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NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

# Technology Applications For Traffic Safety Programs: A Primer





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16. Abstract This document explores how emerging digital and communications technology can advance safety on the Nation's highways. The range of technology described in this report is available or will be available in the near future to improve traffic safety. As new traffic safety applications become widespread and implementation costs decrease, there could be a network of advanced systems that improve traffic safety by providing information and services to drivers, traffic operations agencies, emergency services personnel, and law enforcement professionals. Discussions in this report include a general overview of traffic safety technology; the use of technology to reach traffic safety goals using the framework of the "Four E's" of engineering, enforcement, education, and EMS; and the technical and non-technical challenges for these technology applications.			
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## Table of Contents

<b>Executive Summary</b> .....	<b>vii</b>
<b>Introduction</b> .....	<b>1</b>
The Need for New Traffic Safety Technologies.....	1
Organization of the Report .....	1
<b>Traffic Safety Trends</b> .....	<b>2</b>
Driving Trends.....	2
<b>Traffic Safety Technology</b> .....	<b>5</b>
“Toolbox” of Components and Technologies.....	5
Communications .....	6
Vehicle-Roadway System.....	7
Global Positioning Systems .....	10
Other Vehicle-Roadway System Components.....	11
Examples of Integrated Technology Systems.....	13
<b>Reaching Traffic Safety Goals with Use of Technology</b> .....	<b>15</b>
The “Four E’s” .....	16
<b>Challenges for Technology Applications Serving Traffic Safety Programs</b> .....	<b>34</b>
Technical Design Challenges.....	34
Technical Design Principles .....	37
Non-Technical Challenges.....	39
<b>Conclusion</b> .....	<b>41</b>

## Table of Tables

Table 1. Fatalities, Injuries, and Crashes from 1990 to 2006 .....	2
Table 2. Total Injuries and Crashes in 1990, 2000, and 2006 .....	3
Table 3. Examples of Crash Scenarios, Using the Haddon Matrix .....	15
Table 4. Engineering Haddon Matrix .....	21
Table 5. Emergency Response Haddon Matrix .....	26
Table 6. Crash Factors and Fatalities .....	27
Table 7. Education and Information Haddon Matrix .....	33
Table 8. The Automotive Environment.....	34

## Table of Figures

Figure 1. Highway Fatalities and Fatality Rates 1994-2005 .....	3
Figure 2. Vehicle Operating Parameters Measured by Sensors .....	8
Figure 3. Haddon Matrix Format.....	15
Figure 4. Crash Type Distribution 2002.....	16
Figure 5. Rear-end Crash Avoidance Technology .....	18
Figure 6. Example of Vehicle-to-Roadway Communication in Intersection Crash Avoidance Technology .....	18
Figure 7. Components of Emergency Response Services .....	22
Figure 8. Example of an In-Vehicle Visual Stop Sign Warning .....	32

## Abbreviations

ABS	antilock brake system
ACN	automatic crash notification
CVO	commercial vehicle operations
ECU	electronic control unit
EDR	event data recorder
EMS	emergency medical services
ETC	electronic toll collection
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GPS	global positioning system
HMI	human-machine interface
ITS	intelligent transportation system
MEMS	microelectromechanical system
MVEDR	motor vehicle event data recorder
PSAP	Public Safety Answering Point
NHTSA	National Highway Traffic Safety Administration
USDOT	United States Department of Transportation
VMT	vehicle miles traveled



## EXECUTIVE SUMMARY

This document explores how emerging digital and communications technology can advance safety on the Nation's highways. The range of technology described in this report is available or will be available in the near future to improve traffic safety. As new traffic safety applications become widespread and implementation costs decrease, there could be a network of advanced systems that improve traffic safety by providing information and services to drivers, traffic operations agencies, emergency services personnel, and law enforcement professionals.

### Technologies

Electronic communications is the key to traffic safety technologies. Types of communications systems and example applications include:

- Vehicle to driver, in which the vehicle communicates information to drivers when predetermined criteria are met, such as if a vehicle drifts out of its lane.
- Vehicle to vehicle, which enables communication among vehicles for such applications as crash avoidance technologies and allowing law enforcement officials to acquire identification information about a particular vehicle.
- Vehicle to and from roadside, in which roadside communications devices send and receive message to and from passing vehicles. The most common application of this technology is electronic toll collection, but there are many potential traffic safety applications.
- Vehicle to and from traffic and emergency call centers, including such applications as automatic crash notification that notifies an emergency call center when a vehicle has been involved in a crash.

### Haddon Matrix

The Haddon Matrix is a useful construct to assess the various stages of a crash (before, during, and after) and factors that contribute to crashes (human, vehicular, and environmental).



This report applies the Haddon Matrix to each of the “Four E’s” of traffic safety:

- Engineering - Examples include antilock brake systems that prevent skidding and electronic stability traction control that helps avoid vehicle rollovers and other loss-of-control situations. Engineering interventions generally occur in the pre- and during-crash phases of the Haddon Matrix.
- Emergency response – Examples include automated crash notification systems that notify emergency call centers that a vehicle has been in a crash; improved 911 services that can detect the location of cell phone callers (enhanced 911); and 911 services that can handle non-voice communication such as video and data streams (next-generation 911). Emergency response technologies apply to the post-crash time period.
- Enforcement and regulations – Examples include alcohol interlocks that prevent drunk drivers from starting their vehicles, electronic vehicle tags that allow law enforcement personnel to identify specific vehicles, and cameras that detect and identify vehicles that run red lights. Enforcement and regulatory activities occur primarily before a crash.
- Education and information – Examples include various driver information applications that inform the driver about road and traffic conditions. Education and information activities affect primarily per-crash conditions.

### **Challenges**

As with all new technology applications, traffic safety technologies come with a variety of design challenges that must be met prior to full implementation. The human-machine interface (HMI) is perhaps the most important consideration in traffic safety technologies. The primary requirement of the in-vehicle HMI is to deliver the needed or desired information while minimizing driver distraction. This can be done through careful placement of the HMI device within the vehicle and by the way it relays relevant information. Available technologies for HMI include voice activation, speech recognition, dashboard lights and icons, heads-up or panel displays, audio devices, voice synthesizers, haptic systems, and onboard printers. Other challenges include the need to protect the security and privacy of data, the need for the various technologies to be interoperable, and the need to ensure that the data generated and communicated by these new technologies are accurate and reliable. There are other challenges that are less technical in nature, such as encouraging wide-spread deployment and managing inter-organizational issues related to new technology applications.

## **INTRODUCTION**

This report explores new and emerging traffic safety technologies and how they can be used on the vehicle-roadway system to prevent crashes, increase compliance with traffic laws, and improve incident management and crash investigations. It is intended primarily for NHTSA field staff who are traffic safety professionals but not technology experts or experts in the field of intelligent transportation systems (ITS). State DOT safety staff and public safety professionals also might find it useful.

### **The Need for New Traffic Safety Technologies**

The number of highway vehicle miles traveled (VMT) in the United States grows each year, as do the numbers of drivers per household, of vehicles per household, and of vehicles per driver. The increase in seat belt use, the introduction of air bags, and the crackdown on drunk drivers have combined to decrease the absolute number of fatalities as well as fatality rates per VMT. However, there are still about 42,000 traffic fatalities per year.

A significant reduction in highway fatalities will require new, emerging, and future technologies. Technology is the means by which the performance of drivers, vehicles, and the roadway can be monitored and adjusted in a way that improves the overall level of safety on the highways. These technologies should be able to:

- Deliver safety information to drivers and vehicles and assist drivers in taking action to reduce the potential for crashes;
- Provide crash- and safety-related information to emergency responders to reduce response time;
- Provide information and automated processes that allow law enforcers to target high-risk drivers and reduce the labor involved in all aspects of traffic law enforcement; and
- Improve traffic safety education and outreach activities to create better prepared drivers who can take advantage of new safety technology applications.

### **Organization of the Report**

Section 2 provides background on traffic safety trends and Federal traffic safety goals. Section 3 describes the basic emerging technology toolkit and presents specific traffic safety technology applications that are currently in use or are being researched. Section 4 examines how these technologies and applications can be used to improve traffic safety. It addresses issues related to vehicle and roadway engineering, emergency response, law enforcement, and education and outreach. Section 5 presents some of the challenges and drawbacks to using advanced safety technologies and discusses ways to overcome them. The most important of these considerations are data privacy and human-factors issues because of their potential for unintended (and possibly dangerous) consequences. Section 6 concludes the report by highlighting successful technology applications and reiterating the potential for new and emerging technologies to have similar success.

## TRAFFIC SAFETY TRENDS

Improving the safety of the Nation's transportation system is USDOT's highest priority. Its goal is to reduce the Year 2000 highway fatality rate of 1.5 people per 100 million VMT to 1.0 by 2011, using the following performance measures:

- Reducing the rate of motorcycle fatalities;
- Reducing the rate of nonvehicle occupant fatalities;
- Reducing the rate of drunk-driving crashes;
- Increasing seat belt use; and
- Increasing use of restraints for infants and children up to 7 years old.<sup>1</sup>

### Driving Trends

The ever-increasing dependency on automobile travel in the United States is clear:

- From 1990 to 2006, the number of licensed drivers grew from 167 million to 202 million, an increase of 20%, about equal to the total change in the U.S. population.<sup>2</sup> During the same period, the U.S. population over the age of 16 increased by 16.5%;<sup>3</sup> the number of registered motor vehicles, by 27.5%; and the number of workers over the age of 16, by 28%.<sup>4</sup>
- From 1990 to 2001 (the most recent year for which vehicles-per-household data are available), the mean number of people per household increased slightly, from 2.56 to 2.58, or less than 1%, while the mean number of vehicles per household increased from 1.77 to 1.90, or 7.3%.<sup>5</sup>
- In 1990, 87% of the U.S. population over the age of 16 had a driver's license. By 2005, that number had increased to 90%.<sup>6</sup>
- In 2005, the ratio of private vehicles to licensed drivers was 1.15, indicating that there are more registered passenger vehicles than licensed drivers.<sup>7</sup>
- From 1980 to 1990, total VMT increased from 1.5 to 2.1 billion, or by approximately 40%. Between 1990 and 2000, this figure increased an additional 28%. By 2005, total highway VMT had increased to 3 billion.<sup>8</sup> This means that VMT doubled in the 25 years between 1980 and 2005.

Despite the mounting exposure of Americans to hazards on the road, both absolute levels and rates of injuries and fatalities per VMT have declined over time, as shown in Table 1.

**Table 1. Fatalities, Injuries, and Crashes from 1990 to 2006<sup>9</sup>**

Year	Fatalities (per 100M VMT)	Change (%)	Injuries (per 100M VMT)	Change (%)
1990	2.08		151	
1995	1.73	-17	143	-5
2000	1.53	-11	116	-19
2006	1.41	-8	85	-27

During the same period, the absolute number of passenger vehicle fatalities declined, from 44,599 in 1990 to 42,642 in 2006, or by approximately 4.4%. While fatalities decreased overall during this 16-year period, they increased by approximately 1.5% from 1997 to 2006.

The fatality rate, although at a historical low, showed signs of leveling off at 1.5 per million VMT. Figure 1 illustrates these trends.

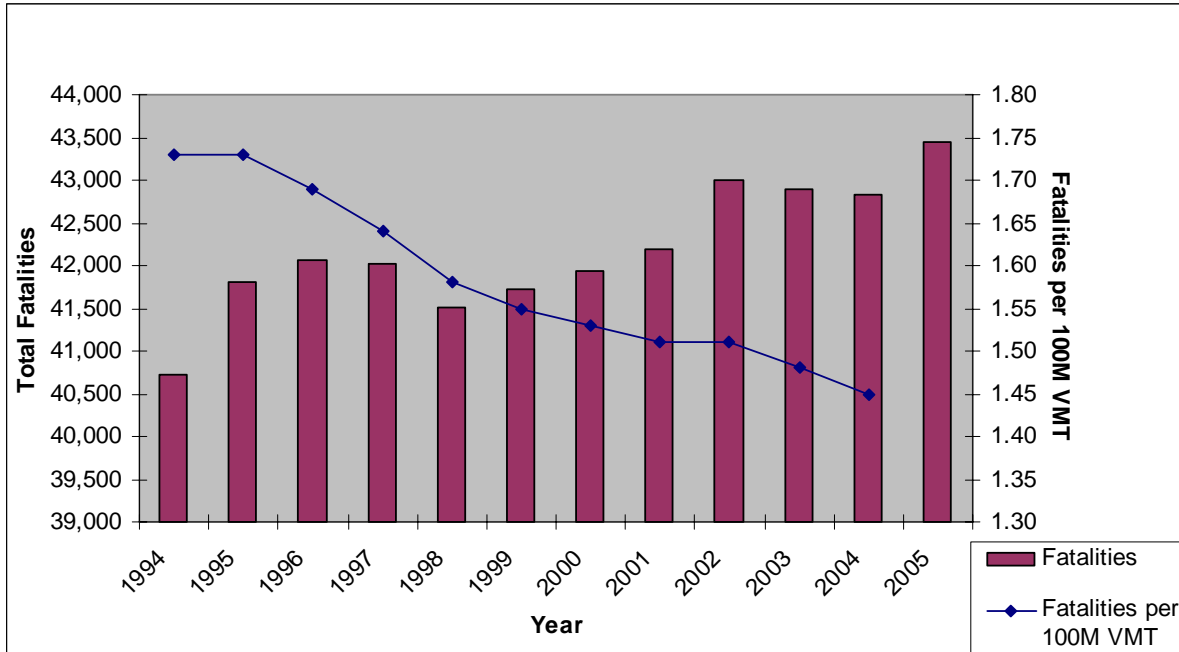


Figure 1. Highway Fatalities and Fatality Rates 1994–2005<sup>10</sup>

The absolute increase in fatalities can be attributed entirely to an increase in deaths of motorcycle riders, which more than doubled from 1997 to 2006, increasing from 2,112 to 4,810 fatalities per year. From 2000 to 2006, there was an absolute increase of 697 passenger-vehicle fatalities. During the same period, motorcycle deaths increased by 1,913.<sup>11</sup>

Between 1990 and 2000, the number of injured people on highways declined slightly each year, from 3.23 to 3.19 million, a 1% improvement, before decreasing sharply (by 19%) to 2.58 million in 2006. The total number of highway crashes went from 6.47 to 6.39 million from 1990 to 2000, a decline of 1%, and it decreased further, to 5.97 million, in 2006, a 7% drop, as shown in Table 2.<sup>12</sup>

**Table 2. Total Injuries and Crashes in 1990, 2000, and 2006**

Year	Total Injuries (in Millions)	Change (%)	Total Crashes (in Millions)	Change (%)
1990	3.23		6.47	
2000	3.19	-1.3	6.39	-1.2
2006	2.58	-19.1	5.97	-6.6

The percentage of total fatalities related to alcohol declined from 51% in 1990 to 41% in 2006. Passive and active restraints—seat belts and air bags—also contributed to a total decrease in passenger-car fatalities. Seat belt usage increased from 58% of vehicle occupants in 1994 to 80% in 2000.<sup>13</sup> In 2007 NHTSA reported seat belt use at 82%.<sup>14</sup> NHTSA estimates that seat belt usage saved approximately 15,383 lives in 2006.<sup>15</sup>

The losses from highway crashes can be expressed in dollars as well as in lives. In 2000, NHTSA estimated the total cost at more than \$230 billion each year, including almost \$33 billion spent on medical treatment. These costs also reflect lost income and other care-related expenses.<sup>16</sup>

Another trend worth noting in the context of traffic safety is the changing demographics of the American public as the population ages. Drivers who are 75 and older have higher fatality rates than all age cohorts except the youngest.<sup>17</sup> Loss of visual acuity, restricted mobility, and slowed reaction time contribute to the decreasing ability with age to cope with challenging traffic conditions. New technology applications such as collision warning systems can help to ameliorate some of the traffic safety effects of aging.

Not only is there an increasing percentage of older Americans who continue to drive, ride, and walk, but more of them want or need to continue to drive at older ages. These trends are already pronounced and will only accelerate as the Baby Boomers age. The U.S. Census Bureau estimates that the population of Americans over 62 will increase by 87% between 2005 and 2030. The number of oldest Americans—those over 82—is expected to increase by the same percentage. This is in contrast to an overall population increase of 23%.



## **TRAFFIC SAFETY TECHNOLOGY**

This section describes the technology building blocks that can be used alone or in combination to create systems or groups of systems that enhance traffic safety. As traffic safety applications become widespread and implementation costs decrease, there could be a network of advanced systems that improve traffic safety by providing information and services to drivers, traffic operations agencies, EMS personnel, and law enforcement professionals.

The combination of digital intelligence and wireless communications is being applied to vehicle and roadway safety systems, and there is great potential for future enhancements and applications. Inside the vehicle, digital intelligence allows for reliable safety-critical equipment such as traction control, antilock brakes, and air bags. Telematics—the combination of computer and communications technologies—allow the car and its occupants to communicate with the outside world. ITS and the Intelligent Vehicle Initiative, whose goal is “to accelerate the development and commercialization of vehicle-based driver assistance products that can assess the driving environment in ways that drivers cannot,”<sup>18</sup> allow communications between vehicles, between vehicles and the roadway, and among elements of the larger transportation-related network of resources.

Onboard automotive electronics systems such as traction control and stability control enhance the ability to safely operate a vehicle. Telematics provide the capability for Mayday notification to a private provider’s call center and possibly for automatic crash notification (ACN) directly to a public-safety answering point. ITS provides real-time traveler information on recurrent and nonrecurrent congestion. The Intelligent Vehicle Initiative will automate crash avoidance. Robust communications and digital networks will allow EMS, law enforcement, and public-safety organizations to communicate electronically with drivers and vehicles in ways that will enhance highway safety.

### **“Toolbox” of Components and Technologies**

The toolbox comprises a growing set of components and underlying technologies that can be assembled in many ways to create a wide range of existing, emerging, and future traffic-safety and enforcement applications. The capabilities made possible by networks enable voice and data communications among in-vehicle and roadway electronic devices, vehicle operators, public-safety communications centers, traffic management centers, and private-sector service providers. For example, collision-warning systems can be implemented with any of several technologies to gauge the distance between a vehicle and objects. These systems might use dedicated short-range communication (DSRC) for electronic communication between vehicles and the roadway, or they could use radar, infrared, and ultrasonic devices.

The technology available for traffic safety and enforcement is affected by trends that drive technological progress in general. The most notable trend is that changes in information technology and telecommunications are rapid and constant, in contrast to longer decision-making and implementation periods associated with the automobile industry and public agencies. Although the implications of these trends are seen most vividly in the consumer electronics market, they have strong significance for traffic safety and traffic law enforcement.

## Communications

Communications is the core technology needed for traffic safety systems. Wireless voice and data networks transmit the messages and other information among traffic system elements (including people) that make automated systems powerful. They can track uniquely identified objects worldwide in real time and transmit large amounts of data (such as video images) to and from mobile data terminals.

Communications technologies can transmit data between in-vehicle devices and allow data being generated within vehicles to be sent to an external entity such as a public safety response center. Data from an onboard system such as a sensing diagnostic module or a motor vehicle event data recorder (MVEDR) can be transferred to handheld, portable, or fixed external devices by crash investigators, vehicle operators, or repair shops.

Communications are enabled through technology standards. For example, if cell-phone companies had not developed communications standards, subscribers from one company could not call those from another vendor. Standards ensure that various devices can connect with others that use the same standards.

Transportation-specific standards are being promoted by alliances of automobile and semiconductor manufacturers, telecommunications companies, computer communications professional organizations, and government agencies for use in telematics and ITS applications. For example, one of the earliest transportation-related communications standards was developed to allow vehicle emissions data to be downloaded by inspectors.

### Types of Communication Systems

Future vehicle networks will have “plug-and-play” capability for mobile devices. This capability allows direct installation of devices without the need for installation of drivers; one simply plugs the device into a host computer and the device works. Such easily installed mobile devices could serve as input and output to the in-vehicle network as well as to external networks. Current handheld systems include:

- Cellular phone with GPS capability;
- PDA;
- Pager;
- Laptop or tablet computer with wireless capability; and
- Key fob implemented for remote key entry.

### *Vehicle-to-Vehicle*

Vehicle-to-vehicle communication is particularly useful for applications requiring communication between a patrol car and another vehicle. (Note that this discussion excludes the specialized area of intercommunication among mobile units belonging to public safety agencies.)

### Key Communications Concepts

**Bandwidth:** The data rate or frequency range of a communications system. The higher the bandwidth, the greater the amount of data that can be transmitted in a given time period.

**Operating band/radiofrequency spectrum:** The portion of the electromagnetic spectrum at which a device operates. In the United States, the FCC regulates radiofrequencies. The International Telecommunications Union regulates frequencies internationally.

**Operating range:** The maximum physical separation of devices within which the system can operate.

Sharply increasing speed and bandwidth available for communications applications are making features such as real-time transmission of video images both technically and financially feasible.

Also related to this type of communication is the ability of a laptop or other handheld system to query systems in a nearby vehicle. Police or other emergency service providers, such as tow-truck operators, could provide specific information to vehicle operators and obtain information directly from in-vehicle systems. It is expected that DSRC will provide one of the mechanisms for this type of communication. Uses of vehicle-to-vehicle and handheld-to-vehicle communications include:

- Aiding crash-avoidance systems;
- Signaling a crash or breakdown in the communicating vehicle;
- Signaling a crash or breakdown in the road ahead;
- Providing warning of an approaching emergency services vehicle such as an ambulance or police car;
- Informing the driver that a traffic-law infraction is occurring; and
- Acquiring identification or other data from the target vehicle.

#### *Vehicle to and from Roadside*

ITS devices at the roadside will have the ability to communicate with passing vehicles, generally using DSRC. Traffic signals, dynamic message signs, traffic condition monitors, and environmental sensor stations may all acquire the ability to communicate local conditions directly to drivers. In-vehicle signage and synthesized voice interfaces will present the information to drivers.

Conversely, the vehicle will be able to communicate with local roadside devices. Data used by traction control devices could alert roadside equipment that the roadway is becoming dangerously slippery. One way to characterize roadside equipment is by the permanence of its location. Permanently installed equipment includes traffic signals, toll booths, truck weigh stations, and garage doors. Mobile equipment includes portable changeable message signs and vehicle-mounted warnings.

#### *Vehicle to and from Traffic and Emergency Call Centers*

It is important for traffic and emergency call centers to be able to locate vehicles, equipment, and 911 callers. Emerging technologies are making this process easier and more accurate. For example, cell phone carriers are required to provide the infrastructure to automatically deliver the phone number and the location of caller with the 9-1-1 call itself. Some public-safety agencies are including location-based services in their intercommunications initiatives so that all units responding to an emergency or incident know the locations of all assets.

Private-sector call or communications centers are maintained as part of telematics and antitheft car-locating services. In current applications, only the automobile occupant or an event affecting the automobile (such as a crash) initiates contact with these centers. In the future, contact initiation by third parties, such as law enforcement agencies, through such centers or by the centers themselves may be possible.

### **Vehicle-Roadway System**

The communications technologies and applications described above link devices to form a road-vehicle-operator system that uses digital data to control the vehicle directly or to provide decision-support information to the vehicle operator. These devices include sensors, computers or electronic control units, actuators/controllers, data recorders, and the human-machine interface (HMI). The sensors digitize physical signals that are processed by a computer and can be recorded by an event data recorder. Through computer processing, actuators and controllers

activate vehicle brakes, steering, or other systems such as ACN. Messages or prompts can be delivered to the operator visually, aurally, or kinetically.

The following discussion will present a variety of sensor devices and systems, ranging from those that measure one logically simple input such as wheel speed to those that are more complex and evaluate data such as video images. Other vehicle control system components will be described briefly.

### Sensors

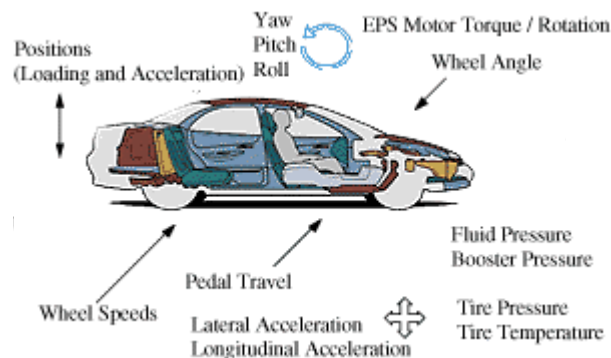
Sensors are being incorporated into vehicles and road environments to provide detailed information to systems and people on the state of the vehicle, the roadway conditions, and potentially, in the case of breath alcohol sensors, the state of the operator. Sensors combined with computing power and communications bandwidth enable the acquired information to be used rapidly by features such as anti-roll and traction control systems. Increasing computing power creates the possibility for more complex sensing systems based on image recognition or biometrics. In combination, these capabilities indicate a future vehicle “aware of” its environment and operating state and that can interact with the environment on the basis of this awareness.

### Onboard Sensor Applications

Figure 2 illustrates the types of vehicle operating parameters that could be measured by sensors. These include accelerometers, strain gauges, humidity sensors, and tire-pressure monitors.

Current onboard applications include:

- Core applications such as navigation and vehicle speed;
- Power-train management;
- Braking and traction management;
- Chassis management;
- Occupant protection; and
- Climate control and convenience.<sup>19</sup>



**Figure 2. Vehicle Operating Parameters Measured by Sensors<sup>20</sup>**

Together, these applications provide increased safety through automated braking, traction control, and rollover protection. They can potentially provide an enhanced traction control system that takes into account road curvature and slippery pavement conditions. The vehicle parameters most often monitored include speed, tire temperature, engine revolutions per minute,

emissions, braking and wheel slip, seat occupancy and seat belt use, gearshift position, and fuel consumption.

The vehicle also may carry devices that monitor and measure the external environment. These sensors provide information that allows the vehicle to interact with its surroundings. Parameters that might be measured include exterior light levels, ambient temperature, and proximity to nearby objects.

Sensing devices could monitor the driver as well as the vehicle and the environment, especially the presence of alcohol in the vehicle or on the driver's breath. Active and passive alcohol sensors are being used to detect drunk drivers and can be wired to vehicle ignition systems. Many States have instituted alcohol ignition interlock programs for drunk-driving offenders, which require the driver to breathe actively into a device that ascertains blood alcohol concentration before being allowed to operate the vehicle. Industry analysts expect that, in the future, passive alcohol sensors in the car will be linked to an integrated driver authentication or vehicle control system, which would be an enhancement of current remote keyless entry systems.<sup>21</sup> Toyota Motor Corporation is currently developing an alcohol interlock system that will use sweat sensors in the steering wheel to detect alcohol in the driver's bloodstream and will not allow the car to start if alcohol is detected.<sup>22</sup>

Sensors to monitor driver fatigue or impairment by tracking eyelid or pupil movement or detecting unusual driving performance require complex measurements and data processing. Nonetheless, such driver-performance monitors could be part of an integrated driver authentication and control system.

#### *Roadway Sensor Applications*

Just as the vehicle can be self-monitoring, sensors placed in or alongside the roadway can monitor passing vehicles for motion, speed, direction, position with respect to other vehicles, type, weight, registration, and permits or authorizations. These sensors can also monitor roadway environmental conditions, including visibility, surface traction, flooding, and icing. This information can be used to set speed limits that vary depending on road conditions.

Environmental sensor stations provide data on local weather conditions to road weather information systems, which in turn provide decision-support information to drivers and roadway operators through automated signage such as dynamic message signs. An environmental sensor station can provide readings for air, subsurface, and pavement temperatures; precipitation type; and intensity.

The roadway also has the ability to monitor its own condition. Strain gauges, optical sensors, and devices to detect corrosion are being used to increase bridge safety. Currently, most such sensor systems do not send information automatically; rather, users need to interrogate the sensors to get data.

#### *Biometric and Biochemical Sensors*

Biometrics refers to the use of innate physical characteristics to identify individuals. Such characteristics include patterns in fingerprints, palms, veins, iris, retina, and voice. Biometrics may also recognize individuals through signature stroke, facial or body geometry, or combinations of measures like weight and height. Advanced driver-authentication and vehicle-control systems are likely to incorporate biometric driver identification in the future. Early applications have been for the authentication of commercial vehicle drivers.

### *Advanced Sensor Technologies*

Sensor technology has been advanced by the introduction of microelectromechanical systems (MEMS) and the integration of mechanical elements such as sensors and actuators with silicon microchips. The microchips can be thought of as the “brains” of the system, while the mechanical elements are sensory receptors analogous to eyes and ears. This combination allows for the creation of relatively inexpensive “smart” technologies.<sup>23</sup> The automotive industry uses MEMS sensors for engine air-intake gauges, accelerometers in air bags, and rate gyroscopes in ABS. The benefits of MEMS include more functionality with less weight and cost.

Another sensor technology being advanced in the automobile industry is the optoelectronic device, which detects either ambient light or a property of light such as intensity or color and converts it to an electrical signal. Proponents of this technology claim higher reliability and longer life because optoelectronic sensors are noncontact devices. These sensors are being used in safety-related comfort and convenience functions such as auto-dimming mirrors, automatic windshield wipers, automatic control of environmental systems based on sunload, and occupancy detection.<sup>24</sup>

### **Global Positioning Systems**

GPS consists of three components:

- Satellites that provide their time and position;
- A series of ground-tracking stations that compute satellite orbits and time corrections; and
- User devices that compute and report location based on signals from the satellites.

Advanced forms of GPS permit the calculation of position with a precision of less than a centimeter. GPS is also a navigational system and enables the calculation of direction and speed, although with less precision than for stationary targets. In transportation and traffic safety, GPS allows tracking of GPS-equipped vehicles. With sufficient accuracy to detect small distances between objects, GPS can be designed into crash-avoidance systems. One of GPS’s major limitations is that the receiver typically requires direct line of sight with four satellites to compute location. This satellite requirement is problematic in certain locations, such as in urban areas with tall buildings or rural areas with mountains, where this direct line of sight is prevented. However, enhancements to GPS technology such as Assisted GPS (A-GPS) allow computation of location by using an assistance server that increases the computing capabilities of the GPS receiver. Such improvements will allow enhanced 911 systems (GPS-enabled 911 systems that can locate other GPS-enabled devices such as mobile phones) to detect the location of more callers.

The Federal Communications Commission requires cell-phone providers to deliver callers’ phone number and location data to public safety answering points (PSAPs, otherwise known as 9-1-1 call centers), either by triangulating callers’ locations with nearby cell towers or GPS. Both forms of technology have limitations. “Triangulated” cell towers are less frequently found in rural areas and the utility of GPS, as previously mentioned, can be limited in urban areas with tall buildings that block signals.

### **Imaging Systems**

Imaging systems enhance the acuity and field of vision of the vehicle operator, provide input to automated vehicle control systems for crash avoidance or adaptive cruise control, and, when installed on the roadway, yield image data for vehicle identification or determination of traffic conditions. Images can be acquired with use of any of several regions of the electromagnetic spectrum, including radar, infrared, and visible light. Systems using ultrasound



to form images are also being developed. The different technologies exhibit varying degrees of applicability for adverse weather conditions, high vehicle speeds, and automated vehicle control systems.

The Eaton vehicle onboard radar system has been installed on several truck and bus fleets as a crash-warning system. It uses several sensors to detect objects alongside and behind the vehicle. The system gives audible and visual alerts to the driver. General Motors is marketing the Raytheon night vision system in some Cadillac models. Used in low-light conditions, this system projects an infrared image of the road onto the windshield, making hard-to-see objects visible to the driver in time for evasive action.

Incident management systems being deployed by roadway operations and public-safety agencies provide real-time images to traffic management center staff and on-scene responders. One such system is the New York State Integrated Incident Management System.<sup>25</sup>

Imaging systems installed on the roadway often add image recognition to image acquisition. For example, the congestion pricing scheme in London uses license-plate-image recognition, which allows authorities to identify vehicles not in compliance with cordon line regulations. Although automated vehicle identification can also be accomplished with electronic tags, imaging systems offer a way to identify vehicles without the need to issue special tags. Image-recognition systems are also being developed to detect traffic conditions or anomalies automatically.

### **Other Vehicle-Roadway System Components**

The above examples of applications of communications technology and sensors in the vehicle-roadway system presume the existence of the system's other components:

- Computers—processors and controllers;
- Actuators—parts that receive electrical signals and convert them into mechanical movements in the vehicle; and
- Data-storage or recording devices—elements that give data persistence and longevity for asynchronous use after the event or circumstances have been recorded.

#### **Computers and Controllers**

The data being generated by sensors are interpreted by an electronic control unit (ECU). The modern automobile can have 80 or more ECUs on board. The ECU determines the proper operating parameter values for the actuators in the system that it controls. The computers contain processing space (memory, expressed in Mb) and processing power (time cycles, expressed in MHz). These resources are limited by cost, power, and reliability.

The software programmed into ECUs interprets sensor inputs, relates them to other data or process protocols, and makes decisions. These decisions include the self-monitoring of component performance, the processing of algorithms linking crash dynamics and likely injury severity, antitheft restrictions, driver performance that suggests impairment, violations of hours-for-service restrictions by commercial vehicle operators, and comparisons of location and associated speed or access restrictions.

#### **Actuators**

Actuators are small motors that convert electrical signals to mechanical motion. In remote key entry, for example, the signal received from an electronic key fob is converted to the movement that actually locks or unlocks the car door. Automobile actuators can be applied to

systems for speed control; ignition; braking; steering direction; windows; door locks; occupant protection; emissions; fuel, air, and power supply; lights; horn; seat position; entertainment; and antitheft devices. In combination with sensors, actuators enable various ignition interlock systems.

### Data Storage and Recorders

Storage devices take different forms and store a wide variety of data and data formats. Over time, they devices are becoming smaller but have higher capacity.

*Personal devices:* Smart cards are data storage devices that are carried by the user. Credit cards and, increasingly, driver's licenses contain a magnetic strip for storing data related to the card's owner. Smart cards allow data to be written to the card. They sometimes contain additional functions that can process the data being stored and produce output to an external system based on that processing.

*Onboard devices:* Event data recorders (EDRs) capture the operating parameters of a vehicle immediately prior to a crash. Data recorded by the EDR are owned by the vehicle owner. NHTSA defines an EDR as, "a device or function in a vehicle that records the vehicles dynamic, time-series data during the time period just prior to a crash event or during a crash event, intended for retrieval after the crash event." Current automobile production models that do incorporate this technology must record 15 operating parameters. These parameters, which include elements such as vehicle speed, change in velocity ( $\Delta v$ ), and driver seat belt status, are instrumental in accident investigation and air bag deployment.<sup>26</sup>

In addition to original equipment EDRs, aftermarket data recording equipment can record information that can be used for additional functions such as:

- Owner-entered data by individuals or fleet owners;
- Driver-entered data;
- Vehicle-generated non-crash data such as that pertaining to speed, acceleration, braking, seat belt use, air bag deployment, cell phone use, maximum operating speed, prior startup locations, fuel consumption, and emissions;
- Shipper-entered data, especially that pertaining to hazardous materials tracking;
- Original equipment manufacturer data, such as updated algorithms for air bags and ACN warnings, entered during manufacturing, at the dealer, or aftermarket;
- Repair data; and
- Data from courts, State departments of motor vehicles, or other authorities.

Aftermarket data recording equipment can be linked to recording systems for imaging data, which have high storage requirements. There is also an opportunity for data to be aggregated to provide early warning for equipment recalls and potential systemic vehicle safety problems.

The mere fact of vehicle monitoring technology installed in vehicles could lead to safer driving behavior. Drivers who are aware that their vehicles' actions are being stored in the device might be less inclined to engage in unsafe driving behavior. Preliminary research findings indicate that this technology, coupled with feedback from parents, has potential to reduce risky driving behaviors among teen drivers.<sup>27</sup>

*Traffic management center devices:* Roadway devices such as automated traffic counters and closed-circuit cameras allow traffic management centers to retrieve and archive an extensive

amount of data. Real-time data are used to control congestion and manage incidents. Archived data help traffic operations agencies, public-safety agencies, and first responders to study incident response and improve their techniques. A system currently operating with use of such archived data is NHTSA's Crash Injury Research and Engineering Network, which links crash, emergency medical response, injury, and treatment data.

### **Human-Machine Interface**

Even if the vehicle control system becomes completely automatic, the HMI will be needed for the vehicle-roadway system to deliver information to and receive it from the vehicle's occupants. Meanwhile, with increasing networked capabilities delivered to automobile occupants from external and in-vehicle systems, the driver will face growing demands on the amount and diversity of information that must be processed while at the same time operating the vehicle. Vehicle control system HMI could include elements that are also part of the in-vehicle entertainment telematics.

The primary requirement of the in-vehicle HMI is to deliver the needed or desired information while minimizing driver distraction. This can be done through careful placement of the HMI device within the vehicle and by the way it relays relevant information. Available technologies for HMI include voice activation, speech recognition, dashboard lights and icons, heads-up or panel displays, audio devices, voice synthesizers, haptic (i.e., using the sense of touch) systems, and onboard printers.

Voice technologies will be a critical part of any HMI. These technologies will need to account for the ambient noise of an operating vehicle. Voice commands should be simple and intuitive so that they do not distract drivers from their primary task of driving. They also need to account for the problem of driver complacency, where a driver becomes dependent on onboard technology and begins to ignore the tasks involved in driving.

### **Examples of Integrated Technology Systems**

The following discussion presents examples of how the devices, components, and systems described above can be integrated into traffic safety applications. Applications often use more than one set of technologies or components.

#### **Locational and Mapping Applications**

Locational and mapping applications use GPS receivers to determine the location of an object and to communicate this information to users. Applications related to traffic safety and law enforcement include:

- Geofencing, whereby an alarm sounds at a center or in the vehicle if a GPS-equipped vehicle enters a previously demarcated area;
- Navigation, to guide drivers to their destination; and
- Vehicle control, whereby information on local road geometry can be delivered from a central location without the need for vehicle-to-roadside communication.

#### **Electronic Toll Collection (ETC)**

ETC requires an electronic in-vehicle identification tag, a roadside tag reader, a wireless communication device to pass information between the tag and the tag reader, and "back-office" databases and software for billing. By using open standards, separate ETC systems are increasingly becoming interoperable, allowing drivers to use their in-vehicle tag to pay tolls throughout the country. This interoperability also provides an opportunity to use toll tags for other applications, such as paying for parking.

### Automated Crash Notification

Current telematics applications provide Mayday functions. In properly equipped vehicles, this function relays a message to a telematics operations center when, for example, the vehicle's air bag has deployed, signaling that the vehicle has been involved in a crash. With General Motors' OnStar system, operation center personnel determine the location of the vehicle through cellular tower triangulation, and then relay the information to the relevant emergency call center as necessary, using predetermined protocols. The OnStar system has included this capability since 2004. OnStar ACN capability is currently limited to drivers who are paying subscribers for this service.

Later-generation systems will provide more sophisticated ACN functions commonly referred to as Advanced Automatic Crash Notification (AACN). Additional sensors could provide telematics operations centers and emergency services personnel with crash details, such as the number of occupants in the vehicles, the force of the crash, and the direction of impact. A PSAP could use these data as part of a comprehensive protocol, to determine the appropriate response. Trauma center could input these parameters into a model to predict the extent and types of injuries involved, to facilitate the most appropriate treatment upon arrival of crash victims.

### ITS/Commercial Vehicle Operations (CVO)

FMCSA and USDOT's ITS Joint Program Office are developing ITS safety applications for CVO. The devices and components include electronic vehicle tags, vehicle and driver smart cards, heads-up data displays, object proximity alarms, wireless communications, and embedded roadside devices for vehicle-to-roadside communication. ITS/CVO applications include:

- Electronic credentials for vehicles, drivers, and loads;
- Automated inspections allowing the downloading of information on truck characteristics, such as identification number and owner/operator;
- Automated size and weight detection;
- Enhanced fleet management;
- Cargo tracking, particularly important for hazardous materials; and
- Electronic driver hours-of-service logs.

## REACHING TRAFFIC SAFETY GOALS WITH USE OF TECHNOLOGY

This section reviews emerging technologies and previews promising future technologies. It describes specific technologies that are currently in deployment, under research and development for near-term (within five years) deployment, or in the conceptual design phase for future deployment. The section has two main purposes:

- To identify characteristics of technologies that successfully reached deployment, thereby aiding in the selection of technologies that can help to eliminate highway crashes
- To help policy makers understand conceptual designs for traffic safety technology so they can decide in which highway safety technologies to invest

### Haddon Matrix

The Haddon matrix, developed by William Haddon, Jr., NHTSA's first administrator, provides a framework for targeting different stages and influential factors of a crash. It consists of a matrix in which the y-axis characterizes the crash sequence as pre-crash, crash, and post-crash. The x-axis separates factors that contribute to crashes into human, vehicular, and environmental (physical or social) categories. Figure 3 shows the Haddon Matrix format.



Figure 3. Haddon Matrix Format

Using the format depicted above, Table 3 provides an example of how the Haddon matrix can be used to analyze a crash.

Table 3. Examples of Crash Scenarios, Using the Haddon Matrix

		Influencing Factors		
		Human	Vehicle	Environment
Stage of Crash	Pre-crash	Driver falls asleep at wheel.	Driver drives too fast on a horizontal curve.	Roadway lighting is poor.
	Crash	Driver crashes into car ahead, and head snaps forward.	Two cars crash head on.	Vehicle spins out and leaves roadway.
	Post-crash	Emergency responders arrive to help injured people and to clear the scene.	Firefighters extinguish engine fire.	Police arrive to assess scene.

### The “Four E’s”

Often used to capture the necessary aspects of a successful traffic safety program, the “Four E’s” are:

- Engineering;
- Emergency response;
- Enforcement and regulation; and
- Education and information.

Engineering focuses on road and vehicle design improvements that promote traffic safety. Emergency response includes 911, paramedics, law enforcement, firefighters, and hospitals. Enforcement and regulation comprise laws and their enforcement. Education and information aim to give drivers knowledge to improve their driving behavior. These four aspects are meant to be addressed together in a comprehensive traffic safety program.

The following discussion divides technologies for traffic safety into the “four E’s.” Each section describes the problem and then presents the possible technological solutions.

### Engineering

#### *Types of Crashes and Avoidance Technologies*

New technologies are emerging that can assist the driver when a crash is imminent by alerting the driver to a threat or by taking over when human reaction would not be adequate. As shown in Figure 4, 85% of all crashes are due to road departures, rear-end collisions, collisions at an intersection, and lane-change and merge collisions. This has led USDOT, in partnership with the automobile industry, to develop and promote collision-warning technologies for these types of crashes, in an initiative known as Integrated Vehicle-Based Safety Systems.

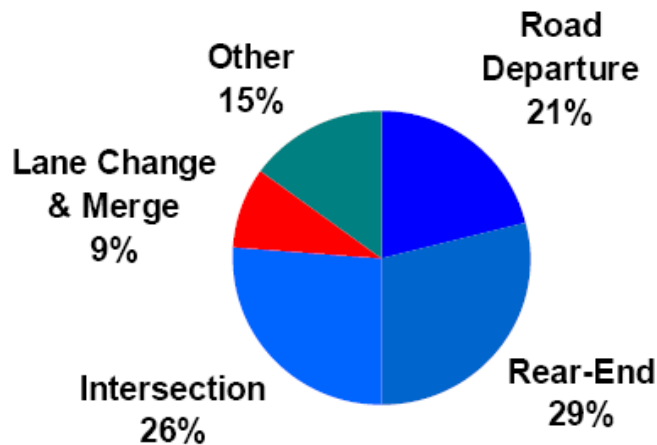


Figure 4. Crash Type Distribution, 2002<sup>28</sup>

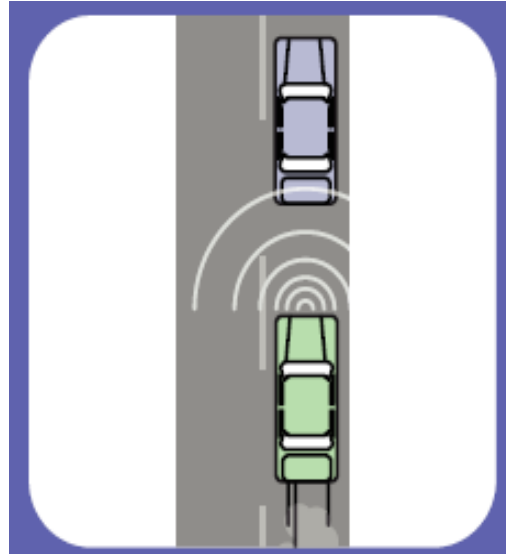
A key component of this initiative is that the various warning systems are implemented as a single system rather than as various stand-alone technologies. While each warning technology is expected “to reduce driver workload and driver reaction time,” the integrated system is expected “to prevent conflicting warnings; reduce false alarms; and reduce unintended consequences such as causing a road-departure crash while trying to prevent a rear-end crash. The integration of these individual crash warning systems is expected to improve overall system



performance, increase safety, reduce system cost, improve consumer and fleet operator acceptance, and enhance product marketability.”<sup>29</sup>

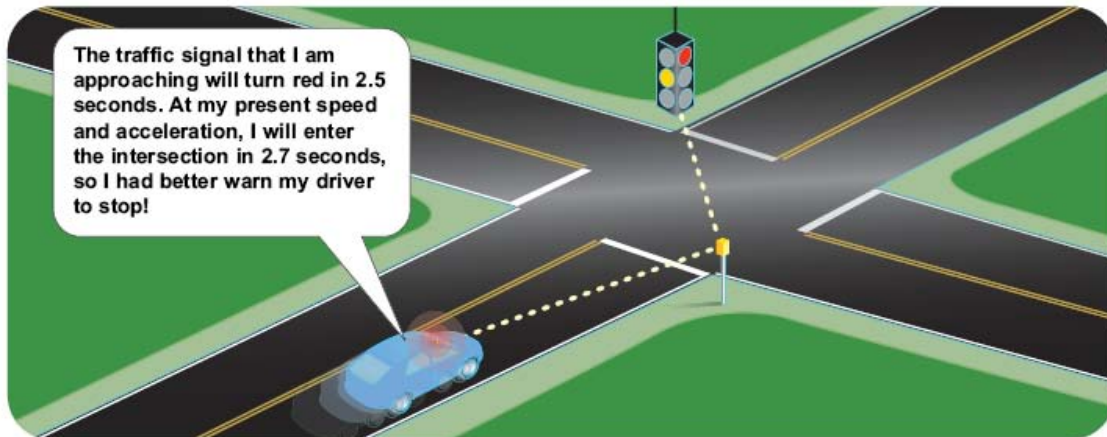
Crash-warning technology systems are engineering solutions to pre-crash scenarios. Research is being conducted on the use of radar or laser radar sensors to monitor vehicles, obstacles, and road markings, as shown in Figure 5.<sup>30</sup> If an impending crash is detected—for example, if a vehicle is approaching another vehicle or an obstacle too quickly, or if the gap between them becomes too small—the system warns the driver through visual or audio cues. An enhancement to the crash-avoidance warning system would involve a technology such as adaptive cruise control, which allows a vehicle’s cruise control to automatically adapt the vehicle’s speed to the traffic environment.

Stand-alone crash-avoidance technology has been implemented on a small scale. Some buses have been equipped with lane-change-assistance and crash-avoidance technology, which detects the presence of and distance to lateral vehicles and objects. Some large truck fleets have been outfitted with rear-end and lane-change crash-avoidance technology to address the most common types of crashes for these vehicles. In 2006, General Motors began to offer rear-end crash avoidance systems and adaptive cruise control as options on several of its models.



**Figure 5. Rear-End Crash Avoidance Technology**

As the technology becomes more sophisticated, vehicle-to-roadway communications systems could be implemented. For example, roadway edge lines could be equipped with electronic tags that trigger an in-vehicle sensor if a vehicle gets too close to the line. Vehicle-to-roadway technology is also likely to be very effective in preventing intersection crashes, as depicted in Figure 6.<sup>31</sup>



**Figure 6. Example of Vehicle-to-Roadway Communication in Intersection Crash Avoidance Technology**

Left-turn-assist intersection crash-avoidance technologies are being developed that would detect pedestrians and oncoming vehicles and control the left-turn signal accordingly. The fully integrated crash-avoidance technology envisioned for the Integrated Vehicle-based Safety Systems initiative is being tested but has not yet been implemented.

#### *Technologies to Assist Drivers in Degraded Roadway Conditions*

Degraded roadway conditions refer to environmental circumstances that impair a driver's ability to drive safely, for example ice, fog, or poor roadway lighting. Research is ongoing to help drivers safely navigate the roadway under these conditions. Some night-vision-enhancement technologies are already on the market. They detect objects by infrared technology and display the objects' images on an in-vehicle device along with audio warnings. Future technologies include infrared reflective lane-edge markings that will help drivers to stay in their lane and avoid lane-drift and roadway-departure crashes.

Speeding—driving over the speed limit or too fast for roadway conditions—is a factor in approximately 31% of all traffic fatalities.<sup>32</sup> A potential tactic to address this problem is implementing safe speed guidelines for different roadway sections under varying weather and roadway conditions. The safe maximum speed limit on a roadway during sunny, clear days can differ dramatically from that on an icy morning in winter. Both vehicle- and infrastructure-based systems are being considered for this application. The maximum safe speed on a roadway could be sent to a database in each vehicle, or it could be broadcast or displayed by roadside equipment. Technology in equipped vehicles could then restrict the driving speed or issue a warning to the driver.

#### *Vehicle Engineering*

Engineers are designing driver-assistance technologies to help with steering out of an emergency situation, similar to the way that ABS has assisted drivers in preventing skidding. ABS is now a component in many new technologies, such as electronic stability traction control. This technology helps to maintain vehicle stability in situations where over- or understeering could result in loss of vehicle control. The use of electronic stability control in sport utility vehicles, which are notorious for their propensity for rollovers, began in the late 1990s and has been shown to have substantial benefits in terms of avoiding crashes and reducing their severity.<sup>33</sup>

Other crash-avoidance vehicle engineering includes electronic brake systems, recently introduced into the automobile market. This technology provides drivers with faster braking response. Future technologies include selective braking and steer-by-wire. Selective braking uses computer processing to apply braking to selected wheels and to influence steering angles, thereby preventing drivers from losing control of the vehicle. Steer-by-wire replaces the mechanical connection between the driver and the front tires with actuators at the front wheels for better brake response. Additionally, steer-by-wire can be applied to the back wheels to offer lateral crash-avoidance options not available in other technologies such as ABS or those for stability control.

#### *Roadway Engineering*

Systems allowing roadside devices to communicate with vehicles are being designed. Tests are being conducted on how to transmit data indicating contact with the right and left edges of the pavement and with pavement markings so that equipped vehicles can detect lane-drifting. Other tests are focused on how to change roadway lighting depending on the time of day and the weather. The Smart Road in Virginia is a two-lane roadway with weather towers that produce simulated weather conditions for the testing of:

- Pavement, pavement markings, and lighting design and markings;
- Advanced headlamps; and
- Signaling systems.

Simulated weather conditions also enable the training of snowplow operators and the testing of advanced snowplows, emergency vehicles, and anti- and de-icing techniques.

#### *Injury Severity*

Before being finalized, vehicle designs go through extensive crashworthiness tests, including those for frontal, side, and offset impacts; rollover resistance; operation at different speeds; and air bag and seat belt effectiveness. Sensors are attached to crash-test dummies to measure the placement, magnitude, and angles of impact.

Recent research for reducing injury severity has focused on:

- *More protective seat belt designs:* Ford and Volvo are investigating the application of four-point seat belts, similar to those worn by race car drivers, for passenger vehicles.<sup>34</sup>
- *Automatic vehicle safety feature adjustments:* Optimal positioning of safety features in a vehicle depends on the size and weight of the occupants. Such positioning can increase the chances of survival and decrease the number and severity of injuries sustained in a crash. Safety features that can be adjusted include mirrors, head restraints, and seats. Adjusting the deployment force and positioning of air bags based on the age, weight, and height of the seat's occupant can optimize the device's effectiveness while decreasing the risks associated with deployment.
- *Side air bags:* In 2007 NHTSA upgraded the Federal Motor Vehicle Safety Standard for occupant protection in side-impact crashes to include head and improved chest protection. The revision will result in the installation of side air bag systems estimated to save more than 300 lives, annually.<sup>35</sup>
- *External air bags:* Car manufacturers are introducing these devices in so-called concept cars to protect pedestrians and occupants of other vehicles during crashes. Air bags located at the front bumper and the windshield are meant to prevent the most common types of pedestrian injuries.
- *Improved vehicle bodies and materials:* Using pedestrian crash-test dummies, Honda has tested specially designed hood structures and hinges, front-frame construction, and breakaway wiper pivots for inclusion in selected vehicle models. These features could reduce pedestrian injuries in the event of a crash. Research is also being conducted on materials and their shapes, both of which contribute to absorbing the impact of a crash and dispersing the impact's energy over a larger area.<sup>36</sup>

#### *Engineering Haddon Matrix*

Applying the Haddon matrix to engineering considerations, the technologies intended to prevent imminent crashes altogether generally apply to the pre-crash phase, while those intended to reduce injury severity fall within the during-crash phase, as shown in Table 4.

**Table 4. Engineering Haddon Matrix**

Technology	Phase	Human	Vehicle	Environment
Alcohol interlocks	Pre-Crash	x	x	
Drowsy driver		x		
Rear-end crash avoidance			x	x
Merge		x	x	
Road departure		x	x	
Lane change		x	x	
Intersection crash avoidance		x	x	
Night vision			x	x
Variable speed limits		x	x	x
Electronic stability program			x	
Roll stability control			x	
Electronic brake systems			x	
Steer-by-wire			x	
Roadway engineering				x
More protective belt designs		During Crash		x
Automatic vehicle safety-feature adjustments			x	
Side air bags			x	
External air bags			x	
Improved automobile bodies and materials to minimize injury to pedestrians			x	

### Emergency Response

The Emergency Response System consists a comprehensive system of emergency medical treatment and transport, including 911, emergency medical services (EMS), law enforcement, and firefighters, hospitals and trauma centers. A coordinated emergency response mitigates the economic and medical consequences of traffic crashes by using resources appropriately and efficiently. Technology and information, appropriately applied and supplied, can be of great assistance in such emergency situations. Figure 7 shows the major components of the emergency response system.

#### *Components of Emergency Response*

EMS systems are generally funded and governed at the local, regional, or State level. EMS systems are complex; the behind-the-scenes activity includes resource management and administration; professional training; the communications system (911, communications centers, and supporting telecommunications links); medical oversight; quality evaluation/improvement; and research. NHTSA's Office of Emergency Medical Services (OEMS) provides leadership to local EMS systems and develops programs and products in partnership with other Federal agencies, such as the Department of Health and Human Services, Department of Defense, Indian Health Service, and U.S. Fire Administration (part of the Federal Emergency Management Agency). NHTSA's goal is to provide everyone, whether in a small town or large city, with timely, effective emergency medical care. NHTSA promotes and supports EMS system integration among levels of government and among all component areas of EMS.

# The Emergency Medical Services System

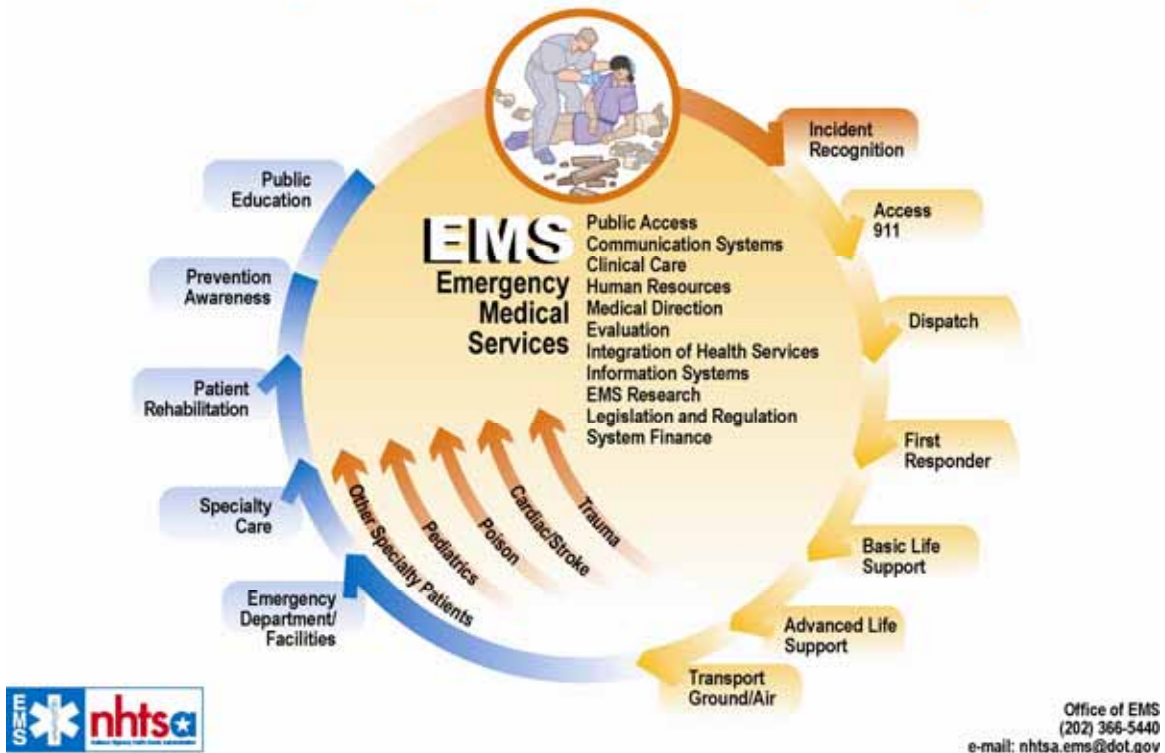


Figure 7. Components of Emergency Response Services

Law enforcement agencies interact with EMS. They are responsible for managing incidents by directing traffic to allow EMS providers to access victims safely, thereby reducing secondary collisions and minimizing the effects on traffic flow of both the incident and the response effort. They are also responsible for collecting crash data and filing the crash report.

## Technological Solutions

*Automatic crash notification:* Automatic crash notification currently takes the form of Mayday systems, such as OnStar, ATX Technologies, and AAA Response. These systems automatically notify a private call center when a vehicle's air bag has deployed or an emergency call button has been depressed and then transmit the vehicle's location as well as establish voice communication with the occupants of the vehicle. The call center alerts local responders to the crash and its location as necessary, consistent with predetermined protocols. It attempts to make a voice connection between the operator and the vehicle occupants so that those who are conscious can provide more detailed information about the crash and the operator can advise them on what to do until help arrives. Mayday systems are now standard in many higher-end vehicles. Such systems can be especially effective in rural areas, where an accident can go unreported for a long period before it is noted by a passing driver.<sup>37</sup>

These current ACN systems require that private call centers—the forwarders of the crash notification—be able to communicate quickly with regional and local PSAPs. Each center currently keeps its own database of contact phone numbers for all PSAPs.



The telecommunication services used by future ACN systems could provide event data such as crash severity in addition to location and a voice channel to the call center. Additional event data could include information such as the change in velocity upon impact, the direction of the crash (frontal, side [right/left], or rear), the number of vehicle occupants, vehicle identification number, and vehicle description. This information would help emergency responders to dispatch the appropriate equipment. PSAP equipment would need to be upgraded to be able to receive electronic data sent from the vehicle so that they could receive the emergency notification simultaneously and emergency responders could be dispatched automatically. The format of the ACN data would need to be standardized so that all response centers could receive and decode it.<sup>38</sup>

Another advance in ACN systems would be the ability to transmit to PSAPs not only event data but also vehicle occupants' medical information and histories, such as data pertaining to preexisting conditions; the names of primary care physicians; and emergency contact information. This might be done through central databases that store medical information accessible only in the event of a crash, on the vehicle, or on a smart-card driver's license. Having highly accurate and consistent medical information available at the crash scene, en route to the emergency room, and on arrival at the hospital would be of enormous value to both crash victims and emergency personnel. Concerns about privacy and security in relation to keeping such information in a central database have been raised and would need to be addressed.

*Efficiency and cost of emergency services:* Technology can improve emergency services efficiency and may reduce costs. It can help reduce response time by dispatching emergency vehicles efficiently and passing information between agencies quickly. Standardized information exchange between 911, law enforcement, fire departments, EMS, hospitals, and traffic management would greatly assist coordination of the emergency response process. Many 911 centers have the ability to quickly and accurately disperse information about incidents. Standardization of this data-exchange format would decrease the costs of upgrading legacy systems and enable regional response centers to share data.

Data from traffic management centers could help emergency vehicles to find the least congested route to the scene of an accident and then to the hospital. Such data could also be useful by allowing the posting of variable message signs to route traffic around the accident site. Reducing the time that emergency vehicles spend in traffic would improve patient outcomes and increase the number of rescues for which each vehicle could be available.

*Crash investigation and analysis:* Much of the same information being reported by ACN systems is useful for crash investigation and analysis. Electronically collected crash data can reduce the time needed for police crash reports to be entered into the community's crash database. It also may discourage unwarranted litigation and fraudulent claims. Detailed data obtained from the crash can be used to generate animated, three-dimensional analyses of crash dynamics and causality. Sensors would have to be developed and installed in vehicles in order for these data to be collected.

The continuous collection and consolidation of crash and medical data, including those pertaining to long-term medical consequences of injuries, would help emergency service personnel to evaluate their programs and better understand the nature and characteristics of transportation problems. Analysis of comprehensive data across traffic safety, health-care delivery systems, and patient outcomes could be used to improve EMS response. An example of such an effort is the Crash Injury Research and Engineering Network (CIREN). In an effort to understand the interactions between crash and injury, the CIREN database compiles over 650

crash, medical, and biomechanical data elements from a sampling of crashes in the National Automobile Sampling System.

*Emergency medicine training:* Frequent training on emergency medicine care keeps EMS providers up to date on advances in emergency response technology and medicine. The Internet can provide access to emergency response training information quickly and uniformly to emergency service professionals across the Nation. Interactive training allows EMS providers to simulate responses to vehicles equipped with ACN, learn about new medical research and techniques, and share information about emergency response best practices from other agencies.

*Enhanced 911:* Most 911 call centers have long been able to identify the phone number and location of landline call. In recent years, the majority of PSAPs have also upgraded their technology to enable them to receive the phone number and the location of callers using mobile phones. Knowing the phone number of the caller is important so that the 911 operator can call the caller back if the phone connection is lost. The location is important for two reasons: first, to route the call to the appropriate 911 call center; and second, to inform emergency responders of the exact location of the caller. The Enhanced 911 (E911) initiative was implemented to address these problems.

The FCC has enacted rules requiring telecommunication companies that are interconnected to 9-1-1 networks, to provide the technologies that automatically deliver 9-1-1 calls to PSAPs with the phone number and the location of the caller. Telecommunication service providers have the option of using either triangulated cell towers or GPS to determine the caller's location.

E911 will enhance emergency response by more accurately locating the site of emergencies. This is especially important for traffic-related emergencies since some roadways—especially freeways and rural roads—lack clearly identifiable landmarks that callers can use to determine and describe their location.

In 2004, Congress passed legislation requiring the creation of the E911 Implementation Coordination Office. This office is a joint program between NHTSA and the National Telecommunications and Information Administration (NTIA) at the U.S. Department of Commerce. The purposes of this office are to facilitate coordination among all 9-1-1 stakeholders, act as a clearinghouse for PSAP information on technology in 9-1-1 services, and administer a federal grant program that provides funding to upgrade 9-1-1 network technology.

*Next Generation 911:* Next Generation 911 (NG911) will allow 911 call centers to receive information in a variety of electronic formats such as text, video, and data, in addition to the voice communication that is now available. This technology will enable emergency responders to receive detailed real-time information about emergency situations.

NG 911, which is currently in the research and development phase, will develop an architecture of 911 technology, demonstrate selected requirements within that architecture, and complete a transition plan that includes strategies for dealing with major implementation issues such as governance and funding. The outcome of this project will establish a foundation for emergency communications within digital, Internet Protocol-based technology and enable PSAPs to receive and share a variety of new and useful information with emergency responders.

*EMS Technology Evaluation Template:* The EMS Technology Evaluation Template is a set of evaluation criteria to help EMS agencies, technology developers, and manufacturers assess

new forms of technology before they are deployed in the field. By establishing common evaluation criteria, it is possible that EMS providers and technology providers can work together to develop technologies that are useful in improving emergency medical care and outcomes for the patients EMS cares for.

*Emergency Response Haddon Matrix*

Emergency response technological solutions apply to the post-crash phase of the Haddon matrix, shown in Table 5. Data collected in this phase could be used to evaluate post-crash procedures and improve crash response.

**Table 5. Emergency Response Haddon Matrix**

Technology	Phase	Human	Vehicle	Environment
Automated crash notification	<b>Post-Crash</b>		x	x
Passenger medical information			x	x
Standardized information exchange			x	x
Electronically collected crash data			x	x
Continuous collection and consolidation of crash and medical data for analysis				x
Educational response information				x
E911				x
NG911				x
EMS Technology Evaluation Template				x

**Enforcement and Regulation**

Traffic law enforcement plays a large role in keeping society mobile and safe. Unfortunately, the number of traffic enforcement officials is limited, and as congestion increases, their job becomes even more difficult. A wide range of areas require enforcement, including impaired driving, aggressive driving, speeding, lack of compliance with seat belt and child-passenger safety laws, registration and licensing, and trucking.

Technology can help to increase the visibility and presence of enforcement agencies. Data-exchange, storage, and analysis systems can help traffic law enforcers to perform their jobs, follow through with penalties, and track repeat offenders. Automated enforcement technology can increase the range of law enforcement’s “eyes and ears.” Technology has the capability to help reduce costs while increasing efficiency.

Traffic safety law enforcement has five essential components:

- Traffic legislation must be passed to determine the laws to be enforced and to set guidelines for enforcers.
- Enforcers must be dispatched. This could take the form of sending verbal messages to officers or of installing cameras to monitor high-risk locations for specific violations, such as red-light-running.
- When a lawbreaker is caught, the enforcer must issue a citation.
- The citation must be adjudicated in court.
- In the event of a guilty finding, a sanction must be applied.

### *Enforcement Issues*

Problems that traffic safety enforcement agencies must address are introduced briefly in the following sections.

*Aggressive driving:* NHTSA defines aggressive driving as “when individuals commit a combination of moving traffic offenses so as to endanger other persons or property.”<sup>39</sup> Acts that are often considered aggressive driving are:

- Following too closely;
- Erratic or unsafe lane change;
- Failure to obey traffic control devices (stop signs, yield signs, traffic signals, railroad grade cross signals);
- Speeding, usually in conjunction with other unsafe driving behaviors; and
- Impaired driving.

*Driving under the influence of alcohol and drugs:* Drugs and alcohol reduce reaction times and inhibit judgment and decision-making. In 2005, 16,885 people in the United States died in alcohol-related motor vehicle crashes, accounting for 39% of all traffic-related deaths.<sup>40</sup> More than one-fifth of all traffic-related deaths of children under the age of 14 involved at least one alcohol-impaired driver.<sup>41</sup> Nearly 1.4 million drivers were arrested for driving under the influence of alcohol or narcotics in 2005.<sup>42</sup>

NHTSA has estimated that between 10 and 22% of drivers involved in crashes were under the influence of drugs, often in combination with alcohol.<sup>43</sup> The 2003 National Household Survey on Drug Use and Health found that 10.9 million people—4.8% of the U.S. population over 15 years—reported driving under the influence of illicit drugs during the past year.<sup>44</sup>

*Unauthorized driving:* The amount of unlicensed driving is difficult to track, but it is clear that unlicensed drivers are among the most dangerous. In 2005, “nearly 18% of all fatal crashes involved at least one improperly licensed driver,”<sup>45</sup> and nearly one out of four motorcycle operators involved in fatal crashes were operating the vehicle with an invalid license at the time of the crash.<sup>46</sup> Targeting these drivers can greatly increase traffic safety by removing inexperienced, unqualified, aggressive, and intoxicated drivers from the road.

*Proper seat belt use:* NHTSA estimates that 15,632 lives were saved by the proper use of seat belts in 2005.<sup>47</sup> The national rate of seat belt use in 2007 was 82%.<sup>48</sup> In 2005, 35% of passenger-car occupants and 37% of light-truck occupants involved in fatal crashes were unrestrained.<sup>49</sup> Among drunk drivers, only 28% of those who were fatally injured were wearing seat belts.<sup>50</sup>

Primary seat belt laws allow police officers to stop and ticket unbelted drivers just as they would apprehend drivers for other traffic law violations. Secondary seat belt laws only allow an officer to issue a ticket for a seat belt violation if the driver is stopped for a different traffic violation. States with primary seat belt laws had usage rates an average of 10% higher than States without such laws in 2005. NHTSA estimates that “If every State with a secondary seat belt law upgraded to primary enforcement, about 1,000 lives and \$4 billion in crash costs could be saved each year.”<sup>51</sup>

### *Other Enforcement Issues*

Other problems that enforcement addresses include:

- *Scofflaws.* Unpaid vehicle registrations and tickets as well as missed court dates are inefficiencies that enforcement agencies must deal with on a daily basis.
- *Vehicle compliance.* Law enforcement is responsible for checking the status of both passenger and commercial vehicle registrations. All vehicles must comply with regulations and have functioning safety parts. Overweight commercial vehicles can be extremely hazardous in crashes, and they cause a disproportionate amount of wear and tear on roads.
- *Worksite enforcement.* Roadway worksites have been identified as dangerous locations for construction workers, pedestrians, and vehicles. In addition to creating narrow roads and obstacles, congestion in work areas may contribute to aggressive driving. Law enforcement officers assist by directing traffic, monitoring driving behavior, and, by their presence, serving as a deterrent to unsafe driving.
- *Pedestrian behavior.* In 2005, there were 4,881 pedestrian fatalities in the United States, representing approximately 11% of total highway fatalities.<sup>52</sup> Visible law enforcement efforts play a large part in keeping pedestrians safe by improving driver attentiveness to such behaviors as using lanes properly, observing speed limits, and yielding right of way to pedestrians. Law enforcement also plays a role by controlling dangerous pedestrian behavior such as jay-walking and crossing against the light.

Table 6 summarizes crash factors and fatalities.

**Table 6. Crash Factors and Fatalities**

<b>Factor</b>	<b>Fatalities (Year)</b>	<b>Source</b>
Alcohol	16,885 (2005)	NHTSA <sup>53</sup>
Unauthorized/unlicensed drivers	Up to 20% of fatalities	AAA Foundation for Traffic Safety <sup>54</sup>
Unrestrained vehicle occupants	16,172 (2005)	NHTSA <sup>55</sup>
Pedestrian fatalities from motor vehicle crashes	4,881 (2005)	NHTSA <sup>56</sup>

### **Technological Solutions**

Technological solutions can create a general deterrent effect as the public becomes aware that violators are more likely to be caught and punished, thus reducing the frequency of unsafe behaviors. They also allow officers to focus enforcement efforts at high crash-rate locations. Potential technological solutions that can assist in traffic law enforcement and enhance court-related processes are discussed below.

#### *Law Enforcement Assistance*

Technology can help to simplify tasks that law enforcement officials must do repetitively; speed up tasks that cannot currently be performed due to time constraints; provide information that can assist in identifying, quantifying, and documenting violations; and protect law enforcement officers and the public.

Electronic citations are an example of a repetitive task that can be made faster and more accurate with use of technology. Reducing the labor associated with issuing citations may give

officers more time for other enforcement activities. Electronic citations could also reduce the amount of paperwork necessary to adjudicate citations. Houston, Texas, uses a Motorola wireless application that enables police officers to retrieve and relay data and prepare traffic citations from a single handheld device.<sup>57</sup>

Electronic driver history checks are another tool available to law enforcement that could increase efficiency and effectiveness. Pilot projects such as the NHTSA/FHWA National Driver History Initiative have been undertaken to design, evaluate, and upgrade automated systems for recording traffic convictions and exchanging driver safety information among courts, police, and licensing agencies.

Electronic vehicle identification systems currently under development will have the ability to transmit vehicle identification numbers, registration information, vehicle inspection status, and other data through transponders. Such systems are being tested for commercial vehicles.

Most DWI crashes occur at night, when visibility is lowest. The ability to transmit information on vehicle and driver history to law enforcement personnel could allow them to focus enforcement efforts on known high-risk drivers. Existing license-plate-recognition technology has not yet been linked with databases containing the necessary information to enable enforcement in this area.

Video recording is a technology that is already proving very beneficial for law enforcement. Its use has decreased the time that traffic officers must spend in court, as some defendants choose not to contest the charge after seeing the video recording of their behavior. Video evidence could also make citation adjudication more objective since it would not be dependent on the subjective recollection of eyewitnesses.

Other developing technologies include:

- *Instruments that measure distance between vehicles.* Information on vehicle-following distance would allow traffic managers to set variable speed limits to reduce congestion, identify aggressive drivers who follow too closely or cut off other drivers, and assign officers to areas where unsafe driving is occurring.
- *More accurate, simpler on-site drug tests.* Tests that are easier and faster to administer and are more accurate would “assist officers in deciding whether to arrest suspected drug-impaired auto or truck drivers.”<sup>58</sup>
- *Extension of commercial fleet technology to passenger vehicles.* AirIQ is a system that tracks commercial fleets with regard to the inventory of each vehicle, geographic boundary alerts, excessive speed notification, vehicle maintenance monitoring and reminders, and vehicle history replay. An additional function of the system is vehicle power disabling/enabling from a workstation, which can be used to ground vehicles that have been lost or stolen. These technologies could be extended to passenger vehicles to assist law enforcement in identifying stolen vehicles, apprehending DWI drivers operating outside their restricted zones, and eliminating high-speed police chases. Such vehicle monitoring technologies might deter some illegal driving if drivers are aware that their performance is being recorded.
- *Traffic stop warnings.* Onboard vehicle warnings could caution drivers about a traffic stop ahead, thereby increasing the safety of traffic officers.

### *Automated Traffic Enforcement*

Automated traffic enforcement can increase the reach and presence of enforcement with minimal additional manpower. Photo enforcement is now commonly used to monitor red-light-running, speeding, toll collection, and illegal rail crossings. It could be extended to monitor inappropriate use of high-occupancy-vehicle lanes and noncompliance with commercial vehicle weigh-in-motion.

Examples of automated enforcement technologies are:<sup>59</sup>

- The Maryland State Police, together with the Aberdeen Test Center, developed and tested the ADVANCE (Aggressive Driving Video and Non-Contact Enforcement) vehicle. When a laser in the vehicle determined that an adjacent vehicle was speeding on the highway, a violation report was assembled automatically by a computer, with video images of the front, side, and rear of the violating vehicle recorded on multiple cameras.<sup>60</sup>
- Several states have a phone number for drivers to call to report aggressive drivers. The Colorado State Patrol implemented a system for logging these calls in a database. When the same license-plate number has been reported three times, a letter is sent to the registered owner of the vehicle, advising the person of the complaint.<sup>61</sup>

Court-required installation of alcohol ignition interlock systems on vehicles of convicted DWI drivers is currently being used to allow convicted DWI offenders to keep their mobility while preventing them from driving under the influence. Drivers can volunteer to have the system installed, or installation may be required as a condition of sentencing. The interlock system requires the driver to perform a breath test to start the engine and to repeat the test at intervals while the engine is running. Current systems have tamper-detection circuitry and data recorders to log vehicle use and BAC, but they cannot perform driver recognition.<sup>62</sup>

Another emerging technology that is very promising in DWI applications is biometric scanning, which identifies the driver through a fingerprint or an eye scan. Insertion of a valid smart-card driver's license in addition to a biometric scan would be required in order for the ignition to start. In a related technology, restricted driver's licenses would activate a GPS warning signal detectible by law enforcement officers if the DWI offender were to operate outside of specified restrictions. Smart-card driver's licenses coupled with biometric scanning could prevent a DWI violator from driving other household vehicles if they were programmed to reject the violator's smart card. Biometric scanning could be used to ensure that only authorized drivers could turn on the ignition of a school bus or to allow parents to restrict teenage-driver access to household vehicles during certain hours.

As the volume of commercial vehicle traffic continues to increase, automated enforcement will become more important in the trucking industry, helping agencies to ensure that safety regulations are up to date. Additionally, this technology could enable a uniform national inspection system that could provide local enforcement personnel with access to a common set of data. To prevent violations, technologies such as truck-brake interlocks could be used to stop overweight or overheight vehicles at truck stops and to restrict hours of service during which drivers can operate. Such technology could reward compliant commercial vehicle operators by reducing their delay time at inspection points. Diagnostic equipment technologies at weigh stations could be used to identify potential problems such as brakes requiring adjustment.

## Data Gathering, Sharing, and Analysis

Data analysis can confer benefit on several aspects of traffic law enforcement:

- *Real-time management of law enforcement staffing:* Data could be gathered to perform real-time manpower assignments and increase productivity.
- *Citation tracking systems:* Such systems would allow law enforcers to identify and target problem areas and repeat offenders. Drivers with many citations, locations with a high number of crashes, and characteristics of crashes could be analyzed systematically. The combination of efficient enforcement, administration, and adjudication would ensure that drivers who violate the law did not escape punishment. The same information could be valuable for developing educational programs for law enforcement officers, prosecutors, and judges.<sup>63</sup>
- *Driver and vehicle registration linkage:* A better link between driver and vehicle registration files would deter suspended and unlicensed drivers from obtaining vehicle registration.

Much of the work in data gathering, sharing, and analysis requires standardization of protocols for data collection, storage, and transmission. NHTSA's National Center for Statistics and Analysis has developed the Model Minimum Uniform Crash Criteria Guidelines to standardize data collection.

## Court-Related Processes

The courts are responsible for filing traffic convictions; handling appeals of traffic infractions such as speeding and red-light-running, conducting hearings for traffic misdemeanors such as DWI and driving without a valid license, and prosecuting felonies such as vehicular homicide. Problems that the courts deal with frequently include:

- Backlogs due to high numbers of violations and appeals;
- Unpaid citations;
- Unavailable records of prior convictions; and
- Missed court dates.

Converting paper filing systems to electronic systems would allow information from different agencies, including equipment operating status, driver history, and vehicle registration status, to be accessible to the courts.<sup>64</sup> Electronic filing of citations would reduce entry mistakes, improve the timeliness of citation notices, and enable automated generation of court-date reminders.

As use of audio and video testimony becomes more common in court proceedings, court officials will have access to more evidence with which to build better cases and the appeals process can be shortened through better information management and communication.

## Education and Information

This section covers the use of technology to improve driver education, information, and awareness.

### *Effectiveness of Education and Information*

Education and outreach can be used in conjunction with advanced technologies to increase driver awareness and use of safety technologies. The *Click It or Ticket* campaign is an example of how enforcement with paid media messages can be an effective strategy for improving seat belt use.



### *Technology Applications*

*Driver education:* Traditional traffic safety is taught in driver education classes at commercial driving schools or in high schools across America. Interactive education has been shown to be more effective than passive educational methods for most topics. As driving simulators improve and become more affordable, driver training can also be improved. In this manner, simulators could help trainees to acquire fundamental perceptual, cognitive, and psychomotor skills.<sup>65</sup>

Currently, most driver education opportunities are available only to beginning drivers, drivers sanctioned to take remedial or defensive driving courses, and commercial drivers. Some states are considering the introduction of a systematic driver's license renewal system that would require periodic retesting or shorter license renewal periods.

*Driver feedback:* Technology can make real-time information available to increase drivers' awareness of their behavior, thereby providing them with an opportunity to change it. For example, drivers could be alerted when they are driving above or below the speed limit or are making illegal turns.

In-vehicle seat belt warning signals could alert all vehicle occupants, not just the driver, when seat belts are not in use. GPS tracking has already been implemented by rental car companies to track the location and operating speed of their vehicles. Using only GPS tracking, it is now possible to print out a report of the exact route that a vehicle took. The same technology could be used as a parental GPS tracking system. This would be especially helpful to parents who are concerned about their teenagers' driving behavior and whereabouts.

*Driver information:* Technology can be very effective in providing information that is ad hoc or customized to specific situations. In-vehicle units can prioritize and store information for drivers. For example, image recognition technology could be used to read and store the speed limit from the most recent speed-limit sign, making this information available at all times rather than just at the intervals where signs appear. Alternatively, speed-limit maps paired with GPS could provide this information to the driver at any location. The European Union's Speed Alert project has designed the architecture for such a system. It is currently being tested by the Swedish Road Administration.<sup>66</sup>

Machine-vision technology is currently being used to recognize signs and recreate them in auditory or visual formats. Signage with transponders could be used to transmit messages inside the vehicle, supplementing the message conveyed on the sign. This feature would be helpful in inclement weather or when traveling on unfamiliar roads. Supplemental in-vehicle signage information could be tailored to the needs of drivers so that, for example, passenger vehicles would not receive messages about roadway height and weight limits. Figure 8 shows a "heads-up" in-vehicle supplemental stop sign that appears on the windshield without impairing the driver's view of the road.

Other safety-related situations that usually require visual recognition by the driver, such as school-bus stops, disabled vehicles, unexpected congestion, or active worksite safety zones, could be equipped with transponders transmitting electronic messages to warn drivers. These alerts could be preempted by warnings of approaching public safety vehicles.



**Figure 8. Example of an In-Vehicle Visual Stop Sign Warning.<sup>67</sup>**

Navigation of unfamiliar territory can be hazardous for drivers of all experience levels. Navigational and route guidance systems are now widely available for both passenger and commercial vehicles. As the popularity of these systems grows, more information could be integrated into advanced route guidance systems. These improved navigational systems could reduce VMT by decreasing the mileage that drivers incur while lost and the number of dangerous or illegal last-minute maneuvers. As more information from different agencies becomes integrated into route guidance systems, drivers will be able to focus their attention on their driving rather than on finding their way around. An advanced route guidance system could direct drivers through alternative routes that would avoid construction or traffic incidents, assist them with use of HOV lanes, and provide information on parking availability.

Such information would be useful even to people who are driving in familiar areas by providing them with options for reducing their travel time. This in turn would aid in reducing congestion, thereby improving the general flow of traffic and decreasing fuel consumption. The information must be detailed, current, and accurate in order to be useful. Research is still being conducted on methods for predicting traffic, algorithms for calculating optimized routes, and consequences of providing such information to the public.

Information can be provided not only to drivers but to all who share the road, including bicyclists and pedestrians. Enhanced crosswalk signals that display the amount of time left for pedestrian crossings and provide confirmation to the pedestrian that the crosswalk button has been pressed have proved to be successful. Crosswalk technologies using additional sensor and warning systems could improve pedestrian safety by detecting red-light runners and warning pedestrians of hazards in advance.

To further advance pedestrian safety, Nissan is developing a pedestrian alert system. Using GPS data from the pedestrian's mobile phone, a vehicle could detect the physical proximity between it and the pedestrian. The system would then warn the driver as needed.<sup>68</sup>

Advanced vehicle status monitoring systems would also contribute to safety performance. An onboard computer, the ECU, currently monitors and optimizes vehicle performance parameters such as air-to-fuel-ratio, fuel injection, and the temperature of various components in most vehicles. The most recent enhancement is tire air-pressure monitoring, which is being introduced in high-end vehicles. In the future, information on upcoming maintenance needs, such as oil change, tire rotation, and 30,000-mile check-up, could be displayed to the driver on the basis of vehicle usage or performance. Maintenance records could be stored electronically and permanently in the vehicle, which would be beneficial to maintenance shops, owners, and used-vehicle buyers. With the addition of communications systems, recalls by manufacturers could be sent directly to owners of applicable vehicles, including those whose vehicles have aftermarket parts.

#### Education and Information Haddon Matrix

All education and information solutions are efforts to prevent crashes and are implemented pre-crash, as shown in Table 7.

**Table 7. Education and Information Haddon Matrix**

<b>Technology</b>	<b>Phase</b>	<b>Human</b>	<b>Vehicle</b>	<b>Environment</b>	
Driver education simulation	<b>Pre-Crash</b>	x	x	x	
Systematic driver's license renewal system				x	
"New regulation" messages		x			
Driver performance feedback		x	x		
All-passenger seat belt warning system		x	x		
Parental GPS tracking system			x	x	
Image recognition technology			x	x	
Speed limit maps				x	
Signage with transponders				x	
Advanced route guidance system				x	
Enhanced crosswalk signals				x	
Advanced vehicle status monitoring system			x	x	

## CHALLENGES FOR TECHNOLOGY APPLICATIONS SERVING TRAFFIC SAFETY PROGRAMS

This section builds on the previous descriptions of promising technology components, systems of communications and information management, and problem-solving concepts to help improve traffic safety. It describes principles that might be adopted by designers who must translate the concepts into specific technical specifications or guidelines for practical, safe, and affordable safety products and services. An array of unique technical design requirements that seem likely to be sought by diverse traffic safety program advocates is then introduced. The section concludes with an introduction to non-technical aspects of technology applications for improving traffic safety—those related to institutional, economic, financial, legal, and privacy considerations.

### Technical Design Challenges

The automobile is a severe environment for electronic equipment. Components under the hood are exposed to extreme heat, vibration, dirt, water, and oil, while those in the passenger compartment must withstand occupant use and abuse. Table 8 shows the operating conditions to which automotive electronic components are subjected and the requirements that they should meet.<sup>69</sup>

**Table 8. The Automotive Environment**

Operating Condition	Requirements
Durability	10 years or 150,000 miles
Interior ambient temperature	-40 to 85°C
Rapid temperature changes	25°C per minute
Vibration	5 Gs
Shock	20 Gs
Resistance to fluids	Must resist corrosive liquids
Electromagnetic compatibility	20 to 100 volts per meter

ITS applications related to traffic safety and law enforcement face immense challenges beyond their operating environments. The most important of these are presented below.

### Reliability and Accuracy

Reliability refers to the ability to deliver consistent measurements and services over a range of conditions and over the lifetime of the vehicle. Accuracy refers to error-free and precise measurement or service delivery. Both are essential to safety-critical vehicle control functions. If data are to be used as evidence in law enforcement proceedings, their accuracy and reliability must be provable in a court of law.

When sensors and other ITS equipment are not functioning correctly, users should be automatically informed, just as current vehicles display a “check engine” light to indicate a mechanical problem. The warning should also contain information about how to solve the problem. To test for reliability and accuracy of ITS systems and their components, diagnostic instruments should be developed to assess whether the system is accurately capturing information.

Technological advances are increasing the reliability and accuracy of in-vehicle electronic devices. For example, the accuracy and reliability of sensors governing air bag operations and seat belt pretensioners are improving without a significant cost increase.

### Human Factors

Major human-factors considerations other than usability include the introduction of dangerous distractions and driver complacency that could increase the overall risk of crashes. This requires careful attention to dashboard design, ease of data-input functions, and filters to eliminate communication of irrelevant or erroneous information.

Human factors also must account for disabled drivers such as those who are hearing-impaired or paraplegic. Realistic driver notification mechanisms are needed to permit the entire range of drivers to perceive and understand vehicle and roadway messages. In testing various types of HMI, researchers must include inexperienced as well as impaired drivers in the universe of drivers.

### Interoperability

Interoperability is “the ability of two or more systems or components to exchange information and to use the information that has been exchanged.”<sup>70</sup> Open systems and open standards—those that are in the public domain—are necessary (although not sufficient) conditions for interoperability. While some automobile original equipment manufacturers are promoting proprietary systems to preserve and grow their market shares and build brand loyalty, open systems lead to the expansion of markets for electronic device manufacturers, the lowering of equipment costs, and an increase in the ability of onboard networks to deliver more sophisticated functions.

An example of an open standard under development is that of the Institute of Electrical and Electronics Engineers’ MVEDR. An open standard could allow MVEDRs to become plug-and-play devices across automobile manufacturers, enabling consumer upgrades as well as interfaces with other proprietary and nonproprietary equipment.

### Technology Interference

The increasing number of electronic devices and the growing use of wireless communications raise the likelihood of electronic interference between the two types of systems. The Federal Communications Commission takes into account the needs of both the traffic and the public-safety communities when allocating regions of the spectrum. For example, bandwidth buffers between adjacent channels are needed to prevent unintended interference.

### Rapid Technological Change

The speed of technological change contrasts with automobile product-development cycles, public-agency decision-making cycles, and the typical lifetime of the passenger vehicle fleet. Older-model cars without modern electronic safety devices are still common. Even vehicles equipped with new technologies—“early adopters”—may need to be modified for rapid technological change. New technologies sometimes require a real-world learning curve to uncover subtle, unintended consequences, such as the time and experience required to detect the harmful effects of early air bag models on children and small adults.

### Security and Privacy

Vehicle and roadway electronic communications systems carry a vast amount of information that must be carefully protected against misuse. The many dimensions of security and privacy with respect to vehicle and road-system electronic communications include:

- Physical protection of the transponder device, its antenna, and its wiring to resist damage, either accidental or intentional;
- Security against intentional tampering or jamming;
- Security against counterfeiting, identity theft, or other criminal intrusion or illegal transponder activities;
- Security against system circumvention by individuals or by underground manufacturers (analogous to those who sell illegal cable-television descramblers);
- Privacy-protection features and software protocols to prevent unauthorized access to vehicle or driver data; and
- Devices to detect and reveal transponder negligence, fraud, or cheating by a driver or vehicle owner.

## Technical Design Principles

Some of the technical challenges involved in the technologies described in this report are shared by other technologies placed in vehicles or used in highway infrastructure and traffic operations centers. However, many are unique and are associated with demanding features of traffic safety countermeasure devices.

Designs should reflect more than just the needs of vehicle manufacturers and consumers. Other stakeholders within the traffic safety community who have their own requirements include law enforcement, insurers, crash investigators, first responders, and mechanics who install, maintain, and repair the new technologies.

### Unique Vehicle Design Challenges Related to Traffic Safety Programs

#### *Human-Machine Interface*

Designs and applications of human-machine interfaces must take into account:

- Atypical local traffic laws;
- Variable speed limits or other roadway restrictions;
- Frequently changing traffic safety laws and roadside signs;
- Reminders or intrusive signals to motivate legal or desired driving behavior, especially if vehicle owners or drivers cannot be identified for enforcement purposes;
- Warnings of upcoming or current traffic safety violations, perhaps with associated sanctions;
- Notifications of automated enforcement citations;
- Notifications of upcoming incidents or instructions to be followed; and
- Instructions issued by law enforcement officers after a pullover stop.

### Safety in Human Interface Design

As telematics are increasingly introduced into vehicles, there are safety concerns about driver overload, distraction, complacency, and other potentially dangerous unintended consequences. Extensive research is being conducted to ensure that warnings and messages produced by safety devices are intuitive rather than disruptive to driving and are acceptable to drivers. The goal is to provide information to drivers in a safe, convenient, and pleasing format.

Human-factors research is focusing on audio, visual, and tactile interfaces; driver perception and reaction to alarms heard for the first time during a crash; false alarms and driver trust; driver complacency; driver response and response times to warnings and required actions; methods for prioritizing information for drivers; and the timing of information so that drivers will not be distracted yet will have enough time to react.

Safety communications, such as those listed above, need to be considered in the context of competing distractions, such as car radios or CD players. As part of the design, the best methods of communicating information to vehicle occupants must be chosen. Consideration must be given to a wide variety of drivers, such as drivers who:

- Do not speak English;
- Are impaired by alcohol, drugs, or fatigue;
- Are unfamiliar with their vehicle or local roads; and
- Are unfamiliar with the meaning of the signals or messages.

However, technology systems should be designed to eliminate “over-automation,” a situation in which the driver relies too much on automation to control the vehicle and does not pay sufficient attention to the task of driving. In addition, there is a risk of driver confusion about

which automated features they can and cannot rely on under given circumstances. There must be clear driver notification of system status.

### Vehicle and Driver Identification

Vehicle and driver identification technology could be used to target and identify chronic violators of traffic laws, especially repeat drunk drivers. These and other applications will depend on identification of:

- The vehicle (license plate, registration, and vehicle identification number);
- The vehicle's cell phone, toll-tag, security sticker, or transponder (analogous to an aircraft identifier for flight controllers); and
- The driver.

Vehicle and driver identification technology can also be used to inform EMS providers of characteristics of the vehicle and driver in the event of a crash. The U.S. Coast Guard collects similar information about boats and boaters to help notify boaters of dangerous conditions and rescue them in the event of an emergency.

Today, most new cars recognize distinctive wireless signals sent short-range by remote control, different key signals, or voice patterns among household drivers. Upscale vehicle models use these distinctions to automatically adjust seating positions, comfort controls, and preferred radio station settings. In the future, this personalization is likely to trickle down to the rest of the vehicle fleet. The introduction of wireless key signals, smart-card ignition keys, and antitheft security systems will make electronic driver identification more feasible and widespread. There are even emerging applications in which the vehicle's own computer gradually learns to recognize routine users based on their distinctive driving patterns.

### Systems Security and Integrity Protections

Protecting vehicle safety features from damage and alteration by owners who do not want certain electronic devices in their vehicles could be an important challenge. Among the approaches that might be considered are embedding functions deep within vehicle manufacturers' operating software, using redundant identity chips, and installing other integrated circuitry. All technology applications should be designed to minimize opportunities for illegal system evasion or hacking. For example, a signal pre-emption system should be able to block unauthorized signal preemption. There may be a need for non-technical enforcement mechanisms and stiff criminal sanctions when transponder negligence, fraud (e.g., alteration of odometer readings), or cheating by the vehicle owner or driver is detected. In addition, wireless communications messages that contain sensitive information may need to be encrypted to reduce the potential for unauthorized access.

### *Capacity for Upgrades and Expanded Functions*

The long life of the average vehicle contrasts with the fast pace of developments in electronics and technology. Technology systems should be designed to allow upgrades to accommodate future computing or telecommunications applications. If future vehicles were designed to accommodate aftermarket products (products that are added after the vehicle is manufactured), additional options would be feasible for traffic safety programs. Current aftermarket products, such as breath-alcohol ignition interlocks and devices to monitor a teenager's driving are costly because they require redundant electronics or customized adaptations.



### *User-Friendly Interface for Activating or Customizing Vehicle Features or Entering Data Into an Onboard Computer*

Where driver interaction is required, technology systems should include very user-friendly communications interfaces. Ease of use will not only improve safety by minimizing driver distraction; it could also result in more and better use of the technologies if drivers are not intimidated by the technology. New deployment options for traffic safety program devices might become acceptable with such an interface. Systems such as seat belt reminders or interlocks might then be activated or customized to suit the preferences of the vehicle owner, tailored to particular family members (such as teenage drivers), or imposed by a traffic court or a department of motor vehicles. Ideally, systems could be designed that allow users to choose from a variety of HMI features such as an instructional voice or a type of warning sound.

Owners might want to use the interface in conjunction with an onboard data recorder to enter medical data or contact information for retrieval by crash rescuers or to establish antitheft restrictions such as allowable operating hours or locales. States might require owners to electronically enter registration renewal data or driver restrictions.

### *Geographic and Locational Interoperability*

Geographic and locational interoperability are two of the cornerstones of contemporary technology design. Geographic interoperability means that new communications or other system features must function throughout the United States, Canada, and, potentially, Mexico. Vehicle manufacturers would not have to produce different vehicles for different jurisdictions. In addition, system could be designed to employ onboard GPS or another locational system that could be tailored to meet the needs of the vehicle owner.

### *Costs*

Technology designers can expect to feel economic pressure to minimize the hardware, software, installation, and maintenance costs of technology applications for traffic safety programs. Fortunately, the cost of a given technology usually declines with time. Also, investments with a long expected life have low average yearly depreciation.

### *Urgency of Addressing Technical Challenges*

Individually and collectively, the challenges of designing technology applications for traffic safety involve the timely identification and specification of technical requirements, perhaps the toughest being associated with vehicle and roadway design. Consideration of these challenges will be essential in forecasting the capabilities, relevance, and usefulness of emerging technologies and the shaping of standards critical to their development, deployment, and acceptance.

## **Non-Technical Challenges**

Many experts on the evolution and acceptance of technology applications concede that institutional, economic, legal, privacy-protection, and other nontechnical obstacles are often much more daunting than technical ones. Technology applications for traffic safety programs compound some of the familiar development problems, since they raise unique issues about tradeoffs between safety and the public acceptance of more intrusive but effective countermeasures to reduce risky behaviors. Years of hard work by professional safety advocates have led to great strides in reducing risky driving and promoting motorist responsibility, with reliance on conventional traffic law enforcement and coordinated public education and information campaigns. Much of the public is already aware of responsible-driving messages and believes that traffic law violators are occasionally caught and sanctioned.

Yet these historical approaches have been insufficient in achieving ambitious national safety goals. Trends of declining police manpower, coupled with increases in drivers, vehicles, and travel, make innovative approaches more important. More diverse surveillance, vehicle restraints, documentation, and automated enforcement must be considered to foster general deterrence, safe driving, and more widespread compliance. Non-technical factors will play a significant role in the outcomes of controversial technology applications for traffic safety programs.

### Privacy, Driver Identification, and Civil Liberties

In order for many of the described technologies to be effective for traffic law enforcement, the vehicle-roadway system will need to identify and document not only dangerous or unlawful behavior but also the vehicles and drivers involved in the behavior. If all driving behavior were safe and legal, such identification and documentation would not be needed and the traveler would remain “invisible.”

In contrast, many of the technologies being implemented today as a matter of policy prevent the identification of motorists. Traffic cameras with limited focusing or tracking capability are selected to prevent the identification of particular vehicles. One policy drafted for the Privacy Principles that were issued by the Intelligent Transportation Society of America (and endorsed by FHWA) even stated that motorists who sign up for an ITS service have a right not to be “ambushed” by police using the resulting data for another purpose, such as ticketing violators for unsafe or illegal driving behaviors.

The climate of public opinion with respect to privacy issues has changed over time. The convenience of technological solutions such as ETC, the increasing application of surveillance in dangerous or commercial settings, and concerns about homeland security have made the public more willing to accept scrutiny by technological devices. Nevertheless, the widespread perception of a right to privacy while driving “in plain view” will be a prime institutional barrier to rapid deployment of these technologies for both general deterrence and automated enforcement.

The growing technical capability to electronically identify vehicles and drivers is highly valued for the features that it offers to vehicle owners and drivers. However, the use of these same identification capabilities for traffic safety programs, and especially for law enforcement, is the most contentious and politically sensitive issue associated with technology applications. Many people would not want to buy an onboard system that might result in their receiving sanctions for traffic violations or in creating conditions for involuntary surveillance.

If identification were to become generally accepted as a safety-justified societal responsibility associated with the “privilege” of driving, travelers could decide to forego their privacy concerns in exchange for improved mobility. The technology’s benefits to travelers could thus become a tolerated tradeoff. This new responsibility might be manifested as a condition for driver licensing, vehicle registration, insurance, or the benefits of electronic tolling and mobile communications. The incentive of a lower insurance premium might override drivers’ reluctance to implementing such a system.

### Diversity of Stakeholders

The array of stakeholders and “players” involved in the development and deployment of traffic safety devices is large and diverse. Traffic safety advocates must find common ground with the information and telecommunications industries, automobile manufacturers, commercial vehicle operators, highway agencies, insurers, vehicle renting and leasing companies, and public

interest groups of all types. As awareness grows with regard to the benefits that safety technology can provide to prevent or mitigate crash injuries and to reduce tax dollars for medical expenses, these parties must collaborate to bring promising new technologies to the public. Public-safety stakeholders in particular need to become involved in the process of setting technical standards for transponders, MVEDRs, and other emerging technologies to ensure that traffic safety applications are considered in the standards development process.

### Other Institutional Challenges

Additional institutional challenges include:

- Considerations of public perceptions of “fair” technology applications, such as enforcement of laws that target the most dangerous and egregious violators;
- Incentives and disincentives for the deployment of technology in the public interest;
- Appropriate business models for commercial uses of networks and technologies deployed for public purposes; and
- Appropriate marketing strategies to encourage public acceptance, including built-in, adjustable vehicle features or aftermarket installations to deal with particular traffic safety problems.

## CONCLUSION

Emerging technologies hold great promise for increasing highway safety. Engineering advances, such as in-vehicle sensors that warn drivers of nearby objects, can help in crash avoidance. Driver education and information efforts, such as realistic simulators and automated “congestion ahead” warnings, can change driver behavior and improve situational awareness. ACN technology can notify emergency service personnel of a crash and transmit crash characteristics, such as the force of the impact and the number of vehicle occupants, allowing victims to be treated more efficiently and wreckage to be removed. Enforcement mechanisms, such as cameras to detect red-light-running and electronic tags, can convey vehicle and vehicle owner information, increasing the reach and accuracy of traffic law enforcement while reducing the labor involved.

Despite their promise, these new technologies are not without challenges. Developing, testing, and deploying the systems is a long-term process that requires substantial coordination between the automobile industry, designers, government agencies, and other stakeholders. There are three primary human-factors concerns: that in-vehicle technologies such as GPS units will distract drivers from the task of driving safely, that technologies that warn drivers or control the vehicle will lead to driver complacency; and that systems are designed and implemented for optimal usability. Another major concern is privacy. Motor vehicle event data recorders could provide a wealth of information about a crash. However, there are important legal considerations about who owns the information and how it will be employed. Clearly, such information must be protected from misuse.

Recently deployed “smart technology” such as electronic toll collection shows that it is possible to<sup>71</sup> overcome these challenges. There is convincing evidence that technologies being tested and those that are in limited deployment can help to improve traffic safety. As research and deployment efforts move forward, it is important to keep the potential benefits in mind and work through the inevitable challenges in order to achieve the desired result: a reduction in roadway crashes, injuries, and fatalities.

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