guidelines with their teen. The program mails information on high-risk teen driving behavior along with a parent-teen driving agreement. The agreement is designed to help parents set up driving limits for their teenagers in order to safely guide them through their first months of licensure. A study by Simons-Morton et al. (2006) evaluated this program by surveying two groups of parent-teen dyads. One group was enrolled in the Checkpoints program while the other was not. This study found that the Checkpoints program significantly increased the number of driving restrictions compared to the control group. However, there were only slight increases in the restrictions with respect to teen passengers and nighttime driving, which account for the most teen driving risk. More importantly, there was no significant difference in the number of crashes between the control group and the group using the Checkpoints program.

The current TDSS does not monitor or provide feedback about GDL restrictions, but GDL feedback and monitoring is proposed for the next generation TDSS.

3.2 Intelligent Speed Adaptation (ISA)

Intelligent speed adaptation (ISA) is an in-vehicle technology that monitors and enforces speed limits. There are two types of ISA systems. A speed alerting ISA system warns drivers if they are traveling faster than the speed limit. A speed limiting ISA system actually restricts the maximum speed of the vehicle with a governor or speed retarder (Young & Regan, 2007). Speed alerting ISA systems can be further categorized as informative or actively supporting. An informative alerting ISA system warns the driver through auditory or visual cues while an actively supporting informative ISA system provides haptic feedback by increasing resistance in the gas pedal as the vehicle speeds. Actively supporting systems can be overridden by pressing the gas pedal with more force. The most common approach for obtaining speed limit data is to use a GPS receiver with a built-in digital map that associates speed limits with each road.

Recent research conducted overseas showed that ISA has the potential to immediately impact crash rates (Regan, Young, & Haworth 2003). Sweden conducted a number of large-scale field trials of ISA systems, most which showed a reduction in speeding violations and an increase in fuel economy. However, some of the trials showed that ISA can cause compensatory behavior. Participants were observed to run red lights more frequently and to take faster turns while using the limiting ISA system (Regan et al., 2003). These large-scale field trials have led to a push for ISA deployment in Sweden. A national digital road map with speed limits has been constructed that will supplement ISA deployment (Schelin, 2003).

An informative ISA system was evaluated in the Netherlands by Brookhuis and de Waard (1999) that used an in-vehicle display. The display showed the current speed limit of the road on which the vehicle was traveling. If the vehicle was abiding the speed limit, the icon was green.

The display would become amber as the vehicle began to speed. If the vehicle exceeded the speed limit by more than 10 percent, the display would turn red. The study showed a significant reduction in mean speed (4 km/h) and speed variability (.5 km/h). Participants in this study also thought highly of the visual feedback, citing it as useful to always have a reference of the current speed limit available.

A recent Australian ITS evaluation by Regan et al. (2006) instrumented 15 passenger vehicles with ISA. The vehicles were also equipped with other enabling in-vehicle technologies such as a seatbelt reminder system, a reverse collision warning system, and a following distance warning system. The ISA significantly reduced the mean, maximum, and 85th percentile speeds without significantly increasing the average trip time. However, behavioral changes in speed occurred while the system was active, but dissipated once the system was removed from the vehicle. The authors concluded that ISA could reduce fatal crashes by 8 percent and reduce crashes that result in serious injury by up to 6 percent. Furthermore, ISA combined with other enabling technologies proved to reduce crash risk even further.

Large variations in speed are associated with increased crash rates (Lui & Tate, 2004). Recent research found that the crash rate per 100,000 vehicle kilometers traveled is exponentially related to the standard deviation of vehicle speed within the network (Lui & Tate 2004). A simulation study by Wang et al. (2007) concluded that, because ISA systems generally reduce speed variance, ISA implementation could significantly reduce crash rates. They concluded that a 27 percent accident rate reduction could potentially occur if 100 percent of the vehicles within the road network were using ISA technology.

A Danish study by Agerholm et al. (2007) investigated the performance of an incentive based speed alerting/informative ISA system used by 18-28 year old drivers. In this study, speeding resulted in the accumulation of penalty points which reduced the likelihood that the driver would receive a 30 percent discount on driver's insurance. The incentive-based ISA system dramatically reduced speeding on both rural and urban roads. The results of this study suggest that incentives used in association with in-vehicle safety technologies may prove useful for encouraging the adoption of these technologies.

The effect of ISA on novice drivers and younger teens has not received a lot of attention. However, an Australian study by Young, Regan and Mitropoulos (2004) explored the acceptability of ISA systems to young drivers. The study interviewed two different groups, one rural and one urban, of drivers aged 17-25 years. Overall, participants were disinclined to accept ISA systems. Limiting ISA systems were especially frowned upon because the younger drivers felt that such a system posed significant dangers by inhibiting the capability of escaping from a dangerous situation. Research also shows that drivers who speed are likely to turn the system off (Jamson 2002). Furthermore, admitted speed offenders typically voice their displeasure regarding ISA systems in questionnaires and surveys (MORI, 2002). Therefore, the drivers who actually need the system the most are the ones most likely to refuse it. As a result, implementation of ISA at a voluntary level will likely not yield significant crash reductions unless incentives for use are identified and applied accordingly. Studies have found that many drivers think ISA should be used by high risk driving groups such as multiple traffic offenders and novice drivers (Lahrmann, Madsen, & Boroch, 2001; Biding & Lind, 2002).

The current TDSS system provides speed information via the visual interface to the driver while driving. It also alerts teens when they are speeding. In this sense, the TDSS acts as a passive ISA system. The TDSS does not regulate speeding behavior by preventing the teen from speeding, but it does provide continuous feedback about speeding behaviors and will report speeding to the parents when violations occur.

3.3 In-vehicle Systems

Several teen monitoring devices currently exist on the market (see Appendix A). These systems typically use GPS or video footage to track teen drivers and report behavior to parents, who can then choose how to handle their teen driver. Some of these systems show reductions in risky teen driving behavior (e.g., DriveCam; McGehee et al. 2007), but few provide real-time feedback to the driver about risky behaviors/situations that may be useful in changing behavior while the teen is behind the wheel.

One system that includes limited real-time feedback is the DriveCam video monitoring system (see Appendix A). DriveCam records 20 seconds of footage before and after an incident has been detected. An incident is triggered if an internal accelerometer measures a g-force above a preset threshold. The driver feedback function is a small LED that turns on when a driving incident has been detected and the device is recording video footage. The device mounts underneath the rear view mirror and has two cameras pointing in opposite directions. One camera records the interior of the vehicle monitoring driver and passenger behavior, while the other camera records what the driver sees outside of the windshield. The device can also be manually triggered by pressing a button located on the DriveCam device. Footage is uploaded to a PC where it is reviewed and driving behavior can be assessed (DriveCam, 2008). Testing with DriveCam showed a reduction in risky behaviors by drivers when the system is in use. Additionally, teen drivers reported that they liked the LED recording light because it notified them of a recordable event and allowed them to reflect on the situation that had just occurred (McGehee, personal communication). This indicates that real-time feedback could be appropriate for certain risky driving situations, at a minimum by letting the driver know that something inappropriate has occurred.

In general, in-vehicle systems hold promise for potentially altering teen driving behaviors and helping prevent risky situations. For example, the DriveCAM system (McGehee, 2007) has demonstrated that changes in behavior can occur after the implementation of a monitoring system. The effect of real-time feedback on driver behavior is not well understood for teen drivers as most devices do not provide real-time feedback. The development of systems in the marketplace indicates a desire (by parents, at a minimum) for systems that can help make teen drivers safer. However, a successful system must address issues relevant to teen safety, such as speeding, seat belt use and alcohol impairment. Additionally, if parental feedback is involved, reports must be meaningful and useable to allow coaching of the teen driver, and provide guidance for the use of incentives and consequences that are meaningful to teens. Finally, given the existence of GDL provisions in all 50 states, a successful system may also have the capability to support or monitor compliance with those provisions.

4 The Teen Driver Support System (TDSS)

A Teen Driver Support System (TDSS) prototype was developed in 2006. It was designed to provide real-time auditory feedback to assist teens with recognizing speed limits, road curves, and poor weather conditions (Brovold, Ward, Donath & Simon, 2007). The system featured a biometric fingerprint reader for driver and passenger identification as well as a seatbelt ignition interlock. The system also detected speeding and seatbelt infractions and autonomously sent out SMS text messages to parents in real-time.

This system used a full-sized PC-104 computer located in the trunk of the vehicle. The system obtained speed and RPM data from the Second Generation On-Board Diagnostics (OBDII) port that exists on every car sold in the United States after 1996. The system also collected location data through a GPS receiver connected to the computer via RS-232. A cassette audio adapter was used to play auditory warnings through the vehicle's speakers and an external cellular modem to automate text messaging and download weather and road condition data from remote weather stations.

This TDSS performed all its intended functions extremely well, but had several drawbacks as a deployable concept. First, the system was large and required an extensive installation process, which would drastically increase the cost of deploying such a system. Second, the cellular modem had to be manually configured so the system could either send out text message alerts or download weather data. It was unable to accomplish both of these tasks simultaneously. Third, although the system provided real-time audio feedback, there was no real-time visual feedback to the driver. As in the case of in-vehicle warning icons, visual feedback may provide an appropriate feedback mechanism for teen drivers in addition to the auditory messages. However, it is difficult to predict how well either form of feedback (auditory or visual) will perform without full testing of an integrated system. A full description of the original TDSS can be found in Brovold et al. (2007).

These limitations indicated that a smaller, more mobile form of technology would be required to improve the desirability and deployment of such a system. The use of a cellular smart phone was attractive for a number of reasons. First, a smart phone could adequately replace the computer and cellular modem, as well as competently serve as an in-vehicle processor and display. Second, because most cellular phones are equipped with Bluetooth capabilities, data can be wirelessly transmitted from devices such as seatbelt and alcohol sensors to maximize portability and significantly reduce any peripheral installation that may be required. Third, 75 percent of 15-17 year old teenagers already carry cell phones. Due to the growing popularity of smart phones with the introduction of the iPhone and Google Android mobile operating system, teenagers could conceivably carry one multi-purposed device instead of having to deal with many pieces of hardware. Finally, if a smart phone is used as the in-vehicle TDSS, it can be programmed to restrict the teen driver from making and receiving phone calls and text messages while driving.

The goal of this project was to develop a prototype smart phone based TDSS that could perform several of the functions that the original system did as well as additional functions. The cellular phone based TDSS that was developed for this study is an alerting/informative ISA system that uses a GPS receiver with onboard digital maps and feature databases to provide real-time driver feedback and parental reporting regarding speed limits, road curves, stop signs, and poor weather conditions.

4.1 Smart Phone TDSS System Hardware

The prototype smart phone TDSS is comprised of a simple hardware configuration. Other than the cellular phone, there are only two other physical pieces of hardware. The first piece is a GPS receiver that wirelessly transmits longitude and latitude data to the phone via Bluetooth at 1 Hz. The second piece is a device that is connected to the vehicle's OBDII port that sends speed data from the vehicle to the phone via Bluetooth at 1.5 Hz. Figure 4-1 shows the TDSS system overview and how the sensors are integrated. Appendix C provides a detailed description of the smart phone and peripheral hardware used.

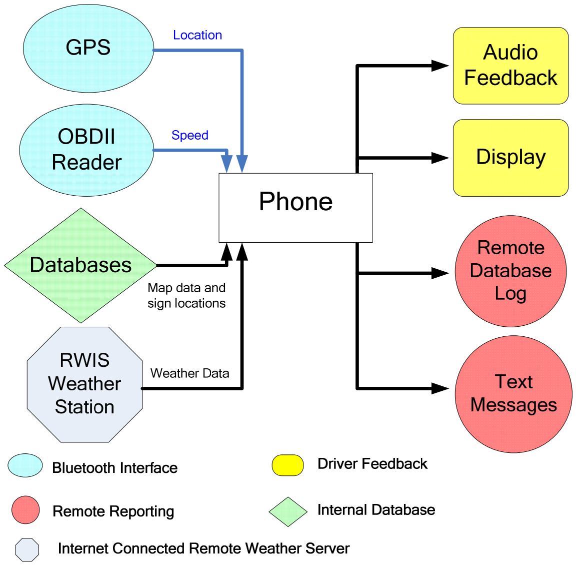


Figure 4-1. TDSS system overview.

4.2 Feedback Functions

The goal of the feedback and reporting functions in this prototype was to demonstrate the ability of the smart phone to provide real-time auditory and visual feedback to the driver. The smart phone screen serves as the driver interface for the TDSS (see Figure 4-2; Figure 4-3). The phone is placed on the dashboard in a way that allows the driver to easily see the phone's display, yet not hinder the driver's view of the road. Reporting features were also developed to demonstrate the system's ability to send real-time text messages to parents about infractions and to upload data to an online reporting system for parents. Figure 4-8 shows reporting functions as circles and feedback functions as rectangles.

Figure 4-2. Placement of TDSS smart phone inside the vehicle.

Figure 4-3. The TDSS display.

4.2.1 Auditory Feedback

Auditory warnings are voice-generated WAV files that were prerecorded and stored on the phone (see Appendix D). The phone plays a message that notifies the driver every time the speed limit changes. Speed limit changes may occur for two reasons. First, speed limits may change when the vehicle makes a turn onto a different road. When the TDSS recognizes the vehicle has made a turn, it responds by stating “Speed limit XX miles per hour.” Second, the speed limit can change for the road on which the vehicle is traveling. In this case, the system uses GPS location and the onboard map to “look” ahead of the vehicle and then plays a message if the speed limit will change. Because curve negotiation is a known problem for novice drivers, particularly when it comes to speed maintenance in a curve, the system also warns of upcoming road curves by indicating the curve direction and speed limit.

Poor weather conditions are also conveyed by an auditory message to the driver. The phone communicates with the Road Weather Information Service (RWIS) server using EVDO to locate the closest station, accesses the weather data, and then once the system decides that a reduction in speed limit is deemed necessary, alerts are played that notify the driver of the hazardous condition type and speed limit reduction. EVDO is a 3rd generation telecommunication protocol for wireless data transmission. The different weather conditions the TDSS detects include low visibility, high wind, snow, rain, hail, and ice. The weather related speed limit reductions employed by this system are recommendations from the Alabama and Washington state DOTs (Goodwin, 2003; see Appendix D).

4.2.2 Visual Feedback

One of the largest advantages of using a smartphone as an in-vehicle driver support system is that the display can be utilized as an in-vehicle visual warning system. The premise of the TDSS visual interface is to make icon variations of traffic control signs so that the driver can more easily interpret the information. Generally recognized symbols that have common meanings can be used to minimize problems with interpretation (Carney, Campbell & Mitchell, 1998). In this case, using icons that look like speed limit signs or stop signs means the information on the screen maps directly to how information is displayed in the driving environment. This can facilitate quick and accurate comprehension by the driver to help minimize the time the driver's attention is away from the road (Campbell, 2004). This is especially relevant for teen drivers because younger people typically spend more time looking at in-vehicle signs than older people (Caird, Chisholm & Lockhart, 2008). Minimal use of words given the small screen size and different colors for different warning situations can also help drivers more quickly distinguish an iconic alert.

Four different items are displayed on the TDSS screen at all times (see Figure 4-3). The first item, shown in the top right corner of the screen, is the speed of the vehicle that is provided by the OBDII reader in miles per hour. The item below the speed indicator shows the number of satellites the GPS unit has acquired. This is an important parameter because it is related the quality of the GPS signal. If the number of acquired satellites becomes small, the longitude and latitude data provided by the GPS receiver will be inaccurate, which means that the map matching algorithm will perform poorly. The third item, displayed underneath the GPS quality, is the name of the street on which the vehicle is traveling. It should be noted that these four items were primarily used by the developer of the system to debug and make sure everything is working properly. If the system is to be put into mainstream use, these display boxes may be omitted from the TDSS.

The largest and most significant item on the display is the picture box measuring 1.5 inches by 1.25 inches that displays variations of traffic control signs depending on the alert condition. One of the objectives of the TDSS display is to provide the driver with a constant reminder of the speed limit and use different colors to signal warnings as this has been shown to help reduce speeding in previous research (Brookhuis & de Waard, 1999). If the driver is driving at or under the speed limit, a white speed limit sign with the current speed limit is shown (see Figure 4-3). The display also warns the driver if the speed limit is exceeded. If the driver speeds, this box will turn red and the speed limit value will start flashing at a rate of 5 Hz (see Figure 4-4).

Figure 4-4. A red flashing speed limit sign indicates the driver is speeding. Actual speed is shown in the top right corner of the display.

If the RWIS weather module detects hazardous weather conditions that warrant a speed limit reduction, the speed limit sign will change its color to blue and display the speed limit value with the appropriate reduction. The figure below shows a speed limit reduction from 30 miles per hour to 25 miles per hour because of icy road conditions (see Figure 4-5). If the driver is speeding in poor weather conditions, a blue speed limit sign will start flashing once the driver exceeds the reduced speed limit. The speed limit sign will become red and the speed limit value will flash if the driver exceeds the unreduced speed limit of the road. Appendix F describes how weather data is gathered and how limits are set depending on conditions.

Figure 4-5. A blue speed limit sign indicates a reduced speed limit is in effect due to weather conditions.

Curves signs with the curve speed limit are also used as visual warnings. Again, this icon is designed to resemble a curve sign that one would find on the road. The picture consists of a yellow diamond with a curved arrow pointing to right or left, depending on the direction of the curve. A rectangular curve speed limit sign with the appropriate speed limit is located underneath the diamond. If the driver speeds through the curve, the sign will turn from yellow to red (see Figure 4-6).

Figure 4-6. Curves signs indicating the vehicle is approaching a road curve.

When the driver approaches a stop sign, the picture box displays a stop sign. Stop sign warning occur when the driver approaches a stop sign. The goal is to inform novice drivers of upcoming stop-controlled intersections, particularly because stop signs may be obscured by vehicles or vegetation.

Figure 4-7. A stop sign indicates the vehicle is approaching a stop sign.

Figure 4-8 shows the logic for how the TDSS determines which icon to present to drivers.

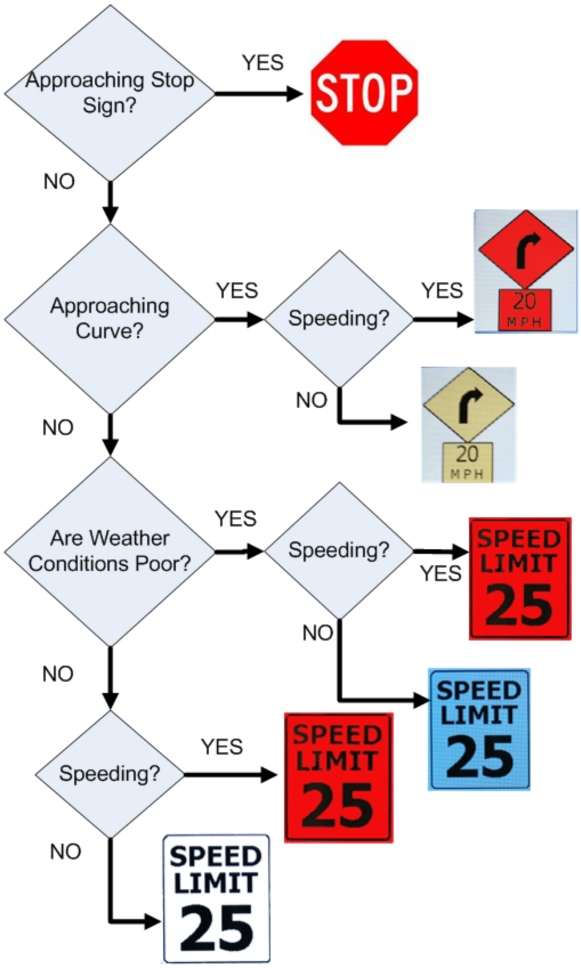


Figure 4-8. System display logic.

4.2.3 Warning Parameters

Speed warnings are instigated when the phone detects the vehicle is traveling at 2 mph or more than the posted speed limit. When this occurs, a two-second timer begins a countdown. If the two-second countdown expires and the vehicle is still exceeding the speed limit parameters the phone will warn the driver via an auditory message that he or she is speeding. Once this message has been delivered to the driver, two random time intervals are selected by the system with a value between 0 and 15 s. When the first interval expires, the system provides an auditory warning to the driver that a text message will be delivered to the parents if the speeding continues. At this point, the second random time interval beings its countdown. The teen must slow down before this interval expires or the text message will be sent. The system notifies the drivers when a text message has been sent.

The random time intervals are chosen so the teen cannot “cheat” the system. If pre-determined time intervals were implemented for these warnings, the teen could learn that he or she can speed for a specific amount of time and never get caught. The stepped warning system is used to allow the teen a chance to correct the behavior before the parents are alerted. This gives the teen an opportunity to correct a behavior that he or she may not have realized they were committing (e.g., may not have noticed they were speeding), provides them with immediate feedback about a risky condition, and can reduce the number of warnings sent to parents so as to minimize annoyance.

4.3 Reporting Functions

The parental feedback features for the TDSS include two forms of feedback to parents. The first feedback source involves real-time text messages that are sent from the TDSS phone to the parent at the time an event occurs. This provides immediate warning to the parent that an infraction has occurred and the parent is now in immediate possession of the information. This facilitates the ability of the parent to address poor driving behaviors as soon as possible after receiving the information about an infraction. In this way, behaviors can be addressed immediately and the teen is not given a chance to brush off an incident without consequence.

The second feedback source is a weekly report summarizing the infractions that have occurred during a 7-day time span. Although the parent has received individual text messages for each infraction when it occurred, this summary report provides an in-depth view of the number and types of infractions that have occurred. This facilitates the ability of parents to understand what issues their teen is facing and which problems are most important to address. It also allows them to present the teen with an overview of all the infractions in one location, which provides context for discussing the deeper significance of a recurring problem.

4.3.1 Real-time Text Messages

Text messages notify the parent of driving infractions in real-time. Figure 4-9 shows the text messages that the prototype TDSS sent out during this study. A text message for a speeding infraction lists the duration of speeding violation, the maximum speed obtained by the driver during the violation, and the intersection where the violation took place. The same information is provided by text messages that pertain to driving too fast for weather conditions. A text message associated with a stop sign infraction provides the intersection location where the infraction took place. The duration of a speeding infraction in the text message may be short (e.g., a number of seconds) because of how the TDSS generates the real-time message. When it generates the messages it will send out the current period of time that has elapsed up until the message was sent. However, the final report to parents should include the full duration of the time period in which speeding occurred. This will indicate whether or not the teen responded appropriately to the TDSS warning.

From 36245
6/17/08 11:32 AM
Speed violation: 37 in a 30 for 14 seconds. Road: 17th Ave SE near the intersection of 4th St SE

From 36245
6/17/08 11:32 AM
Vehicle traveling too fast for weather conditions: 33 in a 25 for 15 seconds. Road: 4th St. SE near the intersection of 6th Ave

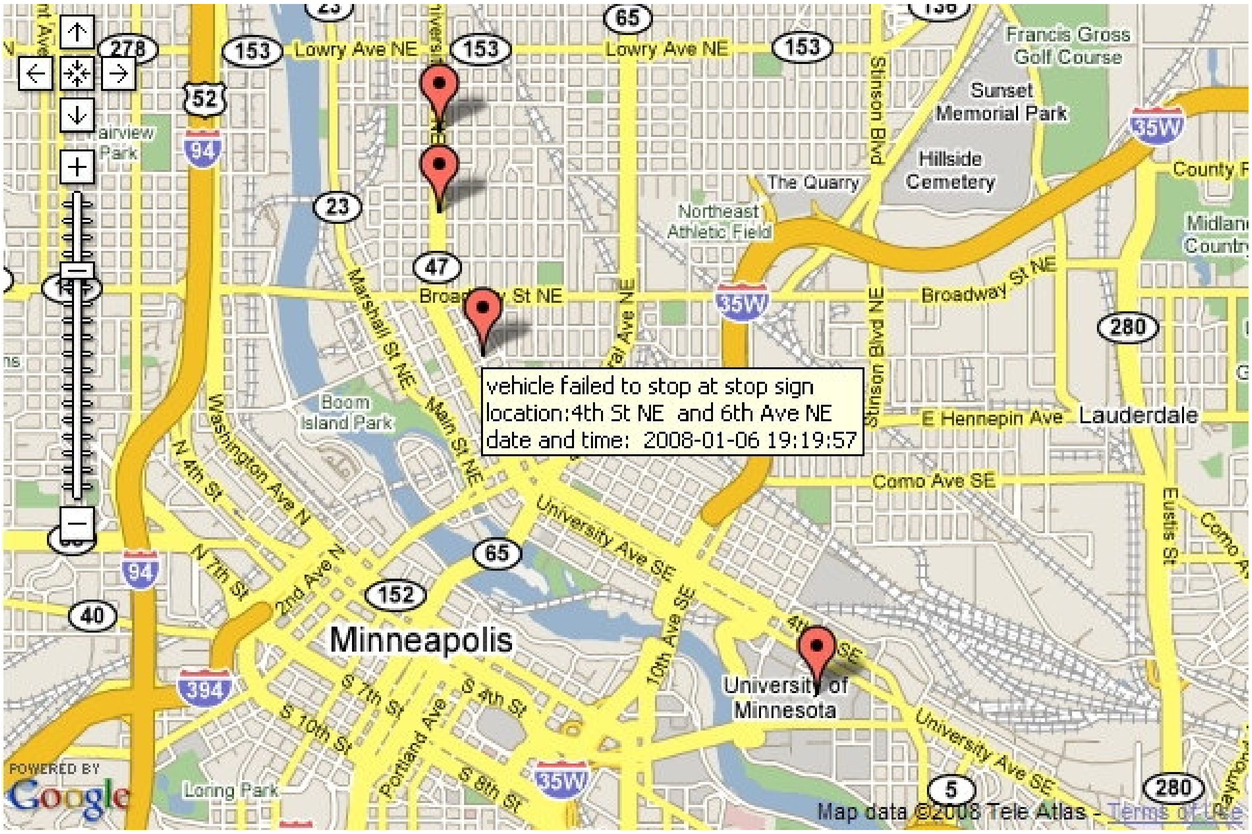
From 36245
6/17/08 11:32 AM
Vehicle failed to stop at stop sign. Location: 5th Ave NE and 4th St. NE

Figure 4-9: Text messages sent out by the prototype TDSS.

4.3.2 Prototype Parental Report and Interface

In the current study, a prototype reporting system was created to demonstrate the ability of the TDSS system to generate reports for parents. This current version is not an all inclusive reporting function for parents. This prototype reporting feature plotted infractions on a web-based map and included the same information that was included with the text messages.

The TDSS phone logged infractions in a Comma Separated text file (CSV file) within the phone. This log was automatically uploaded to a web server via File Transfer Protocol (FTP) after every driving session. The information within the text file that was uploaded to the server was put into a PostgreSQL database (see Appendix G). The information from this database can be remotely accessed from any internet connection. A typical scenario for this type of database involves a parent who is interested in seeing if his or her teen is driving safely. The parent would securely log online using his or her username and password and view the teenager’s driving infractions plotted on a Google Map. Every infraction that was plotted on the Google Map also had a description of the infraction. To view a description, the mouse curser was placed over the location marker and the description appeared in a yellow box. The descriptions are short versions of the text messages that were sent for an infraction. Examples of the current TDSS reporting feature are shown below (see Figure 4-10).



vehicle failed to stop at stop sign
location:4th St NE and 6th Ave NE
date and time: 2008-01-06 19:19:57

Figure 4-10. Stop sign violation.

4.4 Maps and Databases

Digital maps and databases are a vital component of TDSS because they provide the information required to enable the system to know its location in relation to road features such as speed limits, curves and stop signs. Without real-time utilization of such databases, the TDSS would not be possible. The TDSS utilizes a digital map in order to match longitude and latitude data from the GPS unit to a specific road identification number and mile marker. The digital map is stored on the phone as a Standard Query Language (SQL) Mobile database and is queried once a new position is provided by the GPS receiver.

The TDSS uses an onboard feature database that contains the speed limit of the road on which the vehicle is traveling. The database essentially relates a road identification number along with a mile marker range to a speed limit. This database details about 800 miles of speed limits within Hennepin County. (Speed limit spatial location resolution is within 53 ft (16 m).)Because different types of roads within Hennepin County fall under different jurisdictions, this speed limit database was built with resources provided by both MN/DOT and Hennepin County.

The stop sign and road curve databases are prototypes that relate the road identification number and mile marker position to a stop sign and road curve. The road curve database also contains data that pertain to the curve direction and speed limit. The TDSS uses its known location from the digital map and references the road curve and stop sign databases to detect if the vehicle is approaching a curve or stop sign.

Features such as speed limits, stop signs, and road curves are kept in separate databases so that the digital map can be independently updated from commercial sources. If all of the features were stored within the digital map, it would make updating the database very difficult to manage. Also, because some municipalities may not create all of the feature databases, the TDSS can still utilize the databases that exist in the local region.

4.5 Software Architecture

The TDSS software is comprised of seven threads running simultaneously. Figure 5-4 shows how these threads communicate with one another within TDSS. Two threads continuously mine data from the GPS receiver and OBDII port. The GPS thread provides longitude and latitude data to the map matching and weather threads. The OBDII thread provides speed data to the global monitoring thread. A full description of the software, maps and database architectures are located in Appendix E.

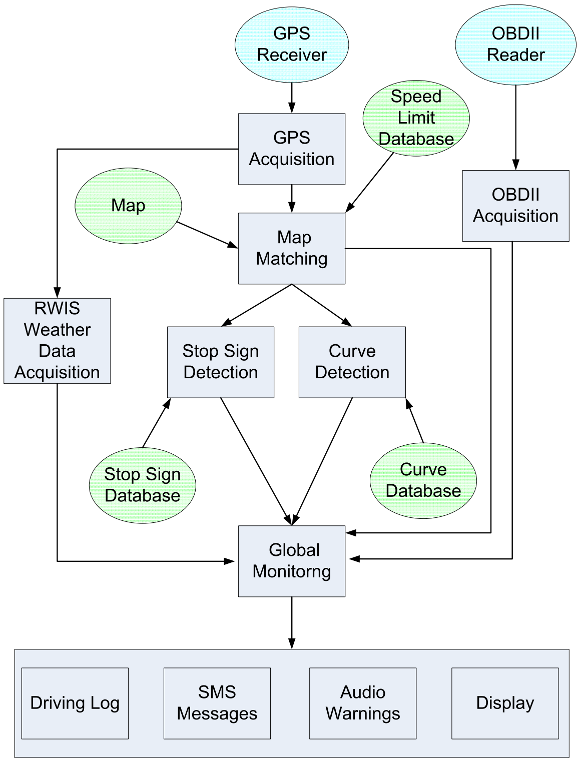


Figure 4-11. TDSS software architecture.

The map matching thread acquires data from the GPS acquisition thread and map data from the on-board database. The map matching thread calculates the most probable road the vehicle is located on, along with a mile marker position that signifies how far along the road the vehicle is located. The map matching also uses the road and mile marker position to obtain the current speed limit from the speed limit database.

The RWIS weather thread acquires longitude and latitude data from the GPS acquisition thread and connects to the nearest RWIS weather station. The most recent weather data are downloaded every 10 minutes via EVDO. The thread analyzes this data to see if a speed limit reduction is needed. The road curve detection and stop sign detection threads use road and mile marker data from the map matching thread to check if the vehicle is approaching a curve or stop sign.

The global monitoring thread takes in data from the OBDII acquisition, weather, stop sign detection, road curve detection, and map matching threads and decides if the vehicle is speeding. This thread is responsible for playing audio warnings, displaying the warning icons, sending out text messages, and keeping a detailed log of driving infractions.

5 TDSS Pilot Field Study

A small-scale pilot field study was conducted with local teen drivers to demonstrate the functionality of the system and to identify potential changes in behavior associated with the system. Additionally, subjective data was collected to capture the teens' impressions of the TDSS. Overall, the system performed reliably within the test circuit and warned drivers of speeding, curves and stop signs. The system also simulated a weather alert during the drive.

5.1 Participants

Sixteen licensed drivers (15 male; 1 female) aged 18-19 were recruited from the University of Minnesota campus and nearby high schools. Twelve of the participants were college students and four were high school students. Among the group, there were a total of 11 moving traffic violations, where 10 were due to speeding and 1 was due to inattentive driving. There were a total of 7 accidents reported by the group where the participant was considered the at-fault driver. There were five rear-end collisions, one loss of control of a vehicle on a curved road, and one collisions with a stationary object while reversing. This sample was not representative of the teen novice driver population in age or driving experience and, instead, represents a sample of convenience for the purposes of testing the TDSS hardware, software and interfaces for system reliability. It is expected, however, to provide insight into how teens may interact with and perceive such a device in their vehicle.

5.2 Procedures

Participants completed the informed consent process prior to beginning the study tasks. The teen participants drove an 8.7-mile circuit in Hennepin County (see Appendix H) twice in normal traffic conditions under the supervision of a research coordinator. The circuit took about 30 minutes to drive and the vehicle driven was a 2000 Toyota Camry LE equipped with the TDSS. This route was chosen because it offered a variety of road conditions, such as curves, stop-controlled intersections and various speed limit changes. Participants were familiarized with the vehicle and the TDSS before beginning the test drives. The first drive was a baseline drive without the TDSS. The second drive occurred with the TDSS activated. The cellular phone was mounted on the dash so that it was in plain view of the driver (see Figure 5-1). After both drives were completed, participants were asked to fill out questionnaires designed to gauge their subjective perceptions of the TDSS system.

Figure 5-1. TDSS in the vehicle.

5.3 Vehicle Data

Driving data was recorded during both runs at a rate of 1 Hz. The velocity of the vehicle, speed limit, and curve presence were written to a comma delineated CVS file. Because speeding is the most common behavior warned of by the TDSS, it was used as the main measure in this study. Speeding was considered to have occurred when the participant exceeded the posted speed limit or when the participant had exceeded the limit by 5 mph. Average speed and maximum speeds obtained on the circuit with and without the TDSS activated were examined.

5.4 Results

5.4.1 Driving Performance Data

Overall, the TDSS had a small effect on teens' speeding behavior in this study. The mean percentage of the circuit covered while speeding was determined for each driver. On average, 30.9% of the circuit was traversed while speeding without the TDSS, whereas only 18.2% of the circuit was traversed while speeding with the TDSS. This difference was statistically significant, $t(15)=4.39$, $p<.01$. The percentage of the circuit travelled at five miles per hour or more over the speed limit with and without TDSS was also investigated. Overall, drivers were less likely to exceed the speed limit by 5 or more miles per hour when the TDSS was active ($M=0.94\%$; $SD=0.67\%$) compared to the drive without TDSS ($M=3.89\%$; $SD=5.69\%$), $t(15)=2.05$, $p<.05$.

Because the system provided advance warning of curves, the percentage of the curved circuit travelled above the speed limit with and without TDSS was examined. Overall, the percentage of curved sections of roadway in which speeding occurred without the TDSS was 17% (SD=13.8%) whereas only 6.74% of curved sections experienced speeding when the TDSS was active, $t(15)=2.69$, $p<.01$.

The TDSS (both auditory & visual interfaces present during drive) also had an effect on reducing the maximum speed obtained by the teen drivers in each speed limit zone. Table 6-1 shows the average maximum speed obtained in each of the different speed limit classifications found on the circuit. There were statistically significant differences in the mean maximum speed in each of the speed zones with and without the TDSS (see Table 5-1). Although these differences are not practically large (e.g., represent about 1 mph faster without TDSS), the trend indicates that the participants were adhering to the TDSS information about speed zones and speeding.

Table 5-1. Average maximum speed for different speed zones on the driving circuit.

	With TDSS		Without TDSS		
Speed Limit mph (km/h)	Average Max Speed mph (km/h)	Standard Deviation mph (km/h)	Average Max Speed mph (km/h)	Standard Deviation mph (km/h)	T-test Results
20 (32.2)	21.9 (35.2)	1.61 (2.59)	22.6 (36.4)	1.96 (3.15)	$t(15)=1.79$, $p<.05$
30 (48.3)	37.5 (60.3)	2.06 (3.32)	38.7 (62.3)	2.56 (4.12)	$t(15)=1.83$, $p<.05$
45 (72.4)	47.0 (75.6)	2.60 (4.18)	48.9 (78.7)	1.97 (3.17)	$t(15)=3.41$, $p<.05$

5.4.2 Subjective Data

Participants rated their perceived level of effort involved in attending to and adhering to TDSS messages while driving. The Rating Scale of Mental effort (RSME) provides anchor points to help individuals gauge how much effort they needed to complete a task (Ziljstra 1993). The average rating of effort for interacting with the TDSS while driving was 23.2 (SD=10.6). This corresponds to a low level of workload to use the TDSS while driving as the 25 rating on the RSME scale is anchored as “a little effort”.

Participants were asked to specify their attitudes toward specific TDSS feedback features on a scale from 1-5. A score of 1 or 2 indicated that the feedback function was annoying. A score of three was as a neutral feeling towards the feedback, and a score of 4-5 meant they thought the feedback function was useful. Table 6-2 summarizes the teens’ attitudes for each feedback function. The majority of participants expressed either neutral or positive feelings towards all of the feedback functions.

Teen participants generally thought the audio feedback was more annoying than the visual feedback. There are two likely reasons for this finding. First, it could be due to the fact that it is much easier to ignore the visual feedback because the driver can simply choose not look at the display. Second, it might be caused by the way the teen drivers interpret the different types of feedback. Visual feedback may be seen as more passive or informative while audio feedback may be come across as intrusive or “yelling” at the driver. The annoyance level for each type of warning modality should be investigated further in future research.

Over 80% of the participants indicated that they felt the system improved driving safety, but half of the teens felt the system made driving more stressful. Additionally, nobody thought the system was unreliable, and only one teen felt the system required extra training to use. Although teens may have found the system annoying when it alerted them to speeding issues, it is not the system’s job to monitor the vehicle’s speed at all times for the driver. The teen must learn to self-monitor and the warnings serve as reminders that they are not monitoring their speed. It is important that the TDSS warnings facilitate but not replace the driver's ability to learn how to scan the vehicle's displays and the environment so they can learn to self-monitor their own behavior.

Table 5-2. Percent of drivers who felt the TDSS features were annoying or useful.

Feedback	Annoying (%)	Indifferent (%)	Useful (%)
Speed Limit Display	6.3	25.0	68.8
Road Curve Display	18.8	25.0	56.3
Stop Sign Display	6.3	43.8	50.0
Audio Speed Limit Warning	37.5	12.5	50.0
Audio Curve Warning	31.3	25.0	43.8
Audio Weather Warning	18.8	18.8	62.5

5.5 Pilot Study Conclusions

Overall, the pilot study demonstrated that the TDSS could operate effectively within a vehicle driven by a teen driver. Warnings and messages were presented to the drivers and corresponding text messages were sent when drivers failed to alter their behavior in relation to a warning. The performance data trended in the direction expected, with the TDSS encouraging lower speeds and less speeding overall. However, the study is not a comprehensive examination of how behavior changes in relation to the presence of the TDSS. The changes observed here appear to be related to the warnings, but the overall level of compliance expected with such a technology cannot be determined from this small test. The participants in this study were experienced, older teen drivers who knew they were in a research experiment. The combination of experience, short driving circuits and presence of a researcher in the vehicle likely influenced their desire to comply with the system.

The teen participants self-reported that very little mental effort was required to interact with the TDSS while driving, but they also reported the system increased their perceptions of stress while driving. Based on their comments, the reported stress appears related to their perception of the system's annoyance, particularly in relation to the auditory warnings. In future studies, measures of stress, including objective measures (e.g., time eyes are off road; time eyes are on interface, etc) should be included to determine the level of stress experienced by drivers using the TDSS and to identify, if possible, the causes of that stress.

Ultimately, a detailed field study with the TDSS is required before determinations of behavior changes and opinions about the system can be effectively generated. Future studies should also seek to identify any unwanted behavioral adaptation associated with the system. For example, drivers should show a reduction in warnings over time as they learn to self-monitor their behavior based on the feedback received from the system rather than simply learning to rely on speed warnings before adjusting their behavior. In the first case, the number of warnings presented to drivers would decrease over time. In the second case, the number of warnings presented to drivers would stay the same over time, but the number of text messages sent to parents would decrease because the drivers are using the initial warning to modify behavior rather than monitoring their own behavior while driving.

6 Proposed TDSS System Design (Future Work)

Ideally, the TDSS would support or have the ability to prohibit most behaviors known to increase the risk of crashes, injury or death for teen drivers. Based on the results of the current research demonstrating that a mobile device can be used as the basis for the TDSS, an ideal set of requirements for the TDSS was proposed for development and testing. This proposed system will provide the basis for the next part of this report.

First, the proposed system requirements will be used to develop the prototype text messages and reporting features that will be used by parents. Second, these requirements will be used to highlight how TDSS can be used in support of currently existing GDL programs.

The proposed requirements for the TDSS are:

- Sensing driving location and time-of-day along with biometric confirmation of the driving teen and supervising adult
- Sensing presence of passengers using low-profile weight sensors in seats. Only passengers (e.g. adults, siblings) pre-screened by parents would be allowed (at the appropriate stage in the GDL) based on biometric confirmation.
- Seat belt compliance using remote sensor switch.
- Restriction of incoming cell phone calls and management of outgoing calls (limited to 911) based on smart phone technology.
- Alcohol detection and ignition interlock if alcohol is detected.
- Sensing speeding events in relation to posted local speed limits and prevailing weather conditions.
- Sensing aggressive driving events in relation to rates of deceleration and acceleration.
- Geofencing to prohibit teens driving at times, locations, and routes other than those specifically approved by parents.
- Monitoring system that automatically notifies parents that their teen has arrived at an approved destination.

7 Proposed Parental Feedback Features and Interfaces

As discussed, the parental feedback features of the TDSS come in two forms: real-time text messages when an infraction is identified and a weekly summary report. Based on the TDSS requirements listed above, a more detailed description of the messages and reporting features can be developed for the system. The text messages will encompass the full range of driving situations that are restricted in most GDL programs. These include nighttime driving restrictions, seat belt use, passenger restrictions and impaired driving. Reporting features will provide a detailed look at the types of infractions and may also provide a short analysis or tools for parents for handling teen driving situations.

7.1 Real-time Text Messages

The proposed TDSS system can be set up to alert parents about possible infractions, including the presence of alcohol, lack of seat belt use or presence of passengers in the vehicle. Table 7-1 shows the proposed monitoring to be conducted by the TDSS, the proposed associated text message content, and an example message for each situation. In general, the reporting features proposed here have not been tested. Future research is needed to understand how parents accept real-time monitoring and how they respond to the monitoring and summary report information when it comes to enforcing or mentoring teen driving behaviors and situations.

Table 7-1. Proposed TDSS monitoring and associated text messages.

Proposed Monitoring	Proposed Text Message Content	Example Message Text
Speeding (General)	• Time duration of incident (at time text message is sent) • Maximum speed attained during incident • Speed zone information (actual speed limit) • Closest intersection where incident occurred • Time stamp (date/time)	Timestamp. Speed violation: 37 in a 30 mph zone for 14 seconds. Road: 17th Ave SE near the intersection of 4th St. SE.
Speeding (Curve)	• Time duration of incident • Maximum speed attained during incident • Speed zone information • Closest intersection where incident occurred • Time stamp (date/time)	Timestamp. Speed violation: 40 in a 25 mph zone for 10 seconds. Road: I-35W at I-694.

Speeding (Weather—too fast for conditions)	• Time duration of incident • Maximum speed attained during incident • Speed zone information, including "weather alert" • Closest intersection where incident occurred • Time stamp (date/time)	• Timestamp. Vehicle traveling too fast for weather conditions. 33 in a 25 mph for 15 seconds. Road: 4th St. SE near intersection of 6th Ave.
Stop Sign Violation	• Stop Sign Violation text • Intersection location • Time stamp (day/time)	• Timestamp. Vehicle failed to stop at stop sign. Intersection: 5th Ave NE and 4th St. NE.
Alcohol monitoring	• Alcohol detected in driver • Time stamp (date/time)	• Timestamp. Alcohol detected by vehicle sensors. • Note: interlock is functional so teen is not able to drive, but presence of alcohol and an attempt to drive is still communicated to parent.
Seatbelt compliance	• Seat belt not detected in use • Time stamp (date/time)	• Timestamp. Seat belt not engaged during drive.
Driving during GDL Curfew	• Curfew violation • Time stamp (date/time)	• Timestamp. Driving after GDL curfew.
Passenger monitoring	• Passengers detected in vehicle • Number of passengers detected • Time stamp (date/time)	• Timestamp. 3 passengers detected in vehicle.
Destination Arrival	• Arrival of teen at approved destination (e.g., work, school event)	• Timestamp. Teen has arrived at [approved destination].

7.2 Parental Summary Report Information and Interface

The smart phone TDSS prototype demonstrated that the system could save, download, and organize driving infractions. However, the map-based report generated by the current TDSS prototype is not sufficient in and of itself to serve as a weekly report for parents. The summary report and interface must provide summarized information for a number of events in a manner that encourages parents to engage their teens in safe driving discussions and to enforce restrictions if necessary. The results of the DriveCAM study co-conducted by the University of Iowa and the University of Minnesota HumanFIRST Program indicated that parents were not always diligent in reviewing the weekly event feedback with their teens (McGehee, personal communication). Therefore, the report design must afford parents an easy opportunity to discuss the weekly list of infractions with their teens in a meaningful manner.

7.2.1 Report Content

An ideal report format should contain several types of information for parents that can be navigated easily, such as in a web-based format where clicking on different tabs or locations brings up new information or more details. The main page of the weekly report should consist of a short summary of the weekly events. This page should not overwhelm parents with the details of individual infractions, but instead make it easy for them to identify larger problems or issues with their teen's driving behavior that have been detected by the system. This page might highlight 1-3 issues related to safety that were identified by the TDSS over the week. These issues could be selected based on the number event types that occurred (e.g., speeding) and the events' criticality to safety (e.g., based on crash risk). For example, a teen that had 10 speeding infractions might have speeding flagged in the summary report because speeding is known to increase the risk of a crash. Alternatively, a teen that ran two stop signs might have stop sign infractions flagged because running a stop sign raises the risk of a crash. Limiting the number of issues in the summary allows parents to focus on safety critical aspects of their teen's driving behavior. It also means they do not have to wade through the individual infraction reports to get a feel for what their teen is engaging in while driving.

In association with this main page, it is recommended that "talking points" or links to key information about teen driving safety be highlighted for parents. Talking points related to the weekly summary would provide parents with facts and information about how to discuss the unsafe behaviors with their teen. It is one thing for a parent to say "Speeding is dangerous" and another thing entirely for the parent to have data, crash statistics or appropriate conversation material available for having the "speeding is dangerous" conversation with their teen. Links to websites with information could also be a useful tool for both parents and teens to view together. For example, this information could include links to crash statistics for teen drivers (and causes) or could include information about the financial costs of receiving a ticket for speeding or reckless driving and how tickets may affect keeping one's probationary license during the GDL phase of licensure. Overall, it is important that the information be relevant to helping parents discuss safety issues in a number of ways that may influence teens to adopt safer driving behaviors and avoid risky situations. Having this information available within the reporting system or through web links means the parents do not have to rely on themselves to seek out information and may increase their desire to review the weekly TDSS information with their teen.

Alternatively, the main summary page can also be used to highlight safe driving behavior when a driver has few or no infractions for the week. In this situation, the talking points might remind parents to praise their teen for adopting safe driving behaviors and adhering to the GDL requirements. Parents could link to information about driving contracts or ways to motivate safe driving through rewards and consequences, but the reporting system should not dictate how (or if) parents should choose to reward or discipline their teen based on driving behavior. The goal of the summary report is to provide parents with information or tools they can use in support of their teen's driving behavior. Motivating parents to be involved with their teen driver and to engage in appropriate communication related to safe driving is a difficult task (Foss, 2007), but parents will engage in setting limits on their teen drivers when they are provided with the information and tools to support the process (see Simons-Morton, 2007 for a review). Additionally, families participating in these types of programs tend to report high levels of satisfaction with the program while the teen drivers themselves report fewer risky driving behaviors.

The supplementary information of the report would include a page that lists the weekly infractions in a table and allows parents to link back to previous reports. Infractions could be grouped on the page by type (e.g., speeding) or chronologically for the week. Table 7-2 shows the characteristics that could be displayed for each infraction. It should be noted that extra information may appear for an infraction on the weekly report that does not appear in the proposed text message format. For example, the proposed stop sign violation text message does not include the speed zone for the roadway approach or the speed of the vehicle when it ran the sign. This information could be important for determining how critical an event is to safety. For example, running a stop sign at less than 5 mph is a common occurrence whereas running a stop sign at the current road speed (e.g., 30 mph) could signal a dangerous situation due to inattention or risk taking.

The report should also include a map page like the one demonstrated in the prototype TDSS. Parents could navigate to this map by clicking on an individual infraction to see exactly where it occurred. A map helps parents identify where their teen is driving and whether they are adhering to parental expectations about where their teen is going with the vehicle.

Finally, the report should include indications of how well the teen is complying with GDL requirements. A page dedicated to the GDL requirements can show the infractions specifically related to GDL. For example, the alcohol, passenger and curfew violations would be specifically listed here. This page would always display the current set of GDL restrictions and whether the teen is in compliance. It could also discuss legal consequences of violating GDL restrictions if caught by law enforcement. Because GDL programs are difficult to enforce by authorities, it is typically up to parents to be aware of the requirements and ensure their teen adheres to the restrictions. Inclusion of a GDL monitoring section within the TDSS could empower parents to enforce the limits of the program with their teen driver.

Table 7-2. Description of potential monitoring data to be included in weekly report.

Monitored Data	Summary of Infraction
Speeding (General)	• Full time duration of incident (might be same or different from duration in original text message) • Maximum speed attained during incident • Speed zone information (actual speed limit) • Closest intersection where incident occurred • Time stamp (day/time)
Speeding (Curve)	• Time duration of incident

	• Maximum speed attained during incident • Speed zone information • Closest intersection where incident occurred • Time stamp (day/time)
Speeding (Weather—too fast for conditions)	• Time duration of incident • Maximum speed attained during incident • Speed zone information, • Weather alert information broadcast by RWIS or from alternate weather source • Closest intersection where incident occurred • Time stamp (day/time)
Stop Sign Violation	• Stop Sign Violation text • Intersection location • Time stamp (day/time) • Speed zone on approach to stop sign* • Vehicle speed at time stop sign was run*
Alcohol monitoring	• Alcohol detected in driver • Time stamp (date/time)
Seatbelt compliance	• Seat belt not detected in use • Time stamp (date/time)
Driving during GDL Curfew	• Curfew violation • Curfew times (midnight-5 a.m.) • Time stamp (date/time) • Identified as an infraction when geofencing is violated or supervisory adult not detected in vehicle via biometric sensing
Passenger Monitoring	• Passengers detected in vehicle • Number of passengers detected • Time stamp (date/time)
Destination Arrival	• Notification that teen has arrived at approved destination

Asterisks (*) indicate information that does not appear in text message.

The report content proposed above provides parents with feedback about the teen's performance (e.g., good, bad, better, worse), the adherence to mandatory requirements set out in GDL, and with tools or information useful for communicating and setting limits on teen driving that may reduce risky behaviors and situations. It is hoped that a report structured in this manner will meet the needs of parent who are using the TDSS to assist in supervising their teen's driving behavior. The one issue this reporting feature cannot address for parents is what the rewards or consequences might be for behavior logged by the TDSS. The selection of rewards and consequences will be unique to families. The best the report can do is to provide tools and information about the strategies (e.g., driving contracts) parents can use to encourage appropriate behavior from their teen driver.

7.2.2 Report Interface

Currently, the reporting feature of the TDSS is envisioned as a web-based report that will be accessible to parents via a secure website. Data is stored locally on the phone and uploaded to a database periodically via the phone's data connection. This type of interface allows for portability and ease of reporting by the system. Some monitoring systems, such as Teen Arrive Alive (2006), already use online reporting systems where the parent logs into an online account using a password. Due to privacy and security concerns, it will be important ascertain how comfortable parents are with this form of reporting and how secure the data will be. Additionally, not all families necessarily have easy access to computers with an internet connection. Therefore, it may be necessary to devise alternative report options (e.g., paper) that will encourage wider acceptance of the technology. Ultimately, initial adopters of the technology will likely have access to a computer with internet connection, given the requirement of a cell phone to operate the TDSS software.

8 TDSS as a Support System for GDL Program Monitoring

Lee (2007) discussed the ways in which driver assistive technologies can improve teen safety, particularly when the system used to enhance proven methods for improving the safety of young drivers, such as GDL. At a minimum, in-vehicle technologies have the capability to facilitate the monitoring of a GDL program by parents by providing information about the teen's behavior and tools for discussing issues with their teen driver about GDL provisions. At a maximum, in-vehicle technologies could potentially provide a means for authorities to monitor and enforce GDL provisions for teen drivers. In this extreme case, the burden of supervision would rest with authorities and not with parents, making GDL provisions and the consequences of violating them more salient to teen drivers while removing parents completely from the role of enforcer. An alternative option to parents or authorities for monitoring teen behavior is a third-party provider that provides the TDSS monitoring as a service, most likely for a fee. This alternative places an extra financial burden on parents, but could alleviate the burden of monitoring and coaching their teen about safe driving. There are pros and cons for each of these scenarios.

8.1 Parents

Monitoring and enforcing teen driving behavior will most likely fall to parents when using these types of in-vehicle technologies. McGehee et al., (2007) noted that strict enforcement of GDL provisions via monitoring could result in an adversarial relationship between parents and teens; therefore, it is important that the system be used as more than just a means for enforcing behaviors. Ideally, the design of the system and its reporting functions would help parents become trusted mentors, guides, and advocates for safe driving rather than strictly enforcers of behavior and GDL provisions. If the system is designed with the notion of parents becoming mentors for their teens, the TDSS could be useful in achieving improved compliance with GDL provisions and a reduction in risky driving behavior without over-burdening parents. In this situation, the use of incentives and consequences for reinforcing safe driving behavior rests solely with parents. The suggested content and format for the proposed reporting summary would assist parents in making appropriate decisions about how to monitor, enforce and reward behavior, but would not specify how the parent should determine consequences and incentives. Parents would have to rely on their own knowledge of what motivates their teen.

The use of a TDSS will also reside with parents, meaning the technology will need to be inexpensive and easy to use in order to attract all types of families to the system. Reasonable availability of the system could result in the TDSS becoming the norm for many families, thus potentially reducing the overall perception among individual teens that they are being singled out by their parents.

8.2 Authorities

Ideally, if authorities (e.g,. law enforcement, Department of Vehicle Services) were able to implement the infrastructure and provide the labor required to monitor all newly licensed teen drivers during GDL requirements using a TDSS, then incentives and consequences could be handled by authorities, thus removing parents completely from the role of enforcer. This would improve the ability of law enforcement to identify GDL infractions. Currently, it is difficult to identify the difference between teens are subject to provisions versus those who are not.

In this scenario, it would be necessary for all teen drivers to receive a TDSS upon licensing so that monitoring occurs equally for all newly licensed teen drivers. Unless this occurred, there may be little incentive for families to pay into a program when enforcement of GDL regulations could not be equally applied to the entire novice teen driving population. Having one's teen uniquely linked to consequences, such as loss of licensure for certain behaviors, would not likely appear fair in light of the fact that general enforcement of GDL provisions for those without a TDSS are limited.

Another difficulty with having authorities monitor compliance is the issue of consequences and incentives. Because of the enforcement nature of these agencies, the ability to provide incentives for good driving would likely be overshadowed by the ability to provide consequences. It is easy to imagine a teen driver having their privileges reduced or revoked for driving infractions monitored by the system, but it is more difficult to identify the types of incentives authorities could provide. It is not appropriate to offer incentives that reduce the GDL restrictions from their current state because these restrictions have been shown to work and are imposed on all teen drivers for a reason (Foss, 2007). Drivers with good TDSS monitoring reports are still teen drivers, a group in which age is a known factor in crash rates, above and beyond issues associated with driving experience (Simons-Morton, 2007). An incentive program that involves earlier access to privileges, such as a reduction in the passenger or nighttime restriction or earlier full-licensure, leaves even the “good” drivers vulnerable to known risk factors simply because they fall into this age category. Therefore, it is likely that authorities would be good at enforcing GDL provisions and applying consequences for poor behavior, but determining incentives for good driving and mentoring of teen drivers would be more difficult.

Ultimately, widespread availability of the technology for all new teens with monitoring and enforcement of GDL provisions provided by authorities is a long-term ideal. The infrastructure and labor requirements for such a widespread deployment and monitoring program would be substantial. Discussions with members of the Minnesota Department of Public Safety (DPS) identified the problem of burdening an already strained infrastructure, making enforcement via monitoring systems by a recognized authority difficult in the near term.

8.3 Third-party Provider

The third option proposed for monitoring would be a third-party provider. In this scenario, the TDSS service would be available for a fee to families and monitoring would be provided by the third-party provider. It is possible to envision a registered provider who works with other agencies, such as insurance companies, to identify appropriate consequences and incentives for teen drivers using the system. For example, it may be possible to offer reduced insurance rates for teen drivers with good driving histories as monitored by the TDSS.

This scenario allows for the provision of coaching or mentoring of teen drivers by someone other than the parent, such as by a licensed driver trainer. Parents could be involved in coaching sessions and could also receive tips on how to demonstrate safe driving practices to their teen while they are driving. In this situation, the parent is removed as enforcer and instead gains an ally in the form of a driving mentor who is familiar with the risks associated with teen driving. In this scenario, widespread market penetration could result in affordable third-party options for many families. Although it does not have the widespread reach of a system maintained and managed by an authoritative body, it has the benefit of a structured reporting and coaching program that can include the parent without over-burdening them.

The infrastructure required for larger-scale TDSS monitoring and data storage could likely be developed more easily by a third-party organization than by government agencies. However, it would likely mean that TDSS monitoring would come with a monthly or annual service fee on top of the cost of the hardware. This increased cost associated with this model might make it difficult for the technology to achieve widespread use. However, parents may prefer to pay a small fee for the chance to remove themselves as primary monitor and coach of their teen's driving. In some ways, this service could be viewed as an ongoing driver training program, with the teen meeting periodically with the third-party coach to review behaviors.

8.4 Use of TDSS to Support the Monitoring of Current GDL Provisions

The proposed TDSS infrastructure already incorporates several features that are useful for monitoring currently existing GDL provisions. In Minnesota, the GDL provisions relate to nighttime driving, the number of passengers allowed in the vehicle, seat belt use, alcohol and driving, and cell phone use or texting while driving. In the proposed system, all of these can be monitored using minimal equipment in the vehicle (see Table 8-1). The prototype TDSS discussed in the first part of this report includes the ability to monitor the time of day when driving occurs and where driving occurs, which primarily encompasses the night-time driving limitation. Other features of the proposed TDSS have been developed to specifically address GDL provisions.

For example, because novice teen drivers are at the highest risk in the first 6 months of full licensure (Mayhew et al., 2003), the TDSS would ideally be implemented as soon as a teen receives their license to ensure the largest benefit to the new driver. Additionally, the system could be adapted for use in the pre-licensure phase of supervised driving where the TDSS would not only provide in-vehicle support to the learner driver but would also log the number of hours of supervised driving. This would make it easier for parents to know how much supervised driving time their teen has acquired before they obtain their license, particularly because many states require a specific number of hours of supervised driving occur before licensure (IIHS, 2008). For example, Minnesota requires 30 hours of supervised driving, 10 of which must occur at night before a teen can obtain their full license (IIHS, 2008). The TDSS would allow parents to easily obtain this data for their teen driver and provide a log of hours to Driver and Vehicle Services when applying for the license.

Table 8-1. Current GDL provisions that the proposed TDSS can support through monitoring.

Current GDL Provisions	TDSS Proposed Monitoring Capabilities
Supervised Driving Requirements Prior to Licensure	Pre-licensure supervised driving hours can be logged by the system. Biometric sensing would identify the teen driver and the supervising adult.
Night-Time Driving Limitation Midnight – 5 a.m. in Minnesota, unless: 1. accompanied by licensed driver age 25 or older 2. driving to/from place of employment or driving to/from home and a school event 3. driving for employment purposes	Biometric sensing identifies the teen driver and the system logs time-of-day of drive 1. Biometric sensing can be set up to identify other drivers, such as parents, who might be supervising late night driving 2. Geofencing can be used to ensure teen remains in designated road areas when driving to/from work or school activities. Arrival at pre-determined destination can also be set and monitored by the system, such as arriving at work.
Passenger Limitations 1. Limit is 1 passenger under age 20 for first 6 months of licensure, unless parent or guardian is present 2. Limit is 3 passengers under age 20, unless parent or guardian is present Exemptions: passengers under 20 who are immediate family	Low-profile weight sensors in seats log presence of passengers. 1. Biometric sensing can be set up to identify other drivers, such as parents, who might be supervising driving with passengers 2. Biometric sensing can be used to identify siblings 3. Biometric sensing can be used to limit the passengers allowed to ride with the teen driver at each phase of the limitation
Seat Belt Use	TDSS logs whether seat belt is latched via a remote sensor.
Cell Phone Calls and Texting	Restriction of incoming cell phone calls and management of outgoing calls (limited to 911) based on smart phone technology.
Drinking and Driving (Zero Tolerance)	Presence of alcohol is detected via sensors and an ignition interlock prevents starting the vehicle.

9 Conclusions

Overall, this research demonstrated that a TDSS could be developed to using a smart phone platform with a minimum number of components. The prototype TDSS was able to provide auditory and visual alerts to the driver as well as communicate infractions to parents in real time using text messages. The prototype also demonstrated its ability to maintain data and create usable summary reports for use by parents. Advances in cellular phone technologies, such as the open-source Android Mobile phone, provide better and more accessible platforms for running the TDSS software and successfully performing the current and proposed functions. Open source operating systems offer a greater opportunity to allow the phone to control incoming and outgoing messages and calls while the vehicle is in motion.

There are currently limitations related to the prototype TDSS. The availability of the appropriate infrastructure and resources necessary to support the mapping functionality to identify speed limits, stop signs, and curves is limited. The system requires comprehensive digital databases that contain these features and, at present, these databases exist in a limited form depending on the county or municipality involved. Other countries, such as Sweden, have recognized the benefits associated with such databases and are working towards creating them with the goal of achieving ISA deployment (Schelin, 2003). As monitoring technologies become more ubiquitous and advanced, it is hoped that the United States would see a benefit in creating, maintaining and offering these databases for use by safety technologies aimed at reducing crashes.

This study also demonstrated the TDSS to a sample of teen drivers. Although the small-scale pilot test was not sufficient to identify any potential long-term effects the TDSS could have on novice driver behavior, the data trended in the expected direction of reducing speeding behaviors. Research on other technologies that involve parental monitoring (e.g., McGehee et al., 2007) suggests that a combination of feedback to the driver and to parents can result in reductions in risky driving behavior while the device is activated in the vehicle. This suggests that if the TDSS is implemented as proposed, reductions in risky behaviors and improved compliance with GDL provisions could be seen among novice drivers using the TDSS. Future research should focus on the timing and frequency of warnings to prevent annoyance and distractions when the system is in operation. In general, intrusive technologies have been rated as less acceptable by teen drivers (e.g., Young et al., 2004) and the TDSS may face criticism from teens because of the restrictions it places on their driving. However, Lee (2007) points out that the least acceptable technology for improving safety among teens in relation to their known crash risks may be the most effective, and that teen driving culture may need to be shaped so that restraints on teen driving are considered acceptable because they improve safety. This change in culture must happen not only from the teen's perspective but from the perspective of parents as well.

Finally, this report discussed the ways in which the TDSS could be used by different agencies as a support system for ensuring teens comply with GDL provisions. Parents will most likely be the primary agents interacting with TDSS monitoring. In this situation, the technology should be developed for ease of use and available at a low cost to ensure market penetration.

Future research should be geared towards developing meaningful and usable information interfaces for the summary report. Information available to parents should be based on what has been shown to be successful in improving teen safety (e.g., driving contracts).

9.1 Future Research

- The TDSS auditory and visual warnings require further testing to determine which format is most beneficial for eliciting positive driver responses and behavioral changes, and is least likely to result in distraction to the teen driver.
- A prototype parental interface needs to be developed and then evaluated by parents to identify the features and information that best supports parent goals and facilitates the parent-teen relationship.
- While not addressed in this report, it is necessary to investigate privacy issues with regard to data generated by the TDSS.
- Once the TDSS has been fully developed it needs to be tested in a larger field study to:
    - Determine the effectiveness of the system's hardware and software in a real-world environment.
    - Determine the effectiveness of the system to promote positive changes in teen's driving behavior while the system is in the vehicle.
    - Determine how teen drivers may adapt to the system while the system is in the vehicle.
    - Determine how the parent-teen relationship may change when the system is in use.
- Because no studies exist to determine the long-term effectiveness of in-vehicle teen driver support systems once the system is removed, a study should be conducted to examine behavior immediately after system removal and over longer periods of time.

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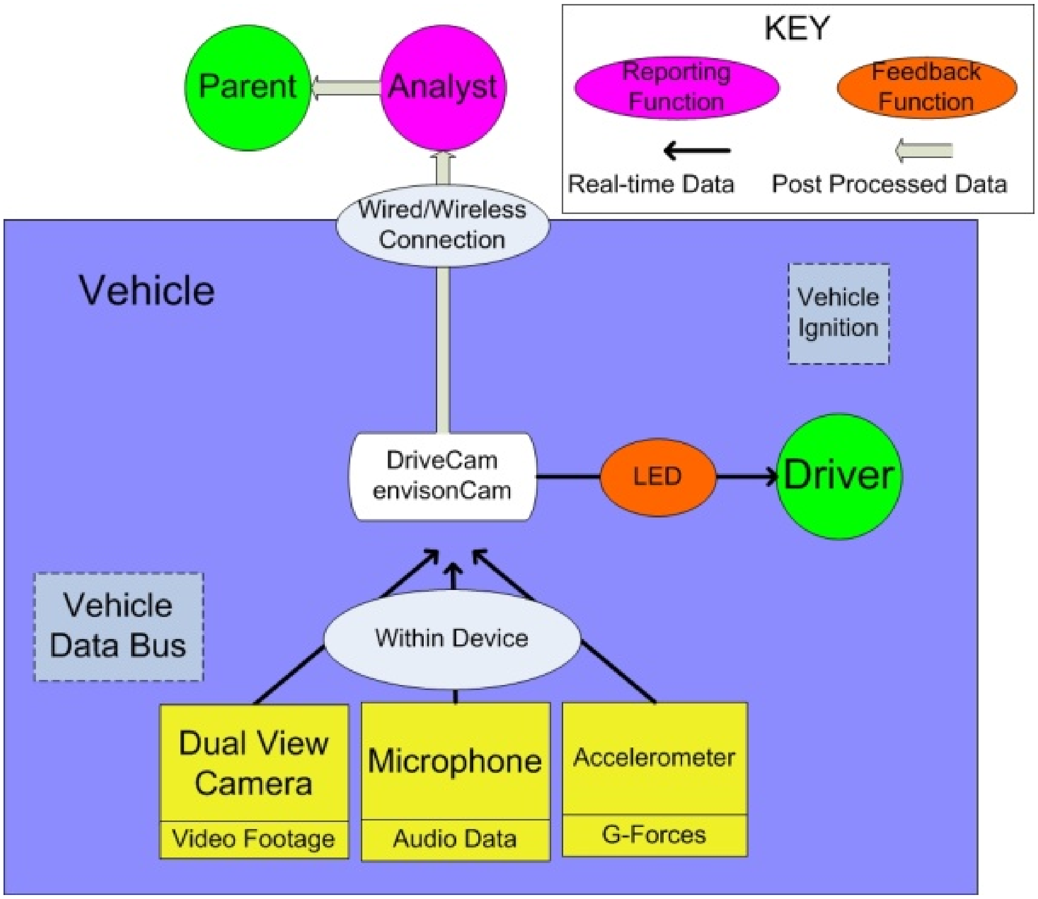
Appendix A. Review of Existing Teen Monitoring Systems

In order to show the functionality of the different classes of teen monitoring systems, a diagram that shows the "anatomy" of the system is shown. The large blue box that contains many of the items within the diagram represents the vehicle. Within the vehicle, the system can interface with the vehicle bus and vehicle ignition, as well as provide feedback to the driver. Outside of the vehicle, the system may report driving behavior to the parent. The arrows denote the data flow within the system. A single arrow represents real-time data, while a double arrow represents post processed data.

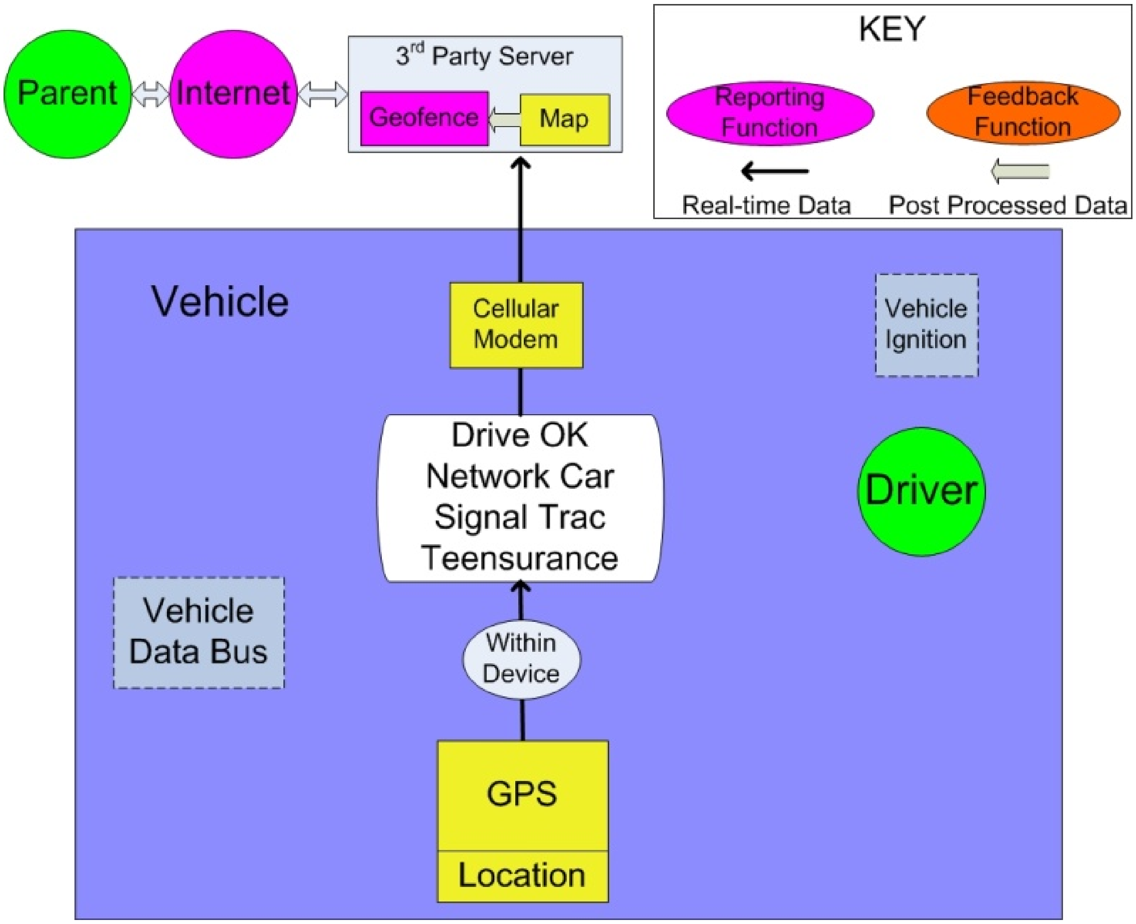
DriveCam



DriveCam

GPS-based Tracking Systems

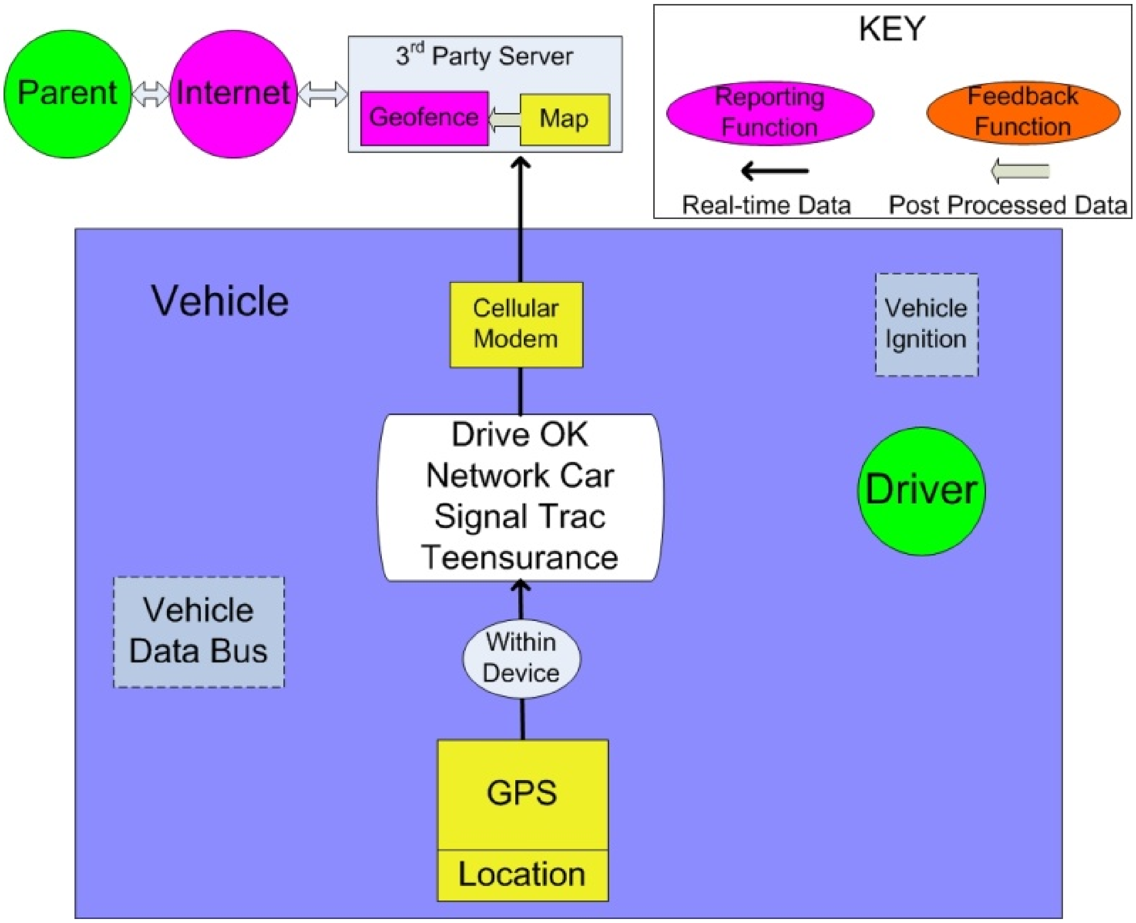
The figure below shows a common class of teen tracking systems that utilize a built in GPS receiver and cellular modem. These systems feature a web interface where the parent can securely log online and see where the teen has been and how fast they were traveling. Although such systems offer peace of mind to the parent, they do not provide any driver feedback (Drive OK 2008; Network Car 2008; SignalTrac 2008).



Systematic diagram of in-vehicle GPS tracking devices

Teen Arrive Alive

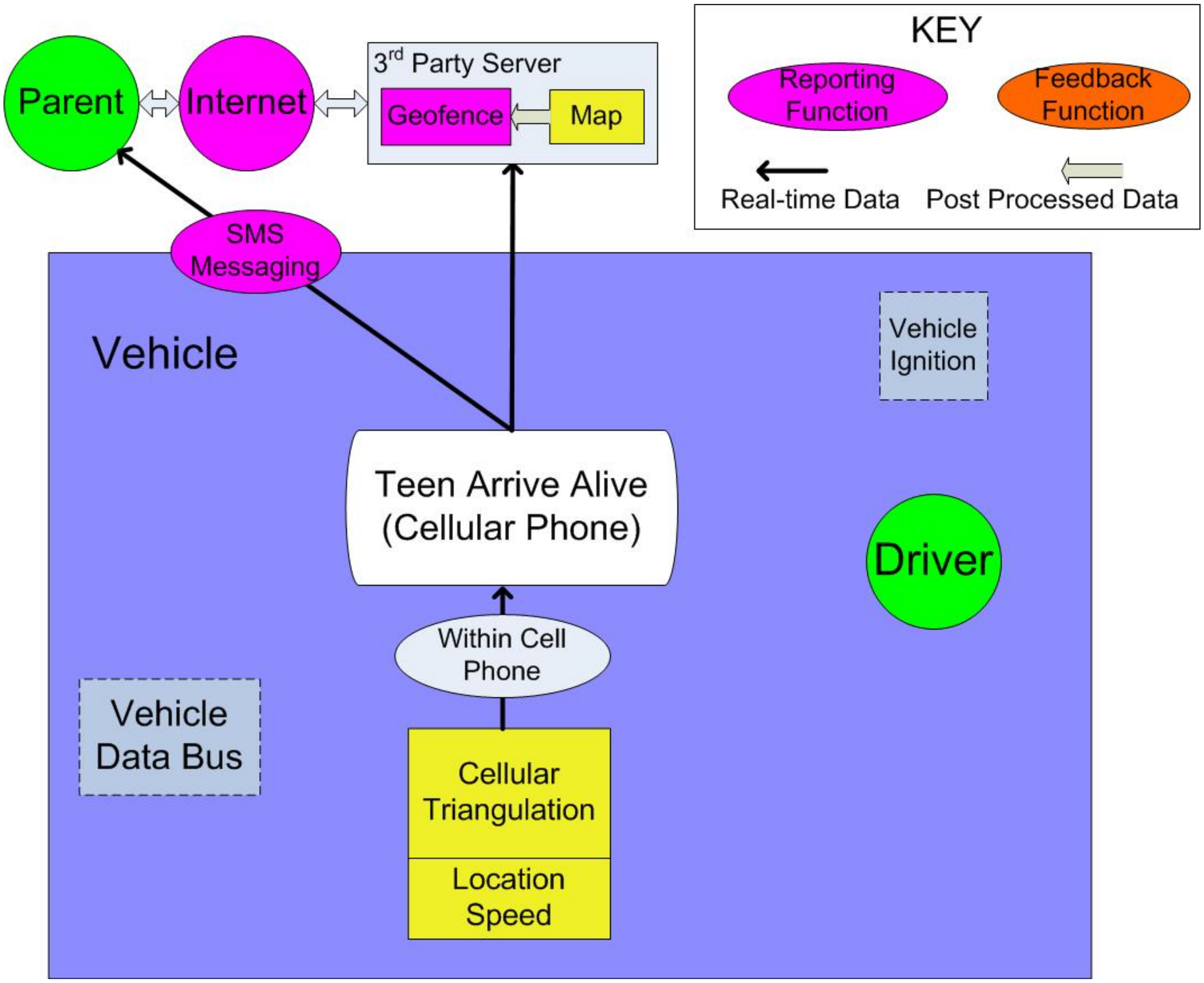
Teen Arrive Alive is a Nextel cellular phone that the teenager has in the car as he or she drives. There is no installation required as the phone does not interface with the vehicle. The system only uses data acquired from cellular phone triangulation. The system reports real-time location and speed to parents via a password protected online account. The parent sees a street level map with the teenager's current location and speed. The system has the ability to send real-time text message alerts to parents if the teenager has exceeded a predetermined speed. Again, this product does not provide driver feedback (Teen Arrive Alive 2006).



Systematic diagram of Teen Arrive Alive

Road Angel

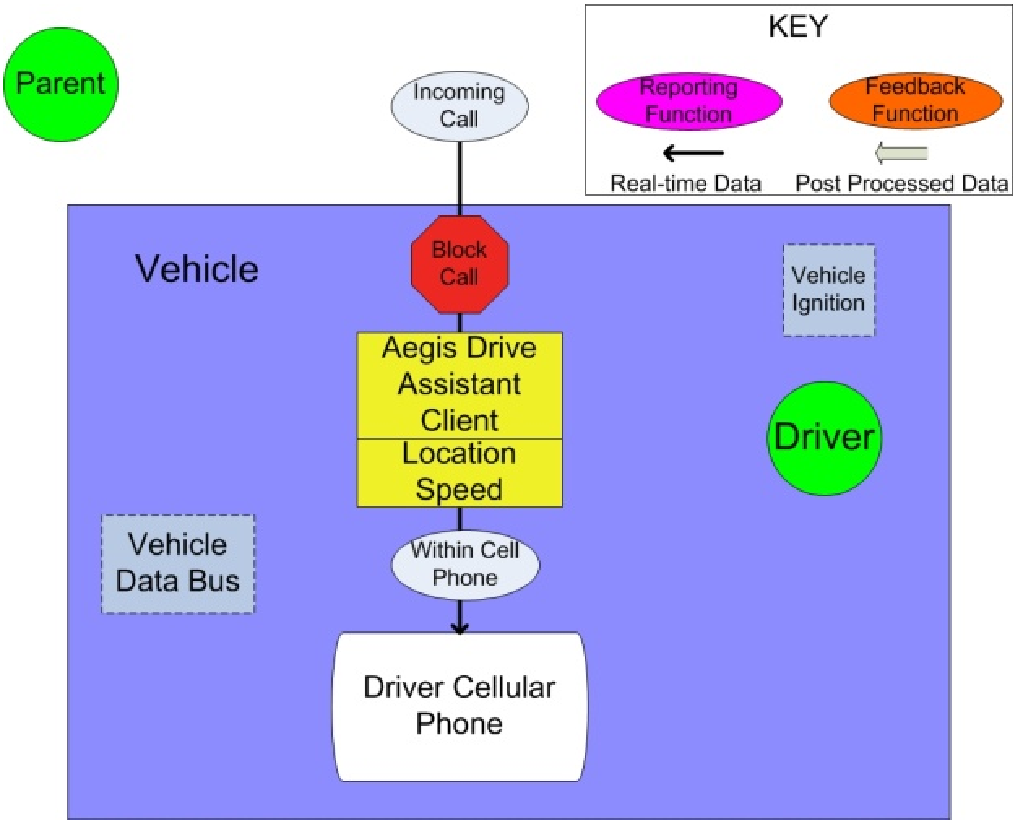
The EVO Road Angel is an Australian road safety unit that incorporates GPS technology to provide real-time driver safety alerts. The device warns the driver through customizable auditory voice generated alerts. The system has a small LCD display that can be mounted virtually anywhere in the vehicle. The unit warns the driver if he or she has exceeded a predetermined speed. The unit also warns against a large number of road hazards, including red light cameras, accident black spots, school zones, speed cameras, and railway crossings by accessing an internal Australian Road Sense Core Road Safety (ARSCRS) database. The database can be updated by connecting the device to a computer and downloading the most recent updates (Road Angel 2008).



Systematic diagram of the EVO Road Angel

Aegis Drive Assistant

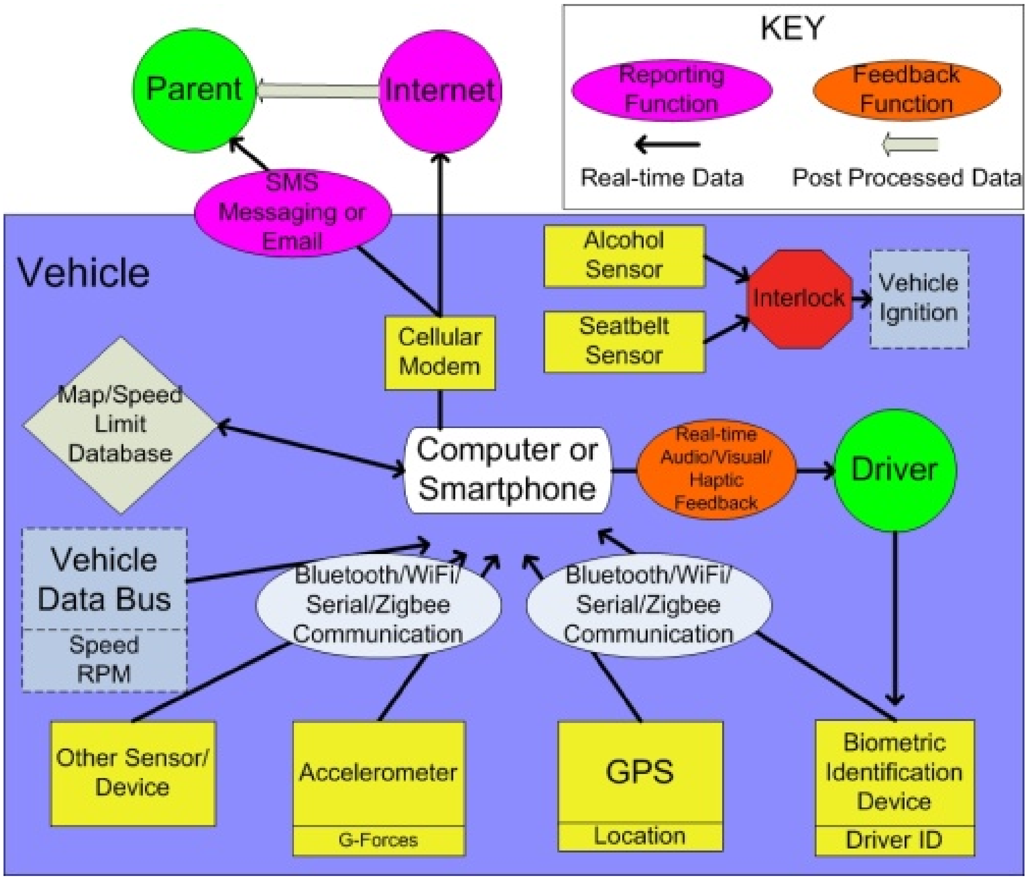
The Aegis Drive Assistant is a software client made for phones with GPS capability. The client will automatically determine if the phone is within a moving vehicle and handle all incoming calls, emails, and text messages according to the subscriber's preferences. Also, the client will not allow outbound calls or text messages to be made while the vehicle is moving (Drive Assistant 2008).



The systematic diagram of the Aegis Drive Assistant

Ideal TDSS

An ideal TDSS system provides real-time reporting to the parent as well as visual, auditory, and haptic feedback to the driver. The system also features biometric identification in order to infallibly identify the driver so teen drivers can be held accountable for dangerous driving behavior. Ignition interlocks ensure that the driver has fastened the seatbelt and is not driving under the influence of alcohol. Speed and RPM data is obtained from the vehicle's data bus, and speed limit data is obtained from an onboard database. The system could also include other sensors such as an accelerometer to detect poor handling, excessive acceleration, and excessive breaking.



Systematic diagram of an ideal TDSS

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Appendix B: BAC Detection Technologies

Breathalyzers and interlock systems have been used for over 20 years to help reduce drinking and driving. Properly administered alcohol interlock programs with medical checkups have been shown to permanently transform drinking and driving behavior (Bjerre & Thorsson 2007). However, there are some systematic problems associated with breathalyzer alcohol interlock systems. First, the test is invasive as the driver is required to breathe into the breathalyzer before starting the vehicle. Second, alcohol interlocks are rather expensive because they require professional aftermarket installation.

Transdermal BAC detection is a means of measuring Blood Alcohol Concentration (BAC) by analyzing perspiration vapor. Transdermal BAC measurement is not as accurate as a breathalyzer and usually underestimates true BAC because it takes much longer (30 minutes or more) for the alcohol to appear in the sweat (USDOT 2007). This technology is currently utilized in the Secure Continuous Remote Alcohol Monitor (SCRAM) device, which has been mandated to be worn by DWI offenders since 2004. The device is worn on the ankle and continuously monitors and records BAC 24 hours a day. SCRAM wirelessly transmits BAC data to a modem that is located within the offender's home. The modem transmits the data to the authorities so that the BAC of the offender can be closely monitored from a remote site. Currently, a smaller SCRAM device is being developed that is designed to wear around one's wrist (SCRAM 2007).

Secure continuous remote alcohol monitoring (SCRAM) device

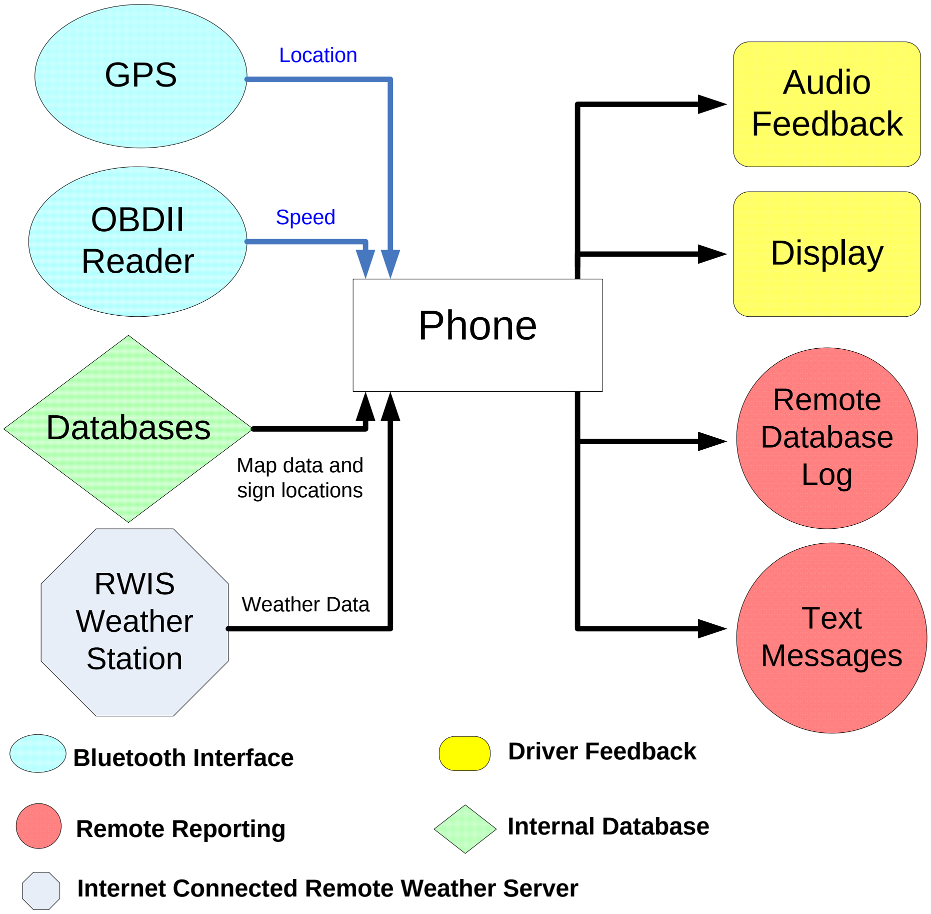
Another remote monitoring device, called the Sobrietor, measures the Breath Alcohol Content (BrAC) of the person being tested. The device uses randomly scheduled voice prompts to let it be known that it is time to take a test. As the test is taken, the Sobrietor is placed near the mouth and voice recognition software is used to identify the person who is being tested. Sensors located near the mouth piece ensure that the Sobrietor stays near the mouth so that another person cannot take the test after the identity of the testee has been confirmed (Sobrietor 2008).

Toyota is developing a steering wheel that utilizes transdermal BAC measurement technology. The vehicle will not start if sensors located within the steering wheel detect a BAC above the legal limit. The system will also continuously monitor BAC while the vehicle is being driven. The vehicle will slowly come to a complete stop if the BAC of the driver has exceeded the legal limit (MSNBC 2007).

Recent studies have shown that is possible to measure BAC by analyzing voice patterns. This is especially interesting in context of this thesis because of the possibility to integrate this technology within a cellular phone. One could imagine a cellular phone based TDSS where the driver would be asked to say a sentence which would be detected by the phone's microphone. On-board software could analyze the voice patterns to measure the driver's BAC. If the system detects that the driver's BAC is above the legal limit, the phone could use its built-in communication capabilities to automatically notify the authority. A study by Levit et al. (2001) examined the achievable accuracy rate of distinguishing intoxicated speech (>.08 g/dl) versus sober speech. The study analyzed 120 different recorded samples of speech spoken at various intoxication levels between 0 g/dl and .24 g/dl. Although the accuracy was very good when analyzing speech spoken at BACs near zero or above .2 g/dl (80 percent), the accuracy rate fell below 50 percent when analyzing speech spoken near .08 g/dl. An overall accuracy rate of 69 percent was reported.

Appendix C. TDSS Sensors and Hardware

The TDSS system utilizes a smartphone coupled with a Bluetooth GPS receiver and OBDII reader. The block diagram shown below illustrates how the phone serves as the core central processing unit that gathers location data from the GPS sensor and speed data from the OBDII port. The phone's built-in modem capabilities allow for remote communication so that the system can upload driving data to a central server and send out real-time text message warnings to parents.



System overview

Smart phone

The TDSS system utilizes a Treo 700wx smartphone running the Windows Mobile 5 operating system. Although this has not been tested, the system software could be ported to any other smartphone or PDA that runs Windows Mobile 5 and has Bluetooth capabilities. Other Windows Mobile 5 phones include the PPC 6700, the HTC 8126, the Samsung Blackjack, the Motorola Q, and the SPV M5000. The Treo 700wx has a 312 MHz processor and 64 MB of storage memory, which is enough memory to store the databases and all WAV files needed to provide auditory feedback. One of the biggest advantages of using a smartphone based system is that all of the communication hardware is built right into the device; thus, there is no need to use an external cellular modem.

TDSS cell phone

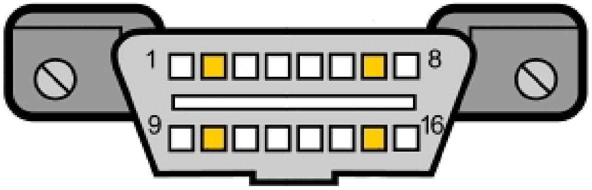
GPS

The GPS sensor provides latitude and longitude data to the smartphone so that the system knows where it is in relation to the geospatial database. The TDSS system uses a GlobalSat a BT-338 GPS receiver that utilizes the SiRF III chipset. The GlobalSat GPS unit communicates with the phone at a rate of 19200 bps and operates at a frequency of 1 Hz. The GPS unit is equipped with a 5 Volt Lithium battery which lasts about 16 continuous hours. A 12 volt cigarette lighter adapter was included so the unit can easily be powered from car.

TDSS GPS receiver

OBDII Communication Interface

Every vehicle sold in the United States since 1996 is equipped with an OBDII port. It is a 16 pin port that is usually located under the dash on the driver's side of the vehicle. The pin layout of the OBDII port in shown below.



OBDII port

There are five different communication protocols that vary between vehicle manufacturers. These are summarized in the table below.

OBDII communication protocols.

Signal Protocol	Vehicle Manufacturers	Data Speed
SAE J1850 PWM	Ford	41.6 kbps
SAE J1850 VPW	General Motors	10.4/41.6 kbps
ISO 9141	Chrysler, Most European and Asian Manufacturers	10.4 kbps
ISO 14230 (Keyword)	Chrysler, Most European and Asian Manufacturers	1.2-10.4 kbps
ISO 15765 (CAN)	Standard in the US by 2008	250/500 kbps

The TDSS system uses the Car Pal Bluetooth OBDII reader manufactured by Vital Engineering. The device uses the ELM 327 chipset, which converts the OBDII data to RS232 data, and easily integrates with all of the OBDII communication protocols. A figure of the Car Pal device is shown below.

Car-Pal Bluetooth OBDII transmitter

This device is intended to be used with proprietary software to diagnose car problems and track fuel economy. However, the TDSS uses standard OBDII parameter identification (PID) codes to gather OBDII data through the Car Pal unit that can be used independently of the proprietary software. One of the disadvantages of this device is that the bandwidth is limited. Speed data can be acquired at about 1.5 Hz; however, querying speed and RPM data slows down the data acquisition rate to 1 Hz. Querying more than one data type drastically slows down data acquisition.

The figure below shows the Car Pal unit within the vehicle. The unit plugs into the vehicle's OBDII port that is located underneath the driver's side dash.

OBDII transmitter in the vehicle

Appendix D. TDSS Supplemental Feedback Information

Auditory Feedback

The TDSS interfaces with the driver in order to convey information regarding the current driving behavior or current driving environment. The TDSS system communicates with the driver in two different manners. The phone provides auditory feedback by playing WAV files through the phone's speaker. The WAV files were created by using AT&T Natural Voice Text-to-Speech demo software available from the AT&T Lab research and evaluation website (http://www.research.att.com /~ttsweb/tts/demo.php). Other text-to-speech software was tested; however, the AT&T software produced the best audio quality.

The auditory interface informs drivers of speed limit changes, poor weather conditions, and road curves. TDSS also plays messages that warn the driver of speeding violations.

Upon startup, the system will welcome the driver by playing the following Voice Introduction Message (VIM).

VIM	"Welcome to TDSS 2.0. Please drive safely"

In order to always keep the driver informed about the current speed limit, the system will play a Voice Warning Message (VWM) that states the current speed limit.

VWM1	"Speed limit XX miles per hour"

This message is played every time the speed limit or name of the street the vehicle is traveling on changes. For example, if vehicle turns onto a street where the speed limit is 30 miles per hour, the system will play a WAV file that states "Speed limit 30 mile per hour".

If the vehicle is traveling down the highway where the speed limit changes ahead, the TDSS system will play VWM2.

VWM2	"Speed limit changes to XX miles per hour ahead"

For example, if the vehicle is traveling down the interstate in a 55 mile per hour zone and is approaching a 40 mile per hour zone, the system will state "Speed limit changes to 40 miles per hour ahead."

If the system detects that the driver is driving above 2 MPH over the speed limit for two seconds, the system will randomly select to play VWM3 or VWM4.

VWM3	"Exceeding speed limit"
VWM4	"Reduce speed"

The system will continue to play these messages until a random time interval has passed. Once this has occurred, the system will play VWM5. This message warns the driver that a text message will be sent to the driver's parents if the driver continues to speed.

VWM5	"Text message will be sent if speed violation continues"

If the driver ignores the previous message and continues to speed, the system will play VWM6. This message is played after a second random timer has expired.

VWM6	"Text message has been sent"

The TDSS system also uses auditory messages to warn the driver of upcoming curves. If the vehicle approaches a curve, TDSS will play VWM7 which informs the driver of the upcoming curve's speed limit and direction.

VWM7	"Right (Left) curve xx miles per hour"

If the vehicle speeds through the curve, TDSS will play VWM8.

VWM8	"Exceeding curve speed limit"

If TDSS has detected that the vehicle has run through a stop sign, VWM9 will be played.

VWM9	"Vehicle did not stop"

A variety of poor weather conditions are detected by TDSS and conveyed to the driver by playing VWM10-VWM14.

VWM10	"Roads may be slippery"
VWM11	"Roads may be icy"
VWM12	"Low visibility"
VWM13	"High wind potential"
VWM14	"Caution, wind advisory"

When a poor weather condition is detected, the TDSS calculates the appropriate speed limit reduction. Depending on the severity of the weather condition, the reduction can be five, ten, or fifteen percent of the current speed limit. This reduction is rounded to the nearest five miles per hour and reported to the driver by playing VWM15.

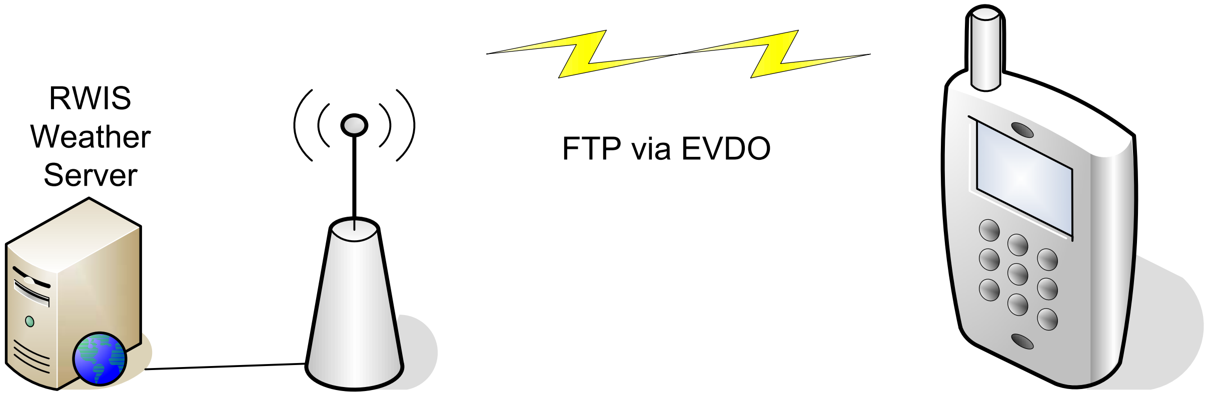
VWM15	"Speed reduction XX miles per hour"

If the vehicle speeds when a speed limit reduction is in effect, VWM16 will be played.

VWM16	"Too fast for weather conditions"

Weather Information

Every ten minutes, the RWIS weather module downloads the weather data from a remote RWIS FTP server via EVDO (ftp://rwis.dot.state.mn.us). The phone automatically provides the necessary login and password information and downloads two comma delineated text files that contain weather data from all of the RWIS weather stations in Minnesota. Only the weather data from the station that is closest to the vehicle is used to evaluate weather conditions. The first file contains atmospheric weather data such as temperature and wind velocity, and the other file contains road surface condition data such as ice coverage and depth.   The program parses the two text files and puts the relevant data into memory. A weather monitoring algorithm uses the data to calculate a speed reduction percentage depending on how dangerous the weather conditions are. This reduction is rounded to the nearest five miles per hour and subtracted from the current speed limit to calculate the weather reduced speed limit.



Wireless weather data transmission

The atmospheric file contains the visibility in feet and the precipitation conditions which include rain, snow, mixed, light freezing, freezing rain, sleet, hail, and freezing. These conditions are classified as heavy or moderate. The following tables define the speed reduction algorithm for the atmospheric weather information. These reductions are based on a number of state DOT weather reduction metrics published in a FHWA report (Goodwin 2003).

Speed limit reductions for visibility conditions

Visibility Range (ft)	Speed Reduction (%)
> 660	0%
450 - 660	15%
280 - 450	30%
< 280	45%

Speed limit reductions for atmospheric conditions

Atmospheric Condition	Severity: Reduction (%)
Rain	Heavy: 15%
Snow	Heavy: 30%; Moderate: 15%
Mixed	Heavy: 30%; Moderate: 15%
Light Freezing	30%
Freezing Rain	45%
Sleet	15%
Hail	Heavy: 30%; Moderate: 15%
Frozen	Heavy: 30%; Moderate: 15%

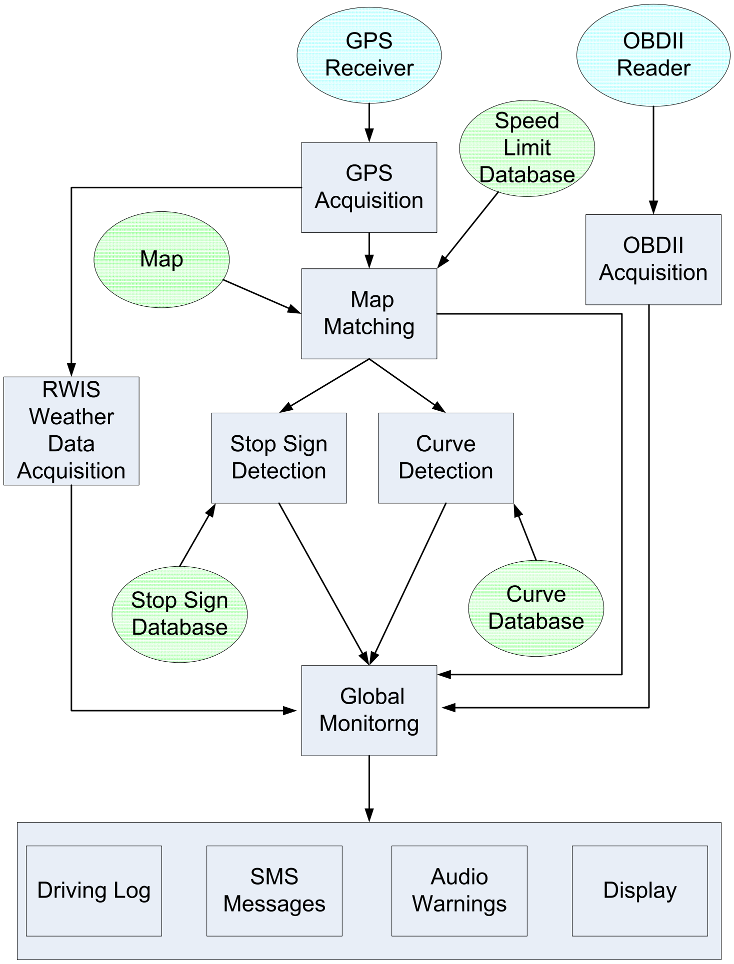
The road surface condition file includes road surface states that include wet, covered with ice, covered with black ice, or covered in snow. In order to gauge the severity of the conditions, the different road condition states are classified into the percent of road coverage or depth in millimeters. The following table shows the speed limit reduction for the different cases of severe road surface conditions. Again, these reductions are based on weather speed reduction recommendations published in a FHWA report (Goodwin 2003).

Speed limit reductions for road surface conditions

Surface Condition	Severity: Reduction (%)
Wet	Depth > 10mm: 15%
Black Ice	Coverage > 85%: 30% Coverage 50 – 85%: 15%
Wet Below Freezing	15%
Ice Warning	45%
Ice Watch	15%
Snow Warning	Depth > 10mm: 30% Depth 0 – 10mm: 15%
Snow/Ice Warning	Depth > 10mm: 30% Depth 0 – 10mm: 15%
Chemical Wet	Depth > 10mm: 30% Depth 0 – 10mm: 15%

Appendix E. TDSS Software Architecture

The TDSS software is comprised of seven different threads that run simultaneously. Two threads continuously acquire GPS and OBDII data. The map matching thread uses the location of the vehicle from the GPS acquisition thread and calculates the road the vehicle is on. Two threads are responsible for detecting stop signs and road curves, and one thread checks the local weather conditions every ten minutes to see of a speed limit reduction is needed. The last thread monitors the speed of the vehicle with respect to the local speed limit and prompts audio warnings, text messages, display icons, and infraction logging. The figure below details how these threads are incorporated within the TDSS.



Software architecture overview

Database Structures

The first task that needed to be accomplished in order to build a cellular phone based TDSS was to construct databases that could be stored on phone and quickly queried using the phone's limited processing power. The SQL mobile database standard was chosen because it had a small enough footprint be installed on the phone, and it easily integrated with the Visual Studio programming environment used to build the TDSS.

The TDSS uses four different databases that provide information regarding the vehicle's location, as well as the whereabouts of features such as speed limits, road curves, and stop signs.

The first database is a comprehensive geospatial database that defines all of the roads within Hennepin County. Two databases characterize road curves and stop signs, while the last database defines 800 miles of speed limits within Hennepin County.

Map

There are three tables within the map database. The largest table (220,000 items), pts_hennepin, includes all of the state plane Cartesian coordinates of the shape points making up all of the roads within Hennepin County. Each shape point is associated with a mile marker position, a road identification number, and a shape point index number. This is shown in the table below.

Shape point table

X Coordinate	Y Coordinate	Road ID	Mile Marker	# of Shape Points	Cell ID
3206745	866987	5324	4.3	5	2004

Preprocessing and reorganization of this database was required because the phone's limited processing power was not able index this query in real-time. In order to remedy this problem, Hennepin County was divided into one square Kilometer cells. Every point shape point within the pts_hennepin table was assigned a cell block identification number. This is seen in the far right hand column in the table above. If the table is indexed with respect to the cell identification column, queries that utilize the cell identification number are quick and can be done in real-time.

In order to efficiently query the pts_hennepin table using cell identification numbers, the identification number of the cell block that the vehicle is located within needs to be known. In order to acquire this identification number, a cell block table is used. The cell block table defines how the cells are oriented within Hennepin County. Since the cells are square, four values are needed to fully define the geometry. These values are shown in the table below.

Cell block table

X begin	X end	Y begin	Y end	Cell ID
846319	847319	299586	298586	2379

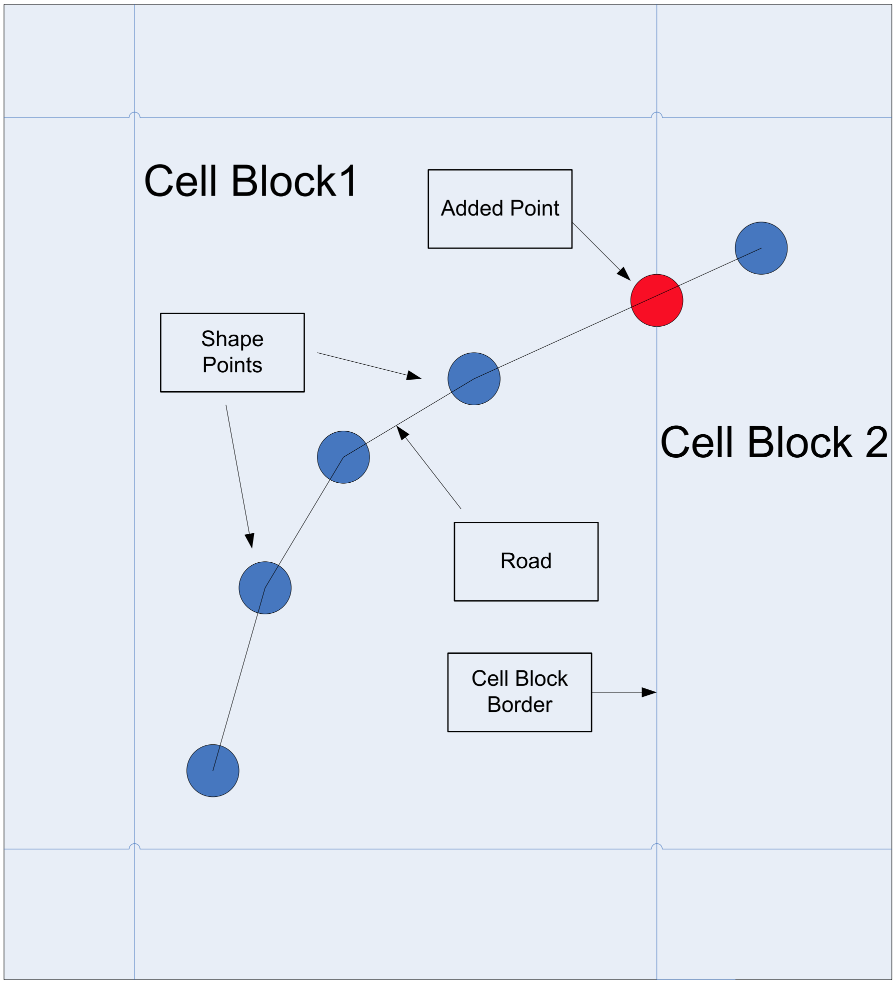
The TDSS obtains the vehicle's X and Y position from the GPS receiver and cross references this table in order to find the current cell identification number.

The SQL select statement below illustrates how the cell identification number is acquired from the cell blocks table. GPSX and GPSY are the X and Y values acquired from the GPS acquisition thread.

```
Select Cell ID from cell blocks GPSX is between X begin and X end and GPSY is between Y begin and Y end
```

It is often the case that cell boundaries intersect roads. Since shape point queries only acquire the points within the cell the vehicle is in, part of the road will be ill-defined because some of the shape points that make up the road will be omitted since they are located within other cells. In order to ensure that the vehicle is always between two shape points within a cell block, fictitious shape points are added to the pts_hennepin table where cell block boundaries intersect the road.

Two points are added for every intersection, which corresponds to one point for each cell block that the point borders. The figure below shows how the shape points are added. It should be noted that the red point actually represents two different items within the database. One item corresponds to the point located within cell block number one while one item corresponds to the point located within cell block number two. Regardless of which cell block the vehicle is in, it will always be located between two queried shape points.



Database preprocessing

The last table that defines the digital map is hwy_hennepin. This table includes the road identification number, the road name, and a Transportation Information Service (TIS) Code. The TIS code is a road identifier which is used to find speed limits, road curves, and stop signs within their respective databases. An item within the hwy_hennepin database is shown in the table below.

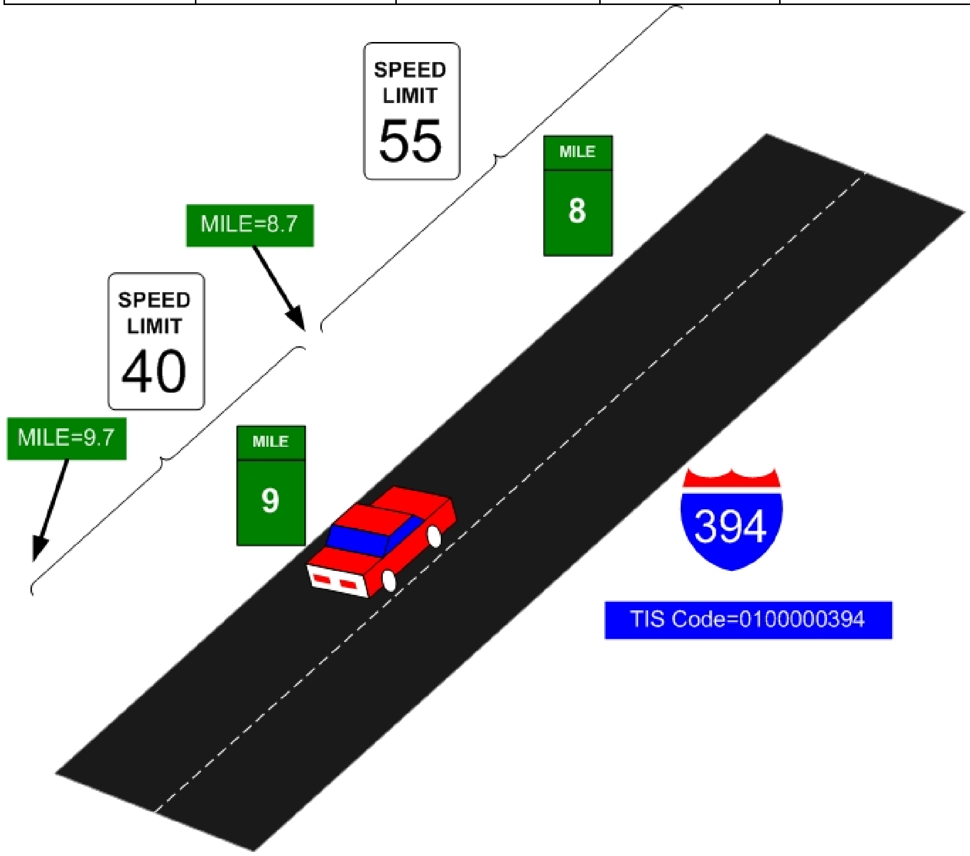
Road ID	TIS Code	Street Name
5324	1025851698	Union St. SE

Speed Limit Database

The speed limit database includes a TIS code, a beginning mile marker, an ending mile marker, a speed limit, and a short description. On the portion of road defined by a TIS code and mile marker location, the speed limit is designated by the speed limit value within the row of the speed_hennepin table where the current mile marker is between the beginning mile marker and ending mile marker. For example, suppose the vehicle is traveling down Interstate 394 at mile marker nine. The row within the table that is shown below determines the speed limit because Interstate 394 has a TIS code of 0100000394 and mile marker 9 is between mile marker 8.7 and mile marker 9.7.

Table: Speed limit database

TIS Code	Beg. Marker	End. Marker	Speed Limit	Description
0100000394	8.7	9.7	40	BEG SL 40 I 94 TO WASHINGTON AVE END 394



Speed limit query example

Stop Sign Database

The stop sign database includes the TIS code, stop sign identification number, mile marker location, and a short description. Table B3-5 shows how a stop sign is stored within the database.

Stop sign database table

TIS Code	Stop Sign ID	Mile Marker	Description
525850197	0003	2.89	5th Ave NE and 4 St NE

Road Curve Database

The road curve database includes the TIS code, curve identification number, the mile marker of the center of the curve, curve speed limit, curve direction, and a short description. Table B3-6 illustrates how a road curve is stored within the database

Road curve database table

TIS Code	Curve ID	Mile Marker	Speed Limit	Curve Direction	Description
1025851698	0003	2.154	20	R	Union St. SE

GPS Acquisition Thread

The GPS receiver supplies a set of sentences that include longitude and latitude data at one Hz. The GPS acquisition thread looks for the GGA sentence, parses the comma delineated GGA string, and places the longitude and latitude data in memory. GGA is a standard NMEA GPS sentence structure that contains UTC time, latitude, longitude, fix type, number of satellites, altitude above sea level, and other relevant parameters. Once the longitude and latitude data has been acquired, the data is converted to state plane Cartesian Easting and Northing values that correspond to the Cartesian coordinates in the pts_hennepin table. The Cartesian coordinate convention provides better accuracy making it more suitable for map matching. As shown in the figure below, Hennepin County is located within the MN South state plane; therefore, the Minnesota South Plane conversion constants are used to calculate the vehicle’s Northing and Easting values within Hennepin County.

Minnesota state planes.

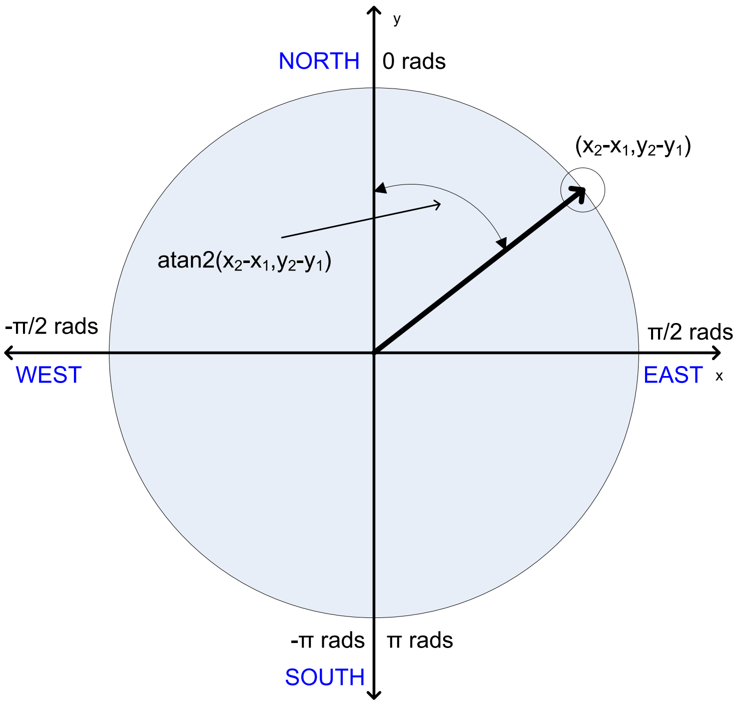
The GPS acquisition thread computes the heading of the vehicle by calculating the direction of the vector created by connecting two consecutive GPS readings. This is accomplished by using the atan2 function shown below. x_1 and y_1 are the Easting and Northing values from the first GPS reading, and x_2 and y_2 are the Easting and Northing values from the second GPS reading.

$$heading_{rads} = atan2(x_2 - x_{1,}y_2 - y_1)$$

Equation 1

If the vehicle is stationary, the two consecutive readings will be very close to one another. However, the noise from the GPS receiver causes the consecutive readings to have a random orientation. It then follows that the heading calculation will be very noisy at low speeds. In order to remedy this situation, the heading angle is only calculated if the vehicle is traveling faster than five miles per hour. It is also important that the GPS receiver has a fix on more than five satellites so that inaccurate heading calculations are avoided. In order to further reduce the amount of noise in the heading calculation, the GPS acquisition thread averages consecutive heading estimates.

The illustration below shows the convention used when calculating the heading angle. Zero radians corresponds to Due North, while both π radians and – π radians are the angles associated with Due South. Thus, there is a 2π radian discontinuity at Due South. For example, suppose the vehicle has a heading angle of 3.1 radians, which means it is heading slightly east of Due South. As the vehicle's heading turns West, it will cross Due South and jump from π radians to –π radians. Although the vehicle's heading only changed by a small amount, the heading calculation changed by 2π radians. In order to account for this, the GPS acquisition thread assumes that the heading of the car does not change much from one GPS iteration to the next. If the GPS acquisition thread detects that the heading has changed by more than π radians in one iteration, 2π radians is added or subtracted from the second iteration angle so that it reflects a small change in heading.



Heading calculation

OBDII Data Acquisition Thread

The OBDII data acquisition thread sends a hexadecimal parameter identification (PID) code to the OBDII reader that requests a particular data set. For example, if a PID code of 010C is transmitted, the OBDII reader would respond by providing the engine's RPM data. However, if a PID code of 010D is sent, the OBII reader provides the speed of the vehicle. This data is piped into the serial buffer where it is stored into memory so other threads may use the data for various calculations. The OBDII reader communicates in hexadecimal; therefore, speed and RPM values are represented as a hexadecimal number that must be converted to its decimal equivalent. Each hex digit represents a decimal number from 0 to 15. This is shown in the table below.

Hexadecimal to decimal conversion table

Hex Number	Decimal Number
0	0
1	1
2	2
3	3
4	4

5	5
6	6
7	7
8	8
9	9
A	10
B	11
C	12
D	13
E	14
F	15

RPM data is represented as two bytes or four hexadecimal digits. An example of a typical RPM value the OBDII reader would provide is 1BF8. This would yield the following decimal equivalent.

$$7160 = (1 * 16^3 + 11 * 16^2 + 15 * 16^1 + 8 * 16^0)$$

Equation 2

By convention, the OBDII always provides RPM data multiplied by a factor of four. Therefore, the actual vehicle RPM value is

$$\frac{1}{4} * 7160 = 1790\ RPM.$$

Equation 3

Speed is calculated in a similar manner. The only difference is that the OBDII reader represents speed as one byte of hexadecimal data instead of two bytes. Converting the hex byte into its decimal equivalent provides the speed of the vehicle in kilometers per hour. A typical speed value provided by the OBDII reader is 4A. The following equation would be used to calculate the speed of the vehicle.

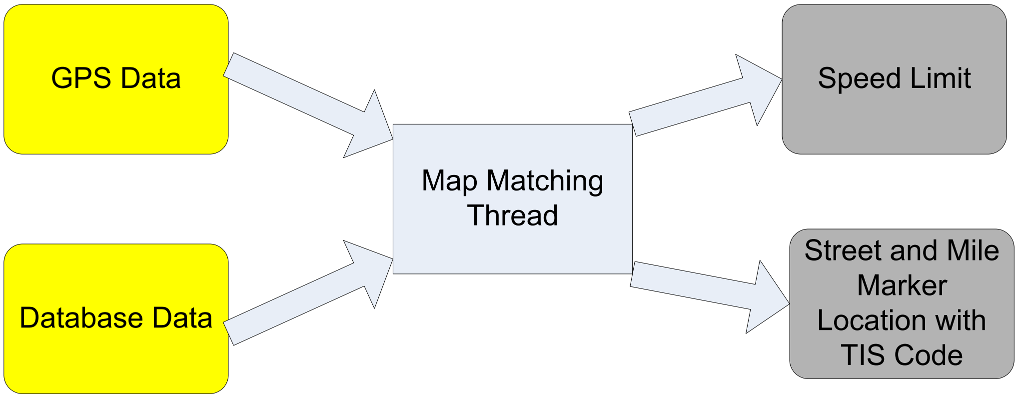
$$4 * 16^1 + 10 * 16^0 = 74\ KMPH$$

Equation 4

Since there is .62137 MPH in one KMPH, the OBDII thread multiplies this factor by the previous result to obtain 46 MPH.

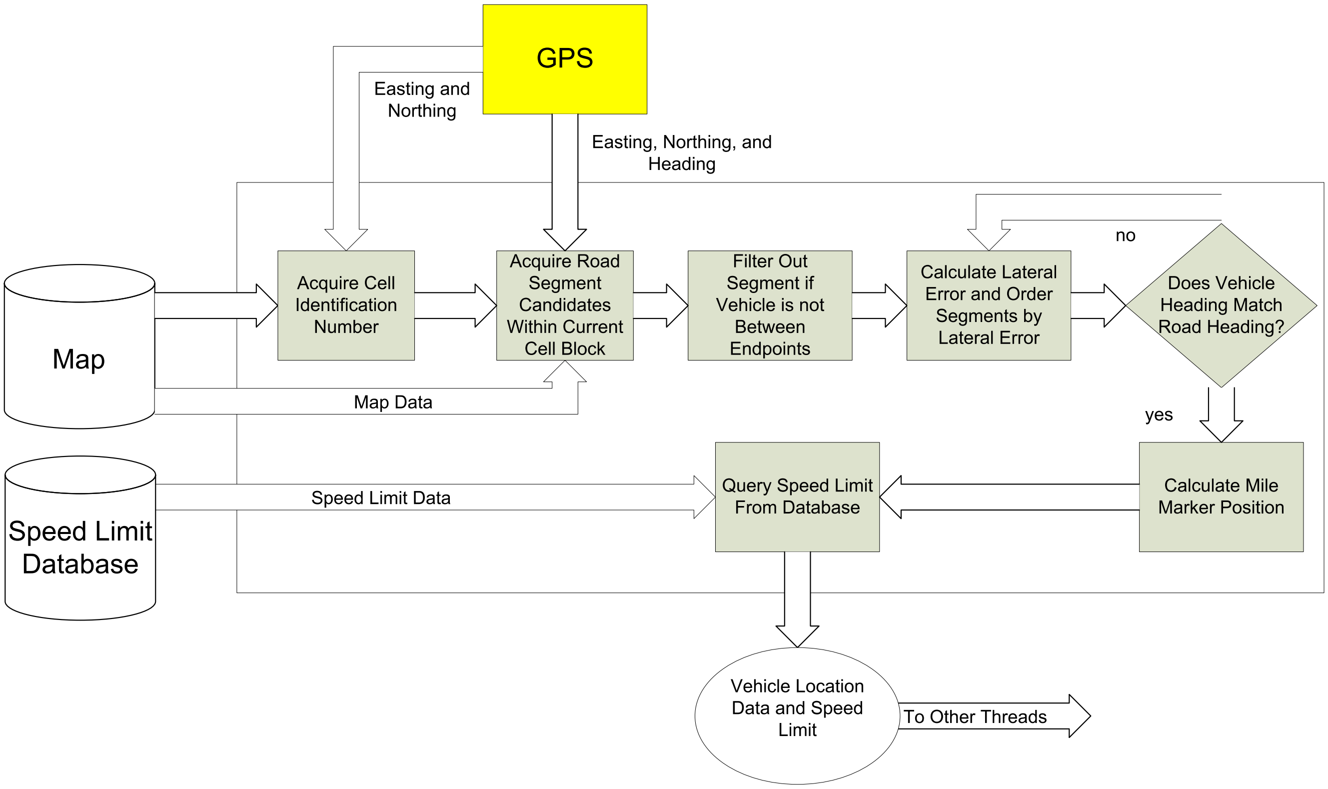
Map Matching Thread

The map matching thread converts the state plane Cartesian coordinates and vehicle heading from the GPS data acquisition thread into a mile marker position on a known street within the geospatial database. The map matching thread provides other threads with the TIS code of the road the vehicle is travelling on and a mile marker location. The TIS code and mile marker position are used to reference stop signs, road curves, and speed limits within the feature databases. The map matching thread is also responsible for querying the speed limit database and acquiring the speed limit of the road the vehicle is traveling on. A diagram showing the inputs and outputs of the map matching thread is shown below.



Inputs and outputs of the map matching thread

A general layout of the map matching thread is shown below. The map matching thread uses the GPS location data to retrieve the shape points of the roads located within the cell that the vehicle is in. Next, shape points segments that the vehicle is not between are quickly filtered out. Subsequently, the lateral error is calculated for each road segment that passes through the previous filter. The vehicle's heading is compared with the road segment directions to find the road the vehicle is on. Once the road has been found, the mile marker position of the vehicle is calculated and the speed limit is queried from the speed limit database.



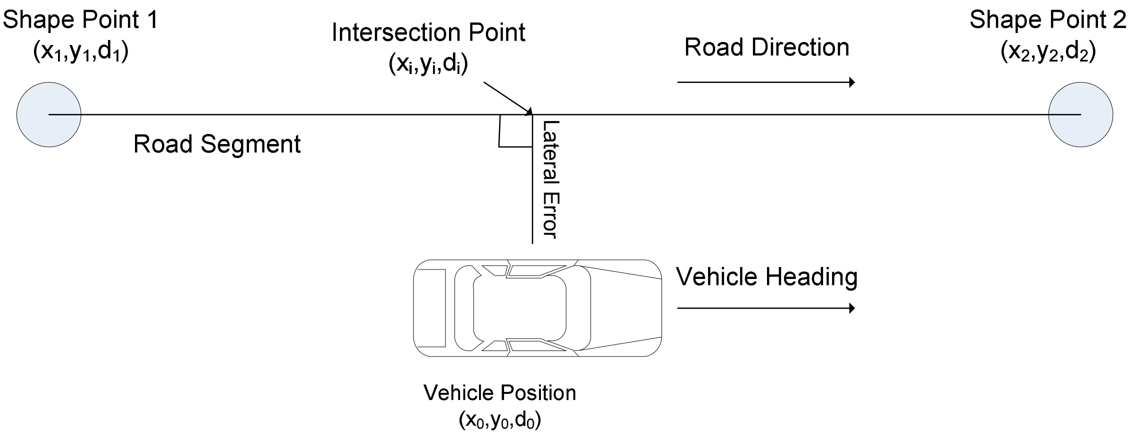
Map matching block diagram

The map first task of the map matching thread is to find the cell block the vehicle is located within. It does this by taking its current X and Y Cartesian coordinate from the GPS acquisition thread and querying the cell identification number from the cell blocks table. The following query accomplishes this task. XGPS and YGPS are the vehicle's Cartesian coordinates. X_beg, Y_beg, X_end, and Y_end are columns within the cell blocks table that define the geometry of the cell.

Select cellblock from cell_blocks where (XGPS between x_beg and x_end) and (yGPS between y_end and y_beg)

If the cell block changes from the previous map matching iteration, the map matching module queries a new set of shape points that correspond to the new cell block.

Once the map matching thread has acquired all of the shape points within the cell, the algorithm calculates the vehicle's lateral error with respect to every line segment connecting consecutive shape points. The geometry of the lateral error calculation is shown in the figure below.



Lateral error geometry

Before lateral error is calculated, the intersection point of the line connecting the two consecutive shape points and a perpendicular line going through the current position of the vehicle must be computed. This point is labeled (x_i, y_i).

Once this point is known, the lateral error is simply calculated using the distance formula. $e_{lateral}$ is the lateral error. x_0 and y_0 is the position of the vehicle provided by the GPS acquisition thread, and x_i and y_i is the position of the intersection point shown in the figure above.

$$e_{lateral} = \sqrt{(x_0 - x_i)^2 + (y_0 - y_i)^2}$$

Equation 5

The map matching module chooses the five segments which yield the smallest lateral error. Afterward, the algorithm finds which road the vehicle is most likely traveling on by comparing heading of the vehicle with direction of the road. The road direction is calculated by invoking the following formula.

$$road\_heading_{rads} = atan2(x_2 - x_{1,} y_2 - y_1)$$

Equation 6

The direction of the road should coincide with the heading of the vehicle. The road segment chosen by the map matching thread is the shape point segment with the minimum lateral error that has a road direction and heading difference smaller than .35 radians.

Once the road segment is known, the mile marker location is calculated so that the current location can be matched to a particular speed limit zone. The mile marker location is calculated as a ratio of distances.

$$d_0 = d_1 + (d_2 - d_1)\sqrt{\frac{(x_1 - x_0)^2 + (y_1 - y_0)^2}{(x_2 - x_1)^2 + (y_2 - y_1)^2}}$$

Equation 7

Once the module knows the road segment and mile marker location of the vehicle, it can quickly find the TIS code and street name that is associated with the road segment by querying the hwy_hennepen table with the road identification number that corresponds to the chosen shape point segment. This query is extremely quick because the road identification number is a unique key.

Select TIS_Code, street name from hwy_hennepin where road_id=id_number

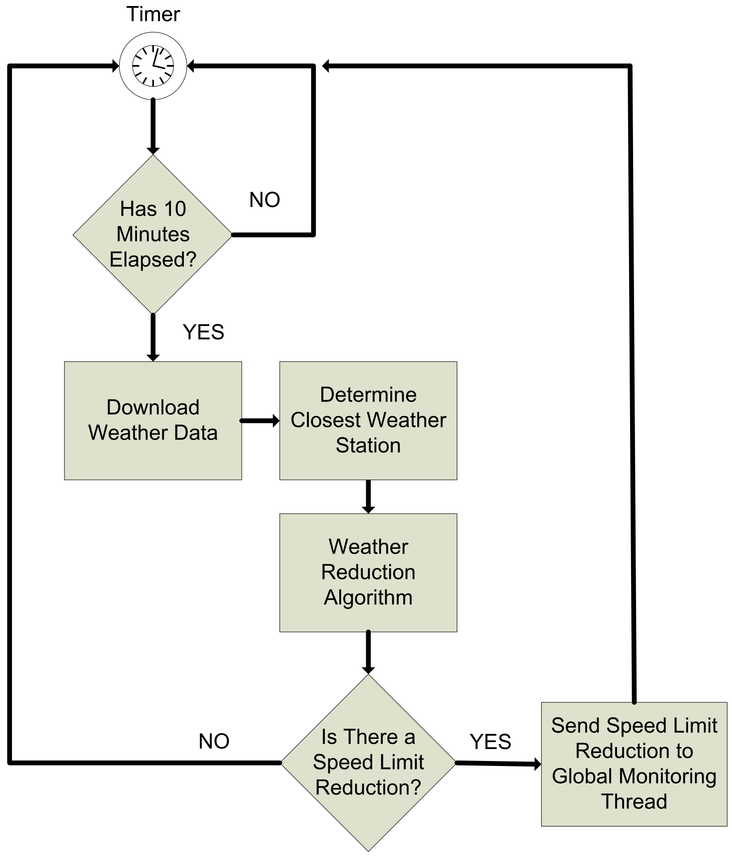
The module now has the TIS code and mile marker location of the vehicle. It now can utilize the speed_hennepin table to query the speed limit. This is done using the following select statement. m_{beg} and m_{end} are the beginning and ending mile marker columns in the speed_hennepin table.

Select speed from speed_hennepin where TIS_code= tiscode and d_0 *between* m_{beg} *and* m_{end}

Once the street name, mile marker position, TIS code, and speed limit, have been calculated, the map matching thread passes this data to the stop sign detection, road curve detection, and global monitoring threads.

RWIS Weather Thread

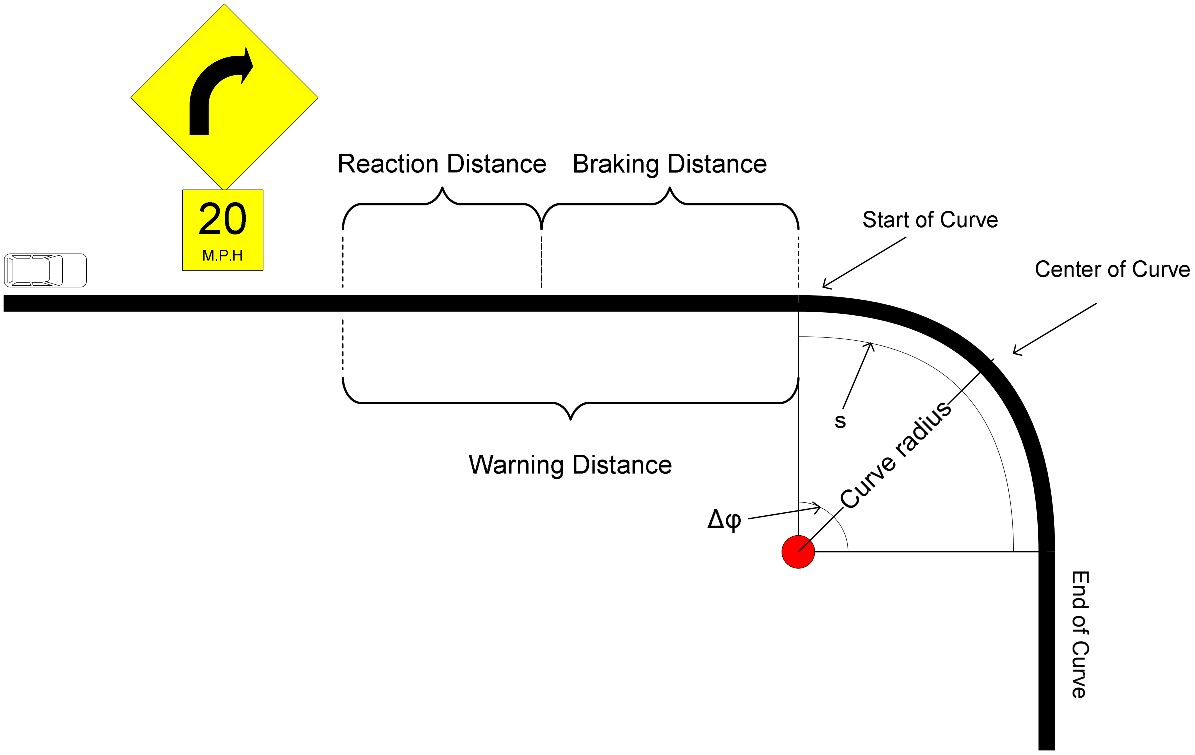
The RWIS weather thread utilizes a timer to download weather information every ten minutes from a remote RWIS FTP server. The phone automatically logs onto the server and downloads two comma delineated files that contain weather data from the RWIS weather stations in Minnesota. One file contains atmospheric weather data while the other contains road surface weather data. The RWIS weather thread uses the location data from the GPS acquisition thread to determine which RWIS weather station is closest and puts all of the relevant data into memory. Once all of the relevant weather data is in memory, a weather reduction algorithm calculates if a speed limit reduction is warranted (see Appendix D for information on when weather reductions occur). If more than one condition warrants a reduction, the TDSS will always choose the condition that corresponds to the maximum reduction. The reduction is rounded to the nearest five miles per hour and then sent off to the global monitoring thread. The global monitoring thread takes the weather reduction and controls the audio and visual cues in order to relay the reduction to the driver. This process is shown in the figure below.



RWIS weather thread block diagram

Curve Detection Thread

The curve detection module continuously monitors the location of the vehicle and looks for upcoming curves in the curve database. Curves are referenced by the TIS code of the road they are located on and the mile marker of the center of the curve. The TDSS uses its known position from the map matching thread and a preview distance to “look” ahead and find a road curve. When the curve module finds a curve, it must calculate when it should warn the driver. Since the road curve database only contains information on the location of the center of the curve, the start of the curve must be calculated. Once the mile marker position of the beginning of the curve has been calculated, the TDSS calculates the appropriate warning distance so that the driver has enough time to slow down to the curve’s speed limit.



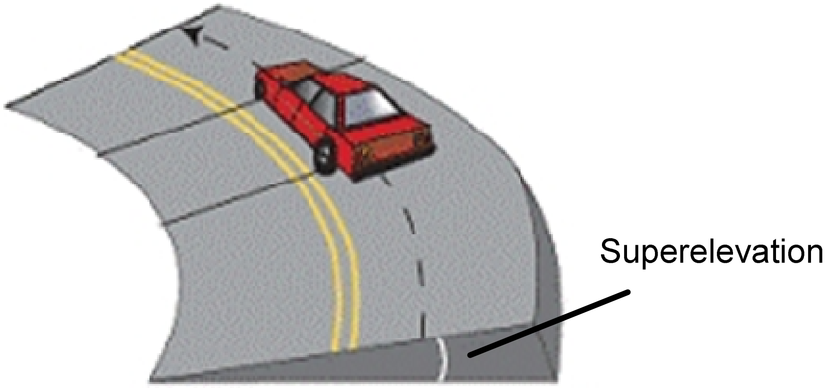
Road curve example

In order to calculate the starting mile marker position of the curve, the arc length of the curve must be calculated. This calculation is based on the curve's radius. The radius of the curve is computed using the following equation found in the Mn/DOT road design manual (2004).

$$R_{curve} = \frac{V_{curve}^2}{15 * (e + f)}$$

Equation 8

V_{curve} is the speed limit of the curve, and e is the superelevation of the road. As shown in the figure below, superelevation is the banking angle that the plane of the road curve makes with the plane of the ground. Mn/DOT stipulates that the superelevation of a curve must be between 0.02 and 0.06 radians (Mn/DOT 2004). By design, the TDSS will always over estimate the radius of the curve so that the driver is given more time to slow down. Thus, the TDSS uses the most conservative value, .02, in this calculation.



Superelevation illustration

f is the friction factor of the road. As documented in the Mn/DOT road design manual (2004), this value is proportional to the velocity of the vehicle and described by the following equations.

$$f = -0.001 * V_{curve} + .019 \; (V_{curve} \leq 50 \; MPH)$$

Equation 9

$$f = -0.002 * V_{curve} + .034 \; (V_{curve} > 50 \; MPH)$$

Equation 10

Once the radius of the curve has been calculated, the arc length can be calculated by utilizing the following equation. ΔΦ is the total arc angle of the curve. Again since it is better to overestimate the arc length of the curve to provide more time for the driver to react, the maximum arc angle value is used, π radians.

$$s = R_{curve} \Delta\varphi$$

Equation 11

The total warning distance is the sum of the reaction distance and breaking distance. The reaction distance is the product of the velocity of the vehicle, V, and the reaction time, t. TDSS uses the same 2.5 second reaction time that Mn/DOT uses when considering sign placement (Mn/DOT 2005).

$$d_{react} = V * t_{react}$$

Equation 12

The braking distance is the difference between the starting and final velocities divided by a deceleration rate. The starting velocity is the speed measured by the OBDII acquisition thread and the final velocity if the speed limit of the road curve. According to the Mn/DOT manual of uniform traffic controls, 8.1 ft/s^2 is safe deceleration rate (Mn/DOT 2005).

$$d_{brake} = \frac{V - V_{curve}}{a}$$

Equation 13

Stop Sign Thread

Similar to curve detection the stop signs are stored in the database by the TIS code and identification number of the road they are posted on and a mile marker. The stop sign thread uses the location information from the map matching thread to "look" for stop signs that are ahead of the vehicle. The warning is computed in the exact same manner in the curve detection thread. The only difference is that final velocity is zero instead of the speed limit of the curve (see equation B3-13). As the vehicle slows down to stop at the stop sign, the TDSS records the minimum speed of the vehicle. If the minimum velocity is not less than 3 MPH, the TDSS assumes that the driver failed to stop at the stop sign. The speed threshold must be larger than zero MPH because of the data acquisition rate of the OBDII reader. Since speed data acquisition is only 1.5 Hz, it is possible to stop the vehicle without the OBDII registering zero MPH.

Centralized Database and Online Interface

The remote central server uses a scheduled "cron" script to check if the phone has uploaded new driving infractions. Cron is a built in Unix utiliy that allows an executable to be run on a specific schedule. If a new file has been uploaded, the script will parse the file place all of the data into a PostgreSQL database.

The database consists of three tables. The first table, named driver_table, contains of all of the relevant information regarding teen drivers who are using the system. This table includes the name of the driver, birth date, address, driver's license number, gender, and driver identification number. The driver identification number is unique to every driver using the system and is used to reference the teen driver within the other database tables. An item within driver_ table is shown below.

Driver table

Driver ID (KEY)	Last Name	First Name	License #	Phone #	Gender	Address	City	State	Zip
000001	Doe	John	W9632555629118	(555) 555-5555	M	123 Pleasant St.	City Name	MN	55555

The second table, named login_table, contains the driver identification number and a username and password so that parents may securely log onto the system via the internet and check on their teenager's driving performance. An item within login_table is shown below.

Login table

Driver ID (KEY)	Login	Password
000001	username	psswd

Once parents access the TDSS website they are prompted to provide a login and password before they may proceed. The login and password they provide are cross referenced within login_ table using the following select statement. Username and psswd are the actual values that the parent types in for the login and password.

Select driver ID from login_table where Login=username and Password=psswd

If this statement returns a valid driver identification number, the parent is able to proceed. However, if the statement returns nil, then the parent has not provided the correct login and password and must resubmit.

The third table, named infractions_table, lists all of the infractions that were committed. This includes the driver identification number of the driver who committed the infraction, the type of the infraction, a timestamp denoting when the infraction took place, the name of the street where the infraction took place, the closest intersecting road, the maximum speed, the speed limit, and the duration of the infraction in seconds. The location of the infraction in the form of latitude and longitude is also included in this table and is used to plot out the infractions on a Google Map so that the parent can easily view where driving infractions occurred.

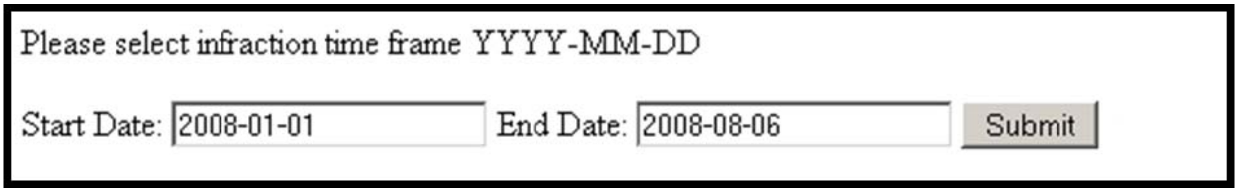
Infractions table

Driver ID (Key)	Timestamp	Infraction Type	Street	Intersection Street	Speed Limit	Speed	Duration (s)	Latitude	Longitude
000001	2008-01-06 19:10:59	speeding	University Ave NE	19th Ave NE	30	36	9	45.00829	-93.2631
000001	2008-01-06 19:19:57	running stop sign	4th St NE	6th Ave NE	25	6	0	44.99515	-93.2595
000002	2008-01-06 19:31:02	speeding through curve	Union St SE	Church St SE	20	27	1	44.97534	-93.2319
000003	2008-01-28 18:51:50	too fast for weather	4th St SE	12th Ave SE	25	29	12	44.98164	-93.2386

Once the parent successfully logs onto the website, the server will automatically query all of the violations that the driver has committed in the last week and plot them on a Google Map. This is done by executing the following select statement. The drivier_id variable represents the driver identification number that was obtained from the username and password table when the parent logged onto the website.

*Select * from infractions _table where Driver ID= driver_id and Timestamp between now()-interval ‘7 days’ and now();*

The parent also has the opportunity to change the date parameters so that the website will query infractions that have occurred between any two dates. In order to do this, the parent changes the start and end date values to reflect the time period that he or she is interested in. An example of this is shown below.



Please select infraction time frame YYYY-MM-DD

Start Date: 2008-01-01 End Date: 2008-08-06

Fields where parent may change the time frame to query driving infractions

The Google Map is created using the Google Map API, which allows one to create custom Google Maps with embedded Gmarkers and zoom utilities using Javascript. The two most important parameters that must be programmed to position a Google Map are the map's center location and magnification magnitude. Once the website has obtained all of the relevant infractions from the infractions table, a Javascript is executed that takes the latitude and longitude values of all of the infractions and calculates where the center of the map should be placed. The center latitude value is the average of the smallest and largest latitude values of all queried infractions, while the center longitude value is the average of the smallest and largest longitude values of all queried infractions. Once the center location has been set, the script sets the magnification level of the Google Map. This is critical because if the magnification level is set too large, the infractions will not be visible as they are located outside boundary of the map. However, if the zoom level is set too small, the map does not aide the viewer in seeing the specific location of the driving infractions because the map is not sufficiently detailed. Thus, the preferred zoom level is the one that is just large enough to fit all of the queried infractions. Within the Google Map API, there is a function that calculates the zoom level required to fit a map within a boundary. The boundary is composed or a Southwest latitude and longitude corner and a Northeast latitude and longitude corner. The Southwest corner is the minimum latitude and minimum longitude while the Northeast corner is the maximum latitude and maximum longitude. The next task the script accomplishes is to mark the infraction locations with Gmarkers and attach a description to each Gmarker that explains the infraction in detail. When the viewer places the mouse cursor over a Gmarker, a description appears that informs the viewer of the infraction details.

References:

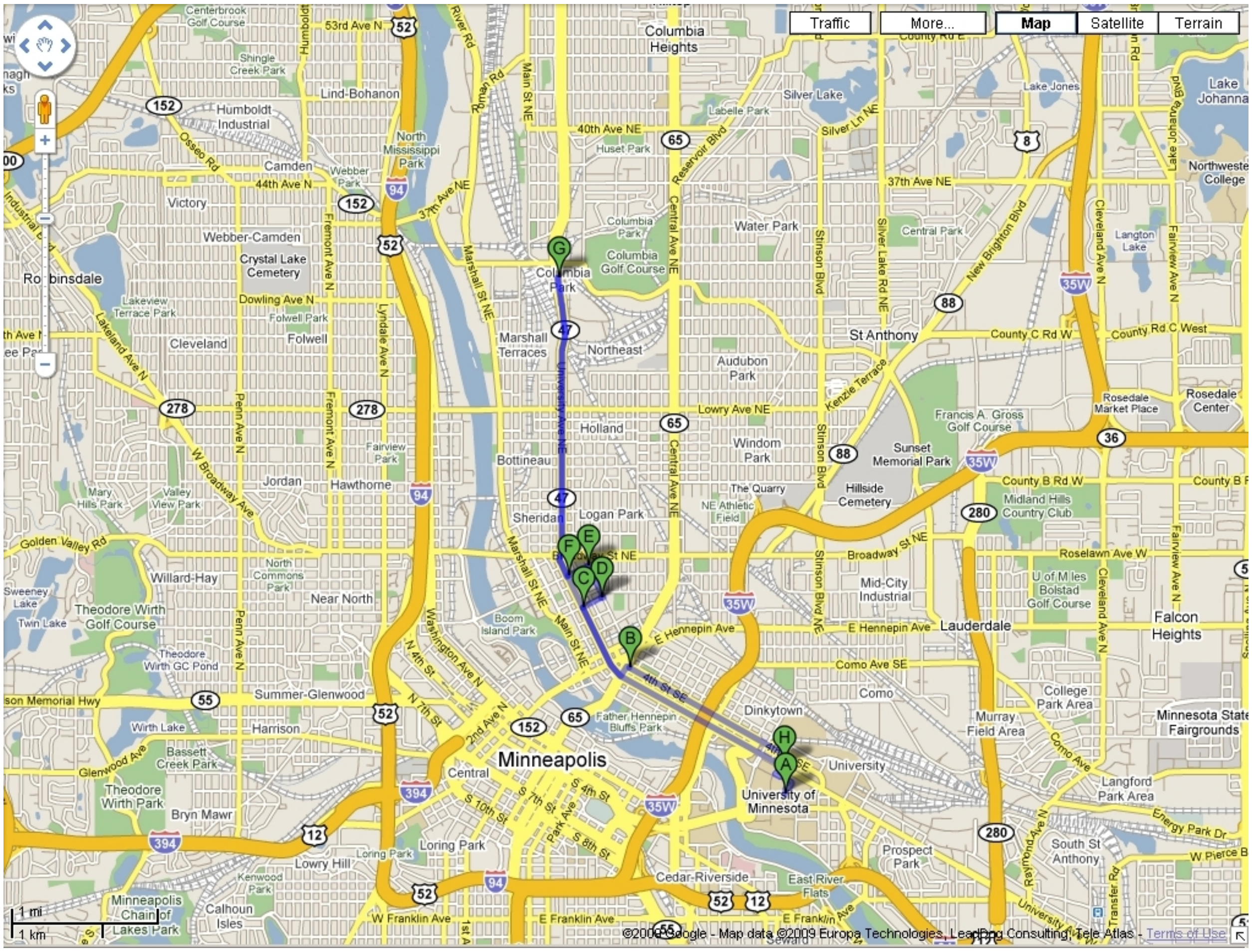
Minnesota Department of Transportation. (2005). Manual on Uniform Traffic Control Devices. St. Paul, MN: Mn/DOT Office of Traffic, Security, and Operations.

Minnesota Department of Transportation. (2004). Road Design Manual. St. Paul, MN: Mn/DOT Design Standards Unit, Office of Technical Support.

Appendix F. TDSS Supplemental Field Study Information

Route Description

The route used for the field test starts and ends on the University of Minnesota campus at the intersection of Union St. SE and Harvard St. SE. This corresponds to point A on the map below. This is a rather convenient place to begin the route because it is near the Mechanical Engineering highbay garage that was used for storing the test vehicle and meeting with participants. The route begins north on Union St. toward Church St. SE. Participants were then asked to turn right onto Church St. SE which turns into 17th Ave SE as University Ave. SE is crossed. A left hand turn is made onto 4th St. SE, and the route continues northwest on 4th St. SE until a left hand turn on Central Ave. NE is made (Point B on the map shown below). The route continues on Central Ave. NE for one block where a right hand turn is taken onto University Ave. SE. The route continues northwest on University Ave. until a right hand turn is made onto 5th Ave. NE (Point C on the map shown below). The participant travels northeast on 5th Ave. NE and turns left onto 4th St. NE (Point D on the map shown below). The route continues on 4th St. NE for three blocks where the participant is asked to turn left onto 8th Ave. NE (Point E on the map shown below). The participant travels one block on 8th Ave. NE and turns right onto University Ave. NE. (Point F on the map below). The route continues north on University Ave. NE until St. Anthony Pkwy is reached (Point G on the map below) where the participant turns around and heads south on University Ave. NE. The route continues south on University Ave. until Church St. SE is reached (Point H on the map below). The participant turns right onto Church St. SE toward Union St SE. The participant turns left on Union St. SE and travels .5 miles toward the Mechanical Engineering building where the circuit ends. In total, the circuit is about 8.7 miles and takes approximately 30 minutes to traverse.



Map of the field study route