Technical Report ECE.P54.2007.9
October 30, 2007

Vehicle Telematics: A Literature Review

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Vehicle telematics is the use of computing, sensing and telecommunication technologies to provide services in an automotive environment. Vehicle telematics service categories include navigation, remote diagnostics, fleet management, safety, information access, context awareness and mobile commerce. Supporting these services requires unique hardware and software architectures. Additionally, issues such as privacy, data security and human factors design must be considered in the implementation of vehicle telematics services. The following sections summarize current work and research in the field of vehicle telematics.

1 Telematics Services

1.1 Navigation

Navigation is one of the earliest adopted and most prevalent telematics services. Typically, this involves the use of a Global Positioning System (GPS) receiver and an interactive map database to provide turn-by-turn directions to a driver. In the automotive environment the reception of GPS signals may be affected by numerous factors including interference from vehicle electronics, antenna placement, antenna performance, multipath interference and obstructions [1]. To improve the performance and availability of navigation systems, a GPS receiver is sometimes combined with an inertial navigation or Dead Reckoning (DR) system as described in [2,3]. An analysis of various navigation system receiver setups in [3] found the combined GPS/DR setup performed better than standalone GPS in terms of coverage fix density and integrity. Another issue affecting the performance of vehicle navigation systems is the accuracy of the map database. Map accuracy may be affected by cartographic errors and changes in the road network [4]. Davies et al [4] describe an algorithm for continuously generating and updating maps using GPS information collected from vehicles as they traverse the roads. They found that their method was able to identify newly created roads which had yet to be added to a reference map.

Efficient routing algorithms are an important area of research for navigation systems. Fawcett and Robinson [5] propose a routing algorithm that uses historic congestion information to plan routes avoiding congestion prior to traveling. The route is then continuously updated with live congestion information using text messages sent via the Global System for Mobile communications (GSM) Short Message Service (SMS). In [6] Letchner et al use GPS data collected from over 100 drivers to incorporate time-variant road speeds for improved routing and to produce routes that reflect individual driving preferences.

1.2 Remote Diagnostics

The transmission of vehicle sensor and diagnostic data enables routine diagnostics and maintenance operations without the need to schedule service. Remote diagnostics systems detect and report fault conditions and alert if unexpected maintenance is required. Additionally, continuous monitoring of vehicle components and operating conditions may lead to advanced prognostics services which further reduce downtime and maintenance costs [7]. A comprehensive overview of remote vehicle diagnostics is given by You et al [8]. They describe current maintenance practices as either corrective or preventive in nature. Corrective maintenance reacts to faults after they occur and can lead to higher costs and reduced availability. Preventive maintenance consists of routine maintenance scheduled according to vehicle mileage or elapsed time and can lead to parts and fluids being replaced prematurely. You et al also identify three major components for a Remote Diagnostics and Maintenance (RD&M) system. The first is an in-vehicle component capable of accepting downloads or upgrades and providing trouble codes, sensor values and maintenance information to a RD&M center. The second component consists of real-time diagnostic and maintenance modules in the vehicle and at the remote service center with appropriate human-machine interfaces. The final component is the RD&M service center which performs advanced diagnostics and maintenance routines and interacts with the driver.

The On-Board Diagnostics II (OBD-II) [9] network is a fundamental enabling technology for remote diagnostics. Commercially available scan tools can connect to the OBD-II network and retrieve sensor and diagnostics data which can be collected by a computer and transmitted to a monitoring center for remote diagnostics. OBD-II consists of an in-vehicle data network of electronic control units (ECU) and vehicle sensors connected to a data bus. OBD-II monitors the powertrain, chassis, body and network of the vehicle and performs diagnostic routines on emissions related systems. All vehicles manufactured for sale in the US since 1996 have been equipped with OBD-II. The intent of OBD-II was to regulate emissions by detecting faults that could lead to increased vehicle pollution. When the OBD-II system detects a fault a diagnostic trouble code (DTC) describing the nature of fault is stored in an ECU and the check engine light is illuminated to alert the driver of the error condition. Originally there were four different standards describing OBD-II data network implementations: SAE J1850, ISO 9141, ISO

14230 and ISO 15765. For all vehicles manufactured from the 2008 model year forward the only protocol used will be ISO 15765-4.3 which is based on the Controller Area Network (CAN) standard operating at 500 kbps [10].

In addition to the sensor readings and diagnostic data available with OBD-II, wireless sensor networks can be deployed within the vehicle for monitoring components and creating aftermarket diagnostics systems [11,12]. Marcy et al introduce the development of wireless integrated networked sensors for area monitoring and vehicle health management [11]. These distributed microsensors are self configuring and include on-board signal processing to reduce the amount of raw data that must be transmitted over the network resulting in increased battery life. Polar et al describe an in-vehicle Bluetooth piconet used to collect and transmit vehicle data for remote diagnostics [12]. The system consists of a master node and seven sensor equipped slave nodes. In order to evaluate the performance of the network, tests were performed for bit error rate, packet loss, data integrity and the time required for a lost node to reconnect to the network for different locations in the vehicle with the engine on and off. Their results suggest that the Bluetooth network is well suited for diagnostics in the automotive environment.

Remote diagnostics can lower operating costs and improve safety by detecting low tire pressure and alerting the driver of the situation [8]. Proper tire pressure is extremely important for the efficient operation and safety of an automobile as it improves fuel economy, increases tread life and reduces stopping distances [13]. For these reasons, the federal government has mandated that Tire Pressure Monitoring Systems (TPMS) be installed in all vehicles after September 1, 2008 [14]. Remotely monitoring the tire pressures for large vehicle fleets such as taxis and rental cars would make them easier to maintain and could lower fuel costs and improve safety.

1.3 Fleet Management

Fleet management services typically utilize vehicle location and diagnostics capabilities for the remote monitoring and management of vehicle assets. Fleet management is intended to improve the logistics, scheduling, reliability and availability of services supported by vehicle fleets such as carrier trucking, car rental, taxi dispatch and public safety operations. Early research in advanced logistics services was stimulated by the creation of the Single European Market in 1993 [15]. There were three reasons for this: increased demand for transportation services, the need for higher quality services, such as just-in-time delivery and online tracking, and increased competition in the European transport industry [15]. Giannopoulos and Boulougaris identified the lack of infrastructure, the cost of implementation and the absence of standards as three challenges for the early development of advanced logistics services [15].

Advances in communications, computing and sensing technologies have led to the development of a number of commercial off the shelf telematics systems that can provide fleet management services. Goel and Gruhn propose a strategy for integrating such systems with existing carrier IT infrastructures to improve functionality and avoid the cost of overhauling existing systems to accommodate telematics [16]. They suggest that the vehicle information provided via a telematics system can supplement the existing IT infrastructure through the use of an intermediary application that is capable of communicating with both systems. They implemented such a system for a real carrier and found that it improved the quality of transportation services by reducing driver and dispatcher misunderstandings and improving the information flow but with the tradeoff of increased communication costs.

The dispatching operations for large vehicle fleet services such as taxis and rental cars can benefit from the adoption of fleet management services. One example of this can be found in the work of Ziqi Liao who proposed an Automatic Vehicle Location and Dispatch System (AVLDS) to overcome inefficiencies in traditional radio-paging dispatch systems for taxis [17]. The AVLDS system combined GPS, wireless communication and computer aided dispatch technologies to automate taxi dispatch services in a large metropolitan environment. Using AVLDS a customer requests a taxi and an automated job request is sent to the nearest available vehicle. If the taxi accepts the fare, the ETA and taxi number are relayed back to the customer. In a study of these systems, the author found that they improved accuracy and efficiency when compared to traditional dispatch methods but that driver training was required to overcome initial resistance to their adoption.

Fleet management services often combine vehicle location data with performance and status information to improve logistics, maintenance and scheduling. One project at Mississippi State University [18] focused on the implementation of a system for remote vehicle location tracking as well as web based performance monitoring. This project utilized technologies including GSM/GPRS for data communication, GPS for localization and OBD-II diagnostics to continuously monitor the status of a bus fleet. The information collected by the system is presented to the public in real time using a web based interface.

A prototype Remote Fleet Management (RFM) application for police cruisers using the Project54 system was proposed by Kim et al [19]. The RFM system consisted of two modules: an automatic vehicle location (AVL) module and a prototype remote diagnostics module for interfacing with the OBD-II network. The AVL module was intended to connect to commercial computer aided dispatch systems and provide them location updates using digital police radio data channels. The bandwidth limitations of the radio data channel required the use of heuristic rules to limit the number of location updates transmitted. One method used was to change the transmission rate depending on vehicle speed and distance traveled.

The improved logistics capabilities offered by fleet management services have the potential to increase the availability of a vehicle fleets. In [20], Fass and Miller performed a simulation to predict the impact of an Autonomic Logistics System (ALS) on logistics efficiency and aircraft availability for the Joint Strike Fighter aircraft program. ALS is a proactive maintenance service for vehicles employing prognostics and health management systems. ALS is used to detect and isolate faults and automate the maintenance process before failures occur. Their simulation results indicate increased availability when ALS is employed with a potential 8% improvement in the mission capable rate of aircraft.

1.4 Safety

Vehicle telematics safety systems combine sensing and wireless communications technology for the detection and avoidance of hazardous situations while driving. OnStar [21] is one example of a vehicle telematics safety service. OnStar transmits mayday alerts using cellular communications which include the vehicles GPS coordinates whenever crash sensors detect an accident or airbag deployment. Emergency vehicle traffic signal preemption systems are another example. Emergency vehicles equipped with these systems transmit an IR alert signal to sensors at traffic light intersections which stop all traffic from entering the intersection while the emergency vehicle crosses. These systems have been shown to lower response times and reduce emergency vehicle accidents [22]. With the recent integration of location technology and cell phones for E911, Zhao [23,24] has suggested that a single device may be used for communications and localization for providing mayday and other alert services.

Much of the recent research in the field of safety telematics has focused on employing vehicle-to-vehicle wireless communication to provide enhanced safety services. Dedicated Short Range Communications (DSRC) is a wireless standard that has been developed to address the need for short range (1000 m) communications in Intelligent Transportation Systems (ITS). Gallagher et al [25] evaluated the performance of DSRC radio links for line-of-sight and non-line-of-sight conditions in the presence and absence of road traffic for both roadside-to-vehicle and vehicle-to-vehicle communication. They described a DSRC resource allocation scheme that allows vehicles to synchronize with each other and receive high-priority safety messages with low transmission latency.

Cooperative collision avoidance (CCA) is an example of a safety system utilizing DSRC as described by Biswas et al [26]. In this system a platoon of vehicles are in constant communication using DSRC. If the lead vehicle is involved in a collision, warning messages are transmitted to all following vehicles. If the latency is low, the messages can be received by following cars in time for them to decelerate and avoid a chain collision.

1.5 Information Access

Information Access services provide vehicle occupants access to information sources located outside the vehicle. One of the earliest examples is the now ubiquitous AM and FM radio receiver which allows vehicles to receive information and entertainment content. Such systems have evolved to include satellite radio and HD radio [27]. Recent efforts at providing information access in automobiles have focused on creating a Transmission-Control Protocol/Internet Protocol (TCP/IP) connection enabling bi-directional communication of all types of data through a standardized interface [28].

Another area of information access involves providing information about vehicles to the public. Maclean and Dailey [29] describe a project called MyBus intended to provide real time information about bus arrival and departure times so that bus riders can make informed decisions about their travel options. A large fleet of busses are equipped with AVL systems which track their positions. This information is used by a predictor to estimate arrival and departure times and the results are made available to the public via a web interface which can be viewed from cell phones.

Access to accurate, complete and up to date information is critically important for supporting public safety operations. A number of efforts at Project54 have addressed this need by expanding and improving information access for officers in the field. LeBlanc et al describe a system for the collection and distribution of data using state operated WiFi hotspots [30]. This system is designed to address the issues of slow transfer speed and limited availability currently encountered using traditional analog and digital police radio systems. It enables temporary, high-speed wireless access to large amounts of data which can be stored locally in cruisers for later use. It also allows cars to quickly upload data to a central location for data collection and auditing. Using handheld computers and distributed computing components, officers can perform driver’s license records checks and control in-car devices while outside their vehicles using the system described by Krstovski et al [31]. Another information access technology being implemented at Project54 involves the use of excess bandwidth available in the public television broadcast spectrum to provide a high data rate connection to cruisers for delivering images, audio and text to officers in the field [32].

1.6 Context Awareness

Context aware vehicle telematics services are based on the collection and distribution of information regarding the internal and external vehicle environment. This information can include vehicle component states, traffic, weather and pollution conditions and information about nearby points of interest. Two examples of context aware vehicle platforms are given in [33,34]. In [33] a sentient car is presented which uses context information to produce adaptive pollution maps. Pollution is monitored using exhaust emissions sensors and the vehicle context is provided via multiple sensors including GPS and a connection to the vehicle ECU for velocity, acceleration, temperature and steering wheel position data. A computer interfaces with the sensors and a GSM data modem is combined with an 802.11b network card to provide communications for transmitting pollution information and receiving updated map data. McCall et al [34] describe an integrated vehicle test-bed designed for studying driver behavior and developing algorithms for ITS. This test-bed provides a complete picture of the interior and exterior vehicle context through a combination of sensors including omnidirectional and rectilinear cameras, radar, microphones, GPS and vehicle state sensors.

Traffic information services for detecting, predicting and avoiding congestion are one of the most common context-based telematics services. Typically these systems employ a fixed network of sensors and communications equipment along a roadway to measure traffic and transmit congestion information. Sensors commonly used for detecting vehicles include inductive loops, video cameras, radars and lasers [35,36]. Fixed sensor networks for monitoring traffic can be expensive to deploy and provide only localized traffic conditions. For these reasons, recent research has investigated using vehicles as mobile traffic probes to detect and report traffic conditions [37-39].

Ishizaka et al conducted a field test in which taxis were equipped with GPS and data logging equipment to record travel times for different road segments [39]. They determined that sampling the vehicle positions at five second intervals provided sufficient accuracy for estimating segment travel times. Using probe vehicles to detect real-time traffic conditions requires a significant communications infrastructure for collecting and processing the data produced by a large number of vehicles. Chen et al [38] addressed the issue of scaling such systems when a centralized server is used for data collection and path routing. They suggest inserting programmable middleboxes to act as intermediaries between vehicles and the server. The middleboxes collect and process traffic data from vehicles in their vicinity before passing the aggregated data to the central server. This allows a large number of vehicles to participate without increasing the workload of the server. For their test setup the use of middleboxes reduced the amount of packets the server had to handle by a factor of ten.

Traffic monitoring systems often produce large volumes of multi-modal sensor data which must be analyzed in real time to provide continuous congestion information updates. Grossman et al [40] describe a system which utilized real time data from over 830 traffic sensors combined with data about weather conditions and upcoming events that may impact traffic to detect changes in traffic conditions. A large set of historic traffic data was used to establish numerous baseline models. Changes in traffic conditions were detected by scoring current data against the baseline models. Real time updates were sent when deviations from the baselines were detected.

The system described in [40] is centralized with all traffic information collected and alerts sent from a single site. An alternative to this approach is to employ a distributed system as described in [35]. Here, Utamaphethai and Ghosh propose a network of distributed traffic management centers which would collect congestion information for highway segments and propagate their information to other nodes in the network using a flooding algorithm. The majority of the processing for routing and traffic avoidance would be handled by in-vehicle navigation systems which would receive updated congestion measures for highway segments whenever they are within communications range of a management center.

1.7 Mobile Commerce

Vehicular mobile commerce services combine information access and context awareness to facilitate business transactions in the automotive environment. Examples of mobile commerce services include location based advertising, on-demand entertainment, interactive games, remote tolling, pay-per-use insurance and accurate parking [41-43]. Many of these applications are highly localized and would require the use of precision navigation equipment. In [41] the authors introduce a project investigating the use of the European Geostationary Navigation Overlay Service (EGNOS) as an alternative to GPS for providing such localized services in the near future.

2 Architecture

2.1 Hardware

Vehicle telematics services are made possible by in-vehicle data networks, integrated sensors, powerful low-cost computers and ubiquitous wireless connectivity. A comprehensive survey of automotive sensors for powertrain, chassis and body systems is provided by W.J. Fleming in [44]. He also identifies a number of emerging state-of-the-art sensor technologies such as oil quality/deterioration sensing and multi-axis micromachined inertial sensors which may have direct applications in telematics systems. In addition to automotive sensor systems, telematics services make use of a variety of commercial sensors including GPS, radar, lasers, video cameras, microphones and inductive loops. The telecommunications standards and technologies supporting vehicle telematics services include 802.11, WiMax, DSRC, cellular, Land Mobile Radio, Bluetooth, Satellite and infrared. Future systems will continue to expand coverage and availability of wireless connectivity. Cianca et al show how high-altitude unmanned aerial platforms carrying communications relay payloads can supplement existing satellite services and provide efficient fleet management and traffic control services [45].

The evolution of the vehicle data network has been necessitated by the rapid expansion of electronic systems in the vehicle. Traditional point-to-point wiring methods for vehicle electronics were bulky and had a negative impact on performance and reliability. This led to the adoption of control networks for creating a shared infrastructure for device communication and control [46]. Leen and Heffernan provide an overview of recent advances in vehicle control networks and discuss how future networking standards will enable X-by-wire systems that replace traditional rigid mechanical components such as the steering column and hydraulic brakes with dynamically configurable electronic units performing the same functions [46].

Project54 provides an example of how vehicle networking standards can be applied for the integration of aftermarket electronics [47]. The Project54 system employs the ITS Data Bus (IDB) standard using version 2.0B of the CAN protocol to create a common interface for aftermarket police vehicle electronics such as lights, sirens, radios and radars. These devices typically provide a serial and/or parallel data connection for monitoring and controlling the device. The aftermarket devices are connected to the CAN network using the Project54 common interface for the IDB. An embedded computer in the cruiser enables control of the networked devices via the Project54 speech user interface (SUI) and touchscreen graphical user interfaces (GUIs).

2.2 Middleware

Vehicle telematics middleware components manage communications resources and facilitate interaction between distributed components and applications. Middleware application requirements vary depending on the services they must support. Various middleware platforms are presented in [48-50]. Bisdikian et al specify four requirements for a middleware platform supporting mobile commerce services: use of open and standard internet protocols, intelligent data filtering and abstraction, dynamic modification of set membership, and security and privacy management [48]. Reilly and Taleb-Bendiab select the Jini middleware to provide application services to remote in-vehicle computers and Palm devices [49]. This middleware architecture satisfied their requirements of suitability for wireless communication, fault tolerance and limited computing resource usage. A middleware platform based on international standards is discussed in [50]. This middleware architecture uses the Java based Open Service Gateway Initiative (OSGi) for device access, authentication and communications. The Automotive Multimedia Interface Collaboration (AMI-C) is also employed to provide a uniform set of application programming interfaces that can be used to provide services in any vehicle.

2.3 Software

The software supporting vehicle telematics must be flexible enough to accommodate many service types. Additionally it should be generic enough to be deployed on a variety of computing platforms. Karimi et al describe a software architecture for supporting remote diagnostics and other services [51]. They identify a number of design principles for their application: distributed architecture, data replication, vehicle client data cashing, carrier independency, filtering and resource-effectiveness. The application of these design principles produced a layered software architecture composed of the four distinct components. The first component was a client application which allows users to interact with the system via a web interface. The second was a remote server which acted as a middleware application between the client application and the database server. The third component was the database server which stored and maintained all system data. The final component was a remote agent which provided the interface between the vehicle and the rest of the system [51].

Munson et al introduce a rule-based programming framework for developing telematics applications based on a sense-and-respond model [52]. In this framework, a telematics event detection service (TEDS) monitors data within a telematics system and evaluates it against application defined rules. When a rule is triggered, the event is acted on accordingly by the application which defined the rule. Examples of event-driven telematics services supported by this framework include vehicle congestion detection, traffic monitoring and location based warnings.

Project54 implemented a software architecture for controlling networked aftermarket electronics which supports a SUI and multiple GUIs [53,54]. The Project54 system software is completely modular and is based on Microsoft's Component Object Model (COM). Application modules for interfacing new devices may be added to the system at any time. The Project54 software messaging scheme allows one-to-one communication between applications. This messaging scheme also enables Project54 deployment and communication across distributing computing platforms such as PDAs. Support libraries for registry access, speech input/output, GUI layout and IDB device communication provide a common framework for Project54 application module development.

3 Implementation Issues

The acceptance of vehicle telematics by the public depends on the ability of service providers to create trust by protecting user privacy. They must assure end-users that data collected in these systems will not be used for exploitative or malicious purposes. Service providers must also ensure their systems are secure physically and logically from tampering and misuse by end-users and third parties in order to provide reliable services. Additionally, these services often require user interfaces that are accessible at high speeds and must be implemented without affecting vehicle reliability. The requirements for security, privacy, usability and reliability (SPUR) [55] as they relate to vehicle telematics are described by Giuli et al in [56]. In addition to discussing the SPUR requirements, the authors introduce a service-oriented architecture providing standardized interfaces to vehicle data and in-vehicle services called the Vehicle Consumer Services Interface.

3.1 Privacy and Data Security

Issues regarding privacy and security in telematics systems are highlighted by the example application of probe vehicles for traffic monitoring in [37]. In this example the privacy of vehicle operators may be compromised because their movements can be tracked when they transmit location and identification data. If the data is transmitted anonymously, then the security of the system may be compromised by unauthenticated attackers. In order to provide for both security and privacy in the traffic monitoring system, Hoh et al suggest an architecture where the authentication and the data analysis are handled by separate entities. Additionally they recommend the use of encryption, tamper-proof hardware and data sanitization techniques to ensure data integrity. The authors also investigate the possibility that data mining techniques known as inference attacks could be used to identify the homes and trace the movements of probe vehicle owners when anonymous location and speed data are available at the analysis entity. They recommend suppressing the amount of data collected by sampling at an interval of several minutes to reduce the effectiveness of data mining techniques.

Computational inference attack methods for home identification using location data and possible countermeasures were investigated by Krumm [57]. In this study, anonymized GPS data was collected from 172 subjects over a two week period. Inference attack methods investigated included last destination, weighted median, largest cluster and best time attacks. The last destination algorithm performed best in terms of locating subject's home addresses. Countermeasures studied included: spatial cloaking in which data samples near the home location are deleted, adding Gaussian noise to location samples, and rounding whereby each location sample is snapped to it nearest location on a square grid. The analysis of these countermeasures shows that in all cases, significant data corruption is required to completely eliminate the threat of inference attacks.

Duri et al at the IBM T.J. Watson Research Center have proposed a framework that focuses on data protection through user defined privacy policies and secure systems that enable data sharing in telematics [58,59]. In [59] they identify three key concepts implemented in their framework for the purpose of providing trust in telematics systems: defense-in-depth, data aggregation, and user defined privacy policies. Defense-in-depth is a comprehensive security measure where each hardware and software component in the system is as secure as possible from physical and logical attacks. Data aggregation is intended to minimize the amount of private data available outside of the trusted system. Two mechanisms are proposed to ensure proper operation of aggregation applications. First each data aggregation application is isolated from other applications and its access to systems resources such as files and sockets is restricted. Second, all local and network communication is managed by a data protection application which checks data against privacy policies and produces an audit trail. The final data protection framework component is the user defined privacy policy. This policy defines personal user data handling preferences and specifies how service providers will use collected data. Their framework will insure compliance with the privacy policy by classifying data types and defining data handling rules in accordance with the policy.

The security of vehicular networks is extremely important for vehicle telematics safety services such as CCA. In [60] Raya and Hubaux provide an in-depth analysis of the potential threats to vehicular networks with an emphasis on those employing DSRC for safety applications. They categorize potential attackers according to whether they are inside or outside the system, act with malicious or rational intent and whether they are passive or active in their attack methods. Specific forms of attack include: supplying false information, monitoring and tracking vehicles in the network, using a denial of service attack to bring down the network, and masquerading as other vehicles by using false identities. In order to address these security concerns, the authors propose a set of requirements for securing vehicular networks. Security requirements include vehicle authentication, verification of data consistency, ensuring availability, message non-repudiation, privacy and real-time constraints. The authors recommend the use of a public key infrastructure to provide authentication of safety related messages.

3.2 Human Factors Design

The integration of telematics services in vehicles creates challenges in presenting the information provided by these services to drivers in a safe and efficient manner. In addition to the need for safe and efficient user interfaces, these services have the potential to increase the cognitive workload of drivers resulting in driver distraction [61]. Many projects have proposed flexible human-machine interfaces (HMI) and configurable multifunction displays (MFD) to address user interface issues [56,62,63]. In [62] Bernard Champoux proposes a user-configurable MFD that allows drivers to select how data is presented depending on whether they are driving in a city or on a highway. Drivers can create display presets that specify what information appears on the MFD as well as control the size and position of readouts. Drivers can toggle between display presets as needed using controls on the steering wheel.

In some cases the information provided by vehicle telematics services could be presented with the intention of altering driver behavior to enhance safety. Kumar and Kim [63] present a dynamic speedometer that incorporates the current speed limit on the speedometer display for the purpose of reducing speeding. They performed a study using a driving simulator in order to observe speeding behavior with and without the use of the dynamic speedometer. They found that displaying the current speed limit on the speedometer was an effective method to reduce unintentional speeding and encourage drivers to drive slower. They also point out that such a system could be implemented with current technology by incorporating road speed information in GPS digital map databases or using roadside beacons that would transmit speed limit information using DSRC or other wireless communications.

A vehicular SUI allows drivers to interact with data sources and control in-car electronics without needing to take their hands off the wheel or eyes off the road. Project54 has implemented a SUI and GUIs that work in parallel with traditional police hardware user interfaces to provide synchronized control and access to integrated electronic devices including lights and sirens, radars, and radios. In [64] Kun et al evaluated officer use of the SUI, GUI and traditional hardware user interfaces while on patrol. They found that officers tended to use different interfaces to perform the same task depending on their situations. The selection of an appropriate user interface depended on the balance of safety against the speed of the interaction. For example most record queries can be performed faster using the SUI versus the traditional interface and therefore the SUI was preferred for this task. Reviewing the data presented by the record queries is performed fastest using the GUI. However, this interaction is unsafe while driving and only one officer was found to use it. They also determined that the design of the interface should match the way it is used in the field. They noticed that officers consistently declined to listen to verbal feedback responses from the SUI designed to guide the interaction. Additionally they found that training officers in the operation and use of the SUI can improve SUI performance.

To asses the impact of a SUI on driving performance two experiments were conducted at Project54 by Kun et al [65,66]. In [65], a driving simulator was used to create a scenario where participants had to change channels on a police radio using a SUI while driving. Three aspects of the SUI were varied in order to observe their impact on driving performance: SUI accuracy, the use of a push-to-talk (PTT) button, and the type of dialog repair employed. The results of the study indicate that the accuracy of the speech engine and its interaction with the use of the push-to-talk button does impact driving performance significantly, but the type of dialog repair employed does not. In [66] driving performance using the SUI to change police radio channels was compared with the performance using a visual/manual radio interface. The results of this study indicate that the use of a SUI provides a significant improvement in driving performance compared to the traditional manual/visual interface for performing the same task.

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