

Critical National Need Idea Title
**Road Information Infrastructure: A National Resource
for Saving Lives, Improving the Quality of Lives and
the Environment, and Stimulating the Economy**

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1 Area of Critical National Need and Associated Societal Challenges

1.1 Problem: Dangers, Inefficiencies and Limits of Information Access of Road Transportation

As a fundamental element of contemporary society, road transportation has been playing a vital role in commercial activities and the daily lives of the majority of US citizens. Road transportation is used to convey goods and passengers, and for people to commute to and from their jobs. Yet road transportation in the US is presently in difficult circumstances in terms of three aspects: safety, efficiency, and information access. The National Highway Traffic Safety Administration (NHTSA) has reported that there are 6.2 million crashes annually resulting in more than 43,000 fatalities and a cost to society of more than \$230 billion [1]. Half of these fatalities occur in cases of vehicles leaving a road and passing through intersections. In addition, injuries and damages from non-fatal accidents lead to significant costs in terms of health care and property. For example 2.7 million people were injured in motor vehicle crashes in 2005 [1]. Safety systems widely adopted by automakers are typically based on individual vehicle implementations, such as air bags and anti-lock brakes, and beyond some substantial initial gains, these single-vehicle systems have not been able to further alleviate fatalities or injuries significantly. Figure 1 shows that death number has been gradually increased in recent years, even though most of the States have laws strongly supporting for highway safety. Road accidents are often caused by driver carelessness or ignorance, simple misconduct, or lack of experience. In some instances, dangers due to severe weather and road conditions and consequent obstruction of view are also responsible. It is extremely difficult to eliminate these “human” factors due to the inherent limits of human sensing and reaction speeds. All other measures applied failed to reduce the number of fatalities for the last 15 years. More people in the US give their lives in transportation related accidents than any other single cause.

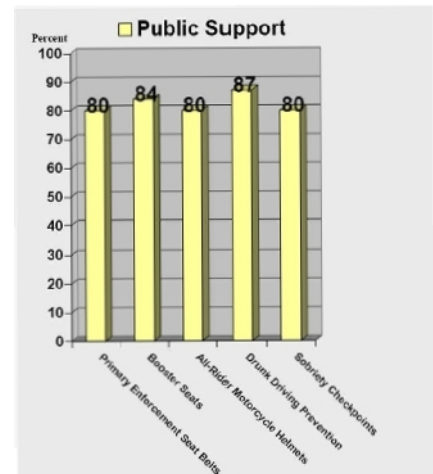
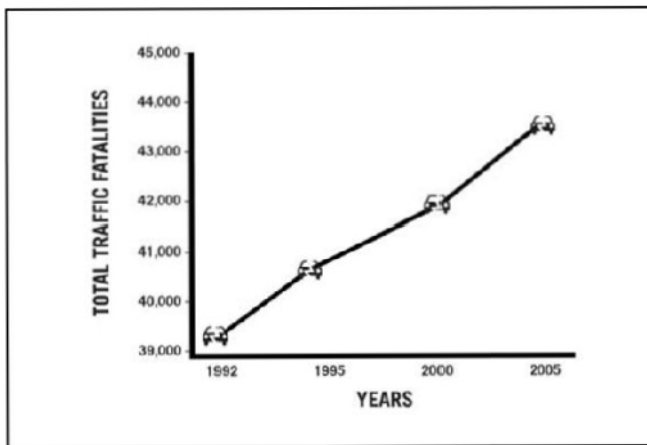


Figure 1: The US traffic fatalities in recent years (left) and percentage of the States with laws supporting various highway safety efforts (right)

Due to aging and increasingly usage of the road transportation infrastructure in US, congestion has emerged as a critical issue that negatively impacts on our lives in multiple ways: it creates inefficiencies in roadway use; it wastes fuel; it causes widespread pollution and noise; and it reduces personal “quality time.” For example, traffic congestion costs Chicago \$7.3 billion per year [2]. The average commute increased 14% in the last ten years, from 22.4 minutes in 1990 to 25.5 minutes

in 2000 [3]. In many areas of the country, traffic congestion has become a major quality of life issue that impacts decisions as fundamental as where to buy a home or where to work [3]. “*We are experiencing increasing congestion on our nation’s highways, railways, airports and seaports. And we’re robbing our nation of productivity and our citizens of quality time with their families.*” (The U.S. Secretary of Transportation, Mary E. Peter. [4].)

Information access for vehicles is presently limited to voice services through the use of cellular phones (including Onstar) and global positioning systems (GPS) . This service, both its quality and data rate, is behind what has been achieved in other communications systems such as wireless local area networks (WLANs). Presently used telematics and vehicle information systems were designed for unique (and sole) applications and these are only utilized in certain geographic regions (such as the tolling systems installed and operated by a lot of States individually) or on certain brands of vehicles (such as Onstar for General Motor made vehicles). All of these “isolated” systems taken together are inadequate to provide high-reliability and high-rate information service through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless links for future intelligent transportation systems (ITS), as advocated by the Department of Transportation (DOT). In addition, consumers are becoming accustomed to having wireless access anywhere and anytime, and roadways are no *exception*. Particularly for passengers in vehicles, current services are inadequate for many comfort or entertainment applications such as web browsing, emailing and data exchanging . A reliable, ubiquitous, and fast wireless network within ITS could remedy this, and induce other benefits such as roadway electronic commerce.

1.2 Why the Problem is Challenging

As noted, changing human behavior and/or significantly enhancing human abilities critical to safe driving is unlikely in any near future. Technological solutions to improve safety, efficiency, and value of roadway travel are thus essential.

The goals of reducing fatalities, increasing roadway efficiency, and enhancing roadway wireless services will require multiple solutions, with significant contributions from several disparate communities. A true enhancement of road transportation will demand systematic and synergistic collaborations among government agencies, automotive manufacturers, Universities, public and private companies, and communication network operators. Foremost, supportive policies and funding from the federal government will show leadership in the development and deployment of a nationwide road information infrastructure. The effectiveness of this road information infrastructure will rely on the successful design and development of high performance inter-vehicle networking. For example, the Administrator of the Research and Innovative Technology Administration (RITA) of the US DOT, Mr. Paul Brubaker, have challenged the nation to reduce transportation accidents related death in the US by 90% over the next decade, through the use of better information technologies.

The technological challenge posed by inter-vehicle networking lies in the establish of reliable, robust and real-time wireless links for both critical safety message and high-speed data exchange. Moreover, stretched over millions of miles, with thousands traffic signal controlled intersections, with 250 Million vehicles running over it and diverse human driver behaviors, traffic network itself has presented significant a challenge as well. With the aid of road information infrastructure for delivering real-time local and global traffic messages and further assuming that most drivers will be acting rationally, the traffic network itself will become more controllable and predictable. However, all of these challenges are not currently well studied and addressed, leading to significant negligence on the great potentials not only for multiple national societal benefits but also to stimulate and advance the nation’s research and technology frontiers.

2 Solution to the Critical National Need: Road Information Infrastructure

2.1 What is Road Information Infrastructure

The road information infrastructure is defined as the networks of many local road areas networks that are connected each other through dedicated networking or the Internet in either wired or wireless links. While inter-vehicle networking specifies the V2V and V2I communications within a local road areas network. Figure 2 shows an example of the configuration of road information infrastructure where a cell of the local road areas network consists of many onboard units (OBUs) and roadside units (RSUs).

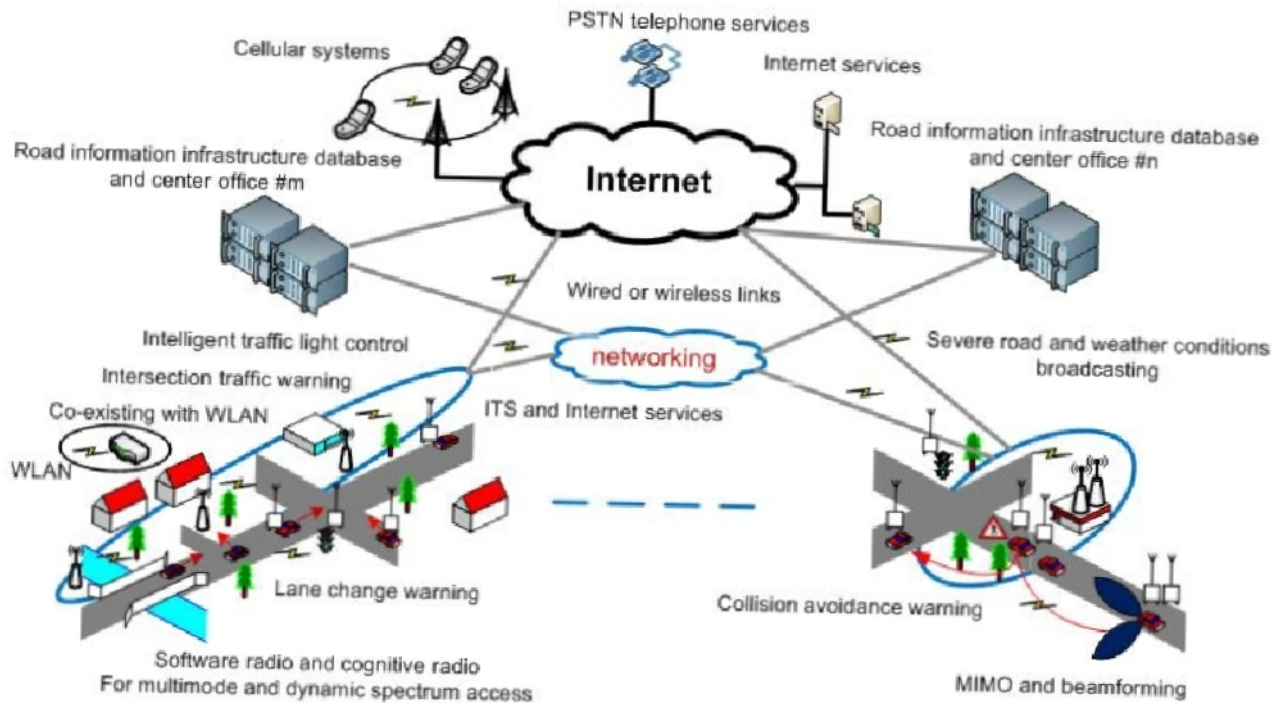


Figure 2: An example of the configuration of road information infrastructure based on inter-vehicle networking and some applications

The road information infrastructure are expected to be with the features listed below:

1. Maintaining local vehicular awareness of surroundings in a real-time manner, through accurate and fast sensing, surveillance, and information sharing among vehicles.
2. Extending perception from local and transient to global and long-term using *prediction* and *preemptive* responses.
3. Translating of situational information to appropriate actions, and developing multiple and collaborative automatic vehicle safety control strategies.

2.2 Significance of Nationwide Road Information Infrastructure Deployment

Vehicles have been operating on roadways on this planet for more than a century in an isolated way. We are at the right time to connect these vehicles and bring our society into a new age.

Similar to the evolution of computer networks, when millions of computers were connected to share resources and information, the Internet emerged and some profound positive changes were made to our way of our life and work. Road information infrastructure are expected to be widely employed in the future nationwide to radically improve the road transportation environment in terms of safety, efficiency and information access. Figure 2 shows some example applications of road information infrastructure for lane change, collision avoidance, and intelligent traffic light control. Deployment of road information infrastructure will fundamentally smooth the progress of ITS by providing roadways with high performance physical platforms for gathering operational data. This deployment will also turn driving and riding into a completely new experience, safer and more pleasant than ever before.

The realization of a nationwide road information infrastructure requires intensive research, development and manufacturing activities. This includes algorithm development for many layers of the communication protocol stack, functional definition of various parts of the infrastructure, subsequent system design, prototype assessment and massive production. The enormous potential market for inter-vehicle networking products can sustain several tier-one automobile suppliers and many supporting companies. The use of road information infrastructure will cultivate the growth of many institutions devoted to providing ITS training for related engineers, sales, service and etc. Thousands of workshops will be needed to install inter-vehicle networking devices to existing billions of vehicles. Moreover, road information infrastructure services could foster the generation of several service operators, the sizes of which could be comparable to that of cellular carriers. In summary, ITS has the potential to generate a fresh information technology industry based upon roadway vehicles, and this will bring the US an opportunity to grow the high-tech sector of its economy and enhance its international economic competitiveness. The magnitude and breadth of the road information infrastructure impacts on the economy of the US are substantial, multi-layered and profound.

American automobile manufacturers are currently encountering unprecedented difficulties and are continuously losing their market share in North American. The first adoption of inter-vehicle networking will help the American automobile industry regain the lost market and a leading position in the competitiveness. The level of impact underlines the necessity to initiate the development of road information infrastructure.

There are approximately 250 Million passenger cars currently in use in the U.S. and about 25 Million cars (10% of the total) are manufactured every year. The market for inter-vehicle networking is clearly huge and growing. For example, in the view of the original equipment manufacturer (OEM) market, massive production of inter-vehicle networking units will generate \$100 Billion revenues if every vehicle in the US is equipped with an OBU (assuming that an OBU costs \$400). The equivalent revenues will be generated if thousands of RSUs are installed nationwide. Moreover, the aftermarket will achieve and exceed the OEM market after inter-vehicle networking devices have been widely deployed. The aftermarket segment includes inter-vehicle networking service and hardware maintenance.

In addition, road information infrastructure is capable of capturing and recording the detailed log of vehicle movements that generate a new resourceful means for homeland security and public safety related issues. On the other hand, certainly the privacy protection concerns surface and related policies are in need to guide associated records access and usage. Government should actively involve in making a suitable policy for the use of road information infrastructure.

In summary, no other solution has the promise to save so many lives as resolving this challenge. Furthermore, the potentials to improve the nation's productivity by reducing road congestion, to increase the nation's competitiveness by increasing the efficiency of its road transport, to positively and significantly influence the environment in a greener direction by enabling reduction of its vehicle

induced crude oil usage, as well as to enhance the nation security by enabling the usage of vehicle recording and tracking, will be regarded as significant and far going.

3 Why Government Support is Needed

3.1 Government Support and Adequate for TIP Program

The current economic situation in the US, and in many countries worldwide, is one of the worst in decades. The US automotive industry has been particularly “hard hit.” Government support is required simply to keep the US automotive companies and hundreds of suppliers from going bankruptcy. Thus in these times automatize companies will not likely invest in major technology development programs without government support.

To sustain the large scale in road information infrastructure research, development and deployment, government support is a must. Current support strength and focuses from a national science foundation (NSF) program are far from sufficient since the related research is a high-risk and high-reward activity that requires innovative solutions and mechanisms, high-integration and cross-layer study, holist strategy and systematic plan, intensive development and optimization design ranging from physical layer transmission technologies, networking algorithms and protocols, mobile computing, database management, complicated system operation, driver behavior analysis based on partial cooperation and the incompletion of road information, integrated circuitry design and prototyping.

RITA and Joint Program Office (JPO) of the US DOT have invested about \$70M for a proof of concept effort for ITS deployment that ended late in 2008 with a conclusion that the solution sought would not provide the desired outcomes and not at the desired conditions. It demonstrates that there is significant interest from US DOT for the deployment of ITS nationwide but not sufficient investment to meet the challenges. Recently US DOT restarted its efforts with a new formulation of national vehicular infrastructure integration (VII) program into a so-called *IntelliDriveSM* program that is chartered to form a national open platform for ITS deployment [5]. The program focuses on enabling activities such as specifications and interface definitions. Currently, no other source of funding is available specifically for the study and advancement of this critical and high-impact societal challenge. The return on investment (ROI) is too far in the future with a great risk for the venture, commercial capital or investment from the private section.

In the meantime, launching a long-term funded road information infrastructure program should actually be a indispensable part of economic stimulus itself. As the breadth and depth of road information infrastructure is explored, new technologies will need to be developed, and this may lead to a new industry specializing in vehicular information access. This would create jobs and increase the base of skilled high-technology workers. In addition, since some of the work in road information infrastructure will be exploratory research, this may incite new scientific discoveries that yield benefits in other areas. For example, wireless communication and networking techniques developed for high-velocity heterogenous vehicular networks have a vital application in military vehicles and wireless networks controlled systems.

3.2 Fit the Goal of TEA-21 Set by the Congress

Road information infrastructure facilitates the national inter-operability of ITS, which is a goal established by the Congress in the Transportation Equity Act for the 21st Century (TEA-21). The ITS America, a Federal Advisory Committee of DOT, has actively worked on defining optimal service and licensing related rules. The American Society for the Testing and Materials (ASTM)

Workgroup E17.51 and the IEEE 802.11p Workgroup both work on the wireless access for vehicular environments (WAVE) standards covering the physical, media access control (MAC), network and application layers specifications.

The ITS America estimates that the deployment of road information infrastructure will double the roadway capacity with an estimated cost of 206 billions in 20 years. This expense is regarded as very efficient when compared to other solutions.

3.3 Consequences of No Government Support

The consequences of no government support for road information infrastructure will lead to following issues:

1. The severe hazards of road transportation in US will not be substantially ameliorated even though a lot of efforts have been or will be taken in the near future. Many US citizens will continue to lose their lives on US roadways.
2. A great number of money, labors and time will be wasted by sporadic and/or uncoordinated efforts to improve roadway safety, efficiency and information access whereas a coordinated road information infrastructure program under ITS would be more efficient and effective.
3. The lack of government support for road information infrastructure will defer or even eliminated the nascent vehicle information industry. This will mean that the opportunity to create thousands of jobs for researchers, engineers and workers in US will be lost in these difficult economic times.
4. Without the opportunity to lead the development and manufacturing in inter-vehicle networking, it will impede the recover of the US automotive industry.
5. Other countries, including British, German, Japan and Korean have begun moving ahead in investing and researching road information infrastructure, with strong support strength from their governments. The delay or lack of government support in road information infrastructure will degrade the economic competitiveness.

4 Potential Technical Solutions

4.1 Existing Efforts in Response to the Challenge

In response to the above challenge, in US people have built up quite a few road transport information systems, such as, electronic toll collection (ETC), automatic vehicle identification system (AVIS), Onstar, and XM NavTraffic.

The existing road transport information systems are incapable of meeting the above challenge due to their limited functions, leverages and performances. ETC, AVIS and XM NavTraffic are all designed for a sole function and work in a simplex model without actual two-way data exchange. Onstar is unable to collect and provide real-time road traffic information such as reports of accidents, constructions, congestions, imminent road hazards, and other information such as AMBER alerts. Moreover, Onstar has a limited data rate ($9.6kbs/s$) and large latency (up to one or several seconds), which is not suitable for critical safety message delivery. Therefore, a nationwide full functional road information infrastructure is highly desired to respond to the aforementioned challenges, and this infrastructure should be capable of accommodating both the real-time safety messages and high-speed data.

4.2 Possible Wireless Technologies for Inter-Vehicle Networking

A good candidate enabling for inter-vehicle networking is the WAVE technology, which is the next generation dedicated short-range communications (DSRC) technology, which provides high-speed V2V and V2I data transmission and has major applications in ITS, vehicle safety services and Internet access. Operating at 5.850-5.925GHz, WAVE systems adopt orthogonal frequency-division multiplexing (OFDM) and achieve data rates of 6-27Mbps/s. In WAVE systems, a RSU can cover a range of up to 1000 feet. WAVE systems are based on the IEEE 802.11p protocol, which is currently under development.

Besides the IEEE 802.11p, there are two related IEEE 802.16e and IEEE 802.20 work groups, aiming at the mobile air interface for high speed wireless access on roads. The former uses 2-6GHz frequency range designed for the mobility objectives in a low mobility. The latter adopts a band less than 3.5GHz applicable for the high-speed mobility situations with large coverage, like high-speed trains.

In addition, the third generation cellular system (3G) and long-term evolution (LTE) also have a potential application to a vehicular environment.

5 Main Research Directions

The fast varying and harsh vehicular environment as well as the complicated road information infrastructure bring in many challenging research areas, which include advanced physical layer technologies, novel network configuration (mesh network and delay tolerance network, DTN), effective media access control (MAC) protocols, robust network algorithms and schemes, mobile computing, multimedia, database management and data mining, security, prototyping, chip design, market and policy. Some research work has been conducted worldwide to address the above technical challenges. However, these efforts are still in the early stage of study and development leaving a lot of technical challenges unsolved or untouched. More intensive research and implementation activities are highly desired to remove major technical barriers and presenting theoretical guidance and perspective. Here we list some research directions as examples.

1. The physical layer challenges include channel modeling for both single input single output (SISO) and MIMO wireless channels over the assigned frequency and bandwidth in diverse road scenarios, Doppler shift study and Doppler frequency detection, the exploration of channel spatial and temporal characteristics, signal dynamic range due to high-mobility of vehicles and the presence of divers and passengers, antenna development and its optimal localization within a vehicle, transceiver design to meet the requirements on size, power consumption, temperature, vibration and electromagnetic compatibility in a vehicular environment, signal processing capability for high-speed real-time modulation/demodulation, time/frequency synchronization, channel estimate and coding/decoding, and cutting-edge wireless technologies applied to inter-vehicle networking: MIMO, space-time coding (STC), smart antenna/beamforming, adaptive modulation, software radio and cognitive radio. [?, ?, 6-11]
2. The theoretical research topics include analysis on performances including capacity, throughput and network latency, optimization of network topology in the forms of mesh network and DTN network, quality of service (QoS) issue through effective MAC protocols, routing algorithms, and cross-layer design for both critical safety messages and high-speed data delivery. Message dissemination protocols will be tailored to different applications including broadcast

of safety related information, unicast for specific server access, and peer-to-peer (*p2p*) data exchange with the critical requirement on quick response under the conditions of high-density transmissions, short connection times and intermittent connections.

3. The security issues are to address the fundamental question on whether a car (and the driver) can trust a message received from another one in the vehicular network where less-administrated communication nodes are involved in information generation and message passing. These topics deal with event data verification, message integrity, sender authentication and the privacy of drivers. Some of the major challenges are: (1) The network lacks a unified administrative security mechanism due to the dynamics in network participants. (2) The connections to the RSUs and between two OBUs can be short, transient and intermittent due to the high-mobility of vehicles, which prohibits using long handshaking procedure in security protocols. (3) Lacking evaluation, validation and testing facilities for the security solutions. [12–14]
4. The compatibility design is to study that how road information infrastructure coexists with the existing WLAN as well as future cellular systems and wireless metropolitan areas networks (WiMax), the data fusion with GPS, sensors within and outside vehicles and radio frequency identifications (RFID), interfaces to portable devices based on bluetooth, vehicular radars for distance detection using either millimeter-wave or ultra wide band (UWB), and even future intra-vehicle wireless networks.
5. The integration with ITS management and applications includes vehicle traffic flow analysis with real-time traffic status information provided by the road information infrastructure, roads system congestion control and planning, collision avoidance strategy, and driver behavior study.
6. The implementation path includes testbed and prototype activities for the proof of concept, validation and testing facilities to enable applications specific integrated circuits (ASIC) chip design and exemplar road information infrastructure and inter-vehicle networking deployment and experiments.
7. The business and policy issues concern business model and market study, privacy regulation for the usage of vehicle records and tracking information, and government policy development and deployment. [15]

6 Conclusions

Road transportation is a critical part of the US economy and the lives of the vast majority of citizens. Yet the current highway system is dangerous, inefficient, and inconvenient. While road expanding and other civil infrastructures will not ultimately cure these problems, a nationwide road information infrastructure based on inter-vehicle networking can make tremendous strides in saving lives, reducing travel time, and improving the quality of life for millions of Americans. A long-term directed program in ITS systems, with road information infrastructure as its core component, will also stimulate the US automotive industry and trigger the creative energies of a generation of engineers, scientists, and civil servants.

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