

VEHICLE INFRASTRUCTURE INTEGRATION (VII) FOR HEAVY TRUCKS: A NEW PERSPECTIVE OF TRUCK RESEARCH

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Abstract

This paper outlines the U.S. Vehicle Infrastructure Integration (VII) program and considers current and future heavy truck research in the light of a future VII-enabled transportation system. It is concluded that VII offers important opportunities for relieving current pressure points being experienced by trucks operating in the highway system. Irrespective of the vicissitudes of the deployment of VII and other forms of co-operative systems, supportive research is needed. Such research should consider the systematic effects of vehicle-infrastructure interaction impacts on the ability of increasing numbers of trucks to continue to flow through the highway network.

Keywords: Co-operative systems, Vehicle, Infrastructure, Driver, Vehicle infrastructure integration (VII), Heavy truck, Wireless communication, Traffic congestion, Safety.

Résumé

En tant que nouvelle technologie des systèmes de transport intelligents (ITS), l'intégration véhicule-infrastructure (VII) apparaît comme particulièrement innovante en créant un système totalement interactif, constitué d'éléments séparés comme les véhicules, les conducteurs, les routes et des facteurs environnementaux comme la météo. Cet article présente le programme américain VII et les recherches actuelles et futures sur les poids lourds dans le cadre d'un système de transport futur intégrant le VII. Il conclue que le VII offre d'importantes possibilités pour résoudre les difficultés rencontrées par les poids lourds exploités dans le système routier. Ceci peut avoir des impacts significatifs sur la capacité des transporteurs à maintenir la qualité de service du transport de fret et de sa distribution. Quelques soient les vicissitudes de la mise en œuvre du VII et des autres formes de systèmes coopératifs, des recherches sont nécessaire en support. Elles doivent prendre en compte les impacts de l'interaction véhicule-infrastructure sur la possibilité d'accroître le nombre de poids lourds tout en maintenant les transits sur le réseau routier.

Mots-clefs: Systèmes coopératifs, véhicule, infrastructure, conducteur, intégration véhicule infrastructure (VII), poids lourd, communication sans fil, encombrement, sécurité.

1. Introduction

Among all of the Intelligent Transportation Systems (ITS) technologies that have been introduced in highways and vehicles, Vehicle Infrastructure Integration (VII) seems to many of us especially innovative because it creates a fully interactive system out of the separate elements of vehicles, drivers, roadways and environmental factors like weather. Comprehensive wireless communication will make that *system* a day-to-day reality, to support our way of life and economy, as well as offering system solutions to complex problems like safety, traffic congestion and sustainability.

In recent years, VII has been strongly supported by the US Department of Transportation, and by certain state DOTs, in order to identify an architecture, set a communication standard and demonstrate proof of concept, hopefully in a way that will be attractive to automotive consumers and the general public. The proof of concept testing is being carried out by a consortium of US automakers with a significant USDOT investment of some \$50 million, mostly predicated on VII applications which will support crash avoidance. So far, there has been little engagement with heavy truck manufacturers or freight carriers, even though VII will need to include heavy trucks and buses in order to reach its full potential.

Similar research programs into aspects of *co-operative systems* are also underway in Europe. Examples include the following European Commission (EC) projects (European Commission 2008): Co-operative Networks for Intelligent Road Safety (COOPERS) and Cooperative Vehicle-Infrastructure Systems (CVIS).

The University of Michigan Transportation Research Institute (UMTRI) is supporting a range of VII activities underway in Michigan and involving the US auto industry (Michigan VII 2007). From this perspective, UMTRI has fostered active discussions in the ITS community concerning the application of VII to heavy trucks (Woodrooffe et al 2006). The present paper aims to outline the VII platform, to consider ways in which VII could contribute to known heavy vehicle issues, and to suggest research to assist the application of VII to these issues.

2. What is VII?

2.1 The US VII program

Vehicle Infrastructure Integration (VII) utilizes wireless communication between individual vehicles, and between vehicles and the infrastructure, to enable a variety of applications to be developed which decisively improve traffic safety and efficiency. VII enables a wide range of applications and business models to support the needs of highway agencies, vehicle manufacturers and other private interests.

The U.S. VII program is a cooperative effort led by the U.S. Department of Transportation (USDOT) and involving vehicle manufacturers, State Departments of Transportation (DOTs) through the American Association of State and Highway Transportation Officials (AASHTO) and local government agencies.

Within the U.S., certain states are playing a leading role in establishing VII test beds and related R&D programs. The Michigan Department of Transportation (MDOT) has established a VII Test Bed on a conurbation of freeways and arterials in South East Michigan. California also operates a VII test bed and proof of concept program.

Currently, the USDOT is sponsoring a VII Proof of Concept (POC) program at the Michigan Test Bed; the POC is being carried out by a consortium of vehicle manufacturers (VII-C). Dedicated Short Range Communication (DSRC) at 5.9 GHz has been deployed in the Test Bed in the form of road side equipment (RSE), and DSRC has also been deployed in a fleet of test vehicles, in the form of on board equipment (OBE). DSRC is a licensed bandwidth which provides highly reliable communication with low latency, suitable for “hard” safety applications such as braking assistance: for example, a vehicle equipped with OBE receives a message that the traffic lights at an approaching RSE-equipped intersection are turning red. The Test Bed also utilizes non-licensed wireless formats such as WiFi for less demanding applications, such as dynamic route guidance.

The Michigan Test Bed has been deployed with 75 miles of roadway, covering freeways and arterials, and incorporates 57 RSE sites connected to a Service Delivery Node (SDN) located at the Road Commission of Oakland (RCOC) County Traffic Operations Center. The VII Consortium is currently testing several crash avoidance applications.

The VII platform is currently concentrating on passenger vehicles but also offers great benefits for heavy trucks, in ways that go beyond the benefits offered to passenger cars. This paper explores the unique benefits of VII when applied to heavy trucks, and the research needed to maximize the benefits of heavy truck VII.

2.2 VII business model

VII requires communication equipment in vehicles and in road sides: vehicle manufacturers make a decision to fit OBE to all vehicles manufactured after a certain date and, in parallel, highway agencies decide to install RSE throughout the road network. Deployment will be progressive, with OBE fitted to new vehicles after a certain data.

The rate of deployment of VII (OBE plus RSE) depends on various parties’ motivations and the strength of their business cases. Vehicle manufacturers may see the VII path to crash avoidance as more cost effective than advanced vehicle-based safety systems utilizing radar and machine vision; they also value real-time data on component durability and maintenance status, with potentially huge savings in warranty costs. Highway agencies see probe data replacing costly highway surveys, as well as providing detailed real-time information such as road weather. Federal agencies see probe data supporting congestion reduction strategies, including a concerted approach to corridor management.

While vehicle manufacturers and state DOTs may initially elect to operate their own data services, there will be a need for larger and more integrated services which clarify data ownership, operate sustainable business models and encourage further deployment of VII in vehicles and in the infrastructure. The VII business model for light passenger vehicles is extremely dependent on the perceptions and actions of automakers and their highly diverse set of customers, but the VII model for heavy vehicles could well be more predictable. Freight carriers have already demonstrated an interest in telematics services providing vehicle position information and communication with drivers. Perhaps more importantly, VII could dramatically improve the consideration of trucks in the future design and operation of the highway system assist, and transform the contribution of the highway system to the economy.

3. How Could VII Contribute to Heavy Truck Research Priorities in the US?

3.1 Federal heavy truck safety research programs

Significant federal research programs are addressing crash avoidance technologies targeted to the most common and serious heavy truck crash scenarios. The Integrated Vehicle Based Safety Systems (IVBSS) program is being carried out by the National Highway Traffic Safety Administration (NHTSA). Integrated vehicle-based sensors and driver interface systems are being developed and evaluated (Nassim and Smith 2007); these systems are designed to address the following key crash types:

- Rear-end (into another vehicle)
- Lane-change
- Roadway departure (run-off-road).

Another NHTSA study is investigating vehicle-based stability control technology for avoiding rollover crashes. This study is considering rollover scenarios based on both curve overspeed and yaw instability, and is determining the effectiveness of a hierarchy of technologies which vary in complexity and cost. The recent USDOT decision to mandate electronic stability control (ESC) for light vehicles helped to raise awareness of the potential of stability control for heavy trucks.

The research program under the Federal Motor Carrier Safety Administration (FMCSA) also addresses aspects of heavy truck crash prevention, with a strong interest in technological solutions. Issues being addressed include vehicle mechanical defects, driver drowsiness and hours of service. In-depth crash investigation is being used to underpin further initiatives: the Large Truck Crash Causation Study (LTCCS) is expected to generate new insights into crash prevention. Early analyses of this data (USDOT Federal Motor Carrier Safety Administration 2006) show that, in 87.2 % of truck crashes, critical reasons center on the driver; and it is instructive to consider how the FMCSA has characterized the driver errors which dominate crash causation:

- “Non-Performance – Driver fell asleep, was disabled by a heart attack or seizure, or was physically impaired for another reason” (11.6%)
- “Recognition – Driver did not recognize the situation by not paying proper attention, was distracted by something inside or outside the vehicle, or failed to adequately observe the situation” (28.4%)
- “Decision – Driver drove too fast for conditions, misjudged the speed of other vehicles, followed other vehicles too closely, or made false assumptions about other driver’s actions” (38.0 %)
- “Performance – Driver froze, overcompensated, or exercised poor directional control” (9.2 %).

It is imperative that appropriate countermeasures are researched, and technological solutions are certain to be high on the agenda in the US. Current technological research, some of which is described above, concentrates on technology within the vehicle and develops limited situation awareness of adjacent vehicles and roadway elements. VII offers much greater depth of awareness of other vehicles, not only current status data but lead data which speaks to future vehicle status. For example, VII vehicle-to-vehicle (V2V) communication can transmit information on current and future vehicle range rate and heading (relative to the host vehicle).

3.2 TRB research needs statements

The U.S. Transportation Research Board (TRB) of the National Academies has created a database of research needs, generated through the vast TRB committee structure. Research needs statements were extracted from the TRB database, on the basis that they generally speak to the following heavy vehicle theme: technological solutions to sustained freight productivity, subject to a range of external influences, system management issues and negative impacts which need to be ameliorated. 41 statements were found meeting this general theme, a small proportion of the hundreds of statements in the database. The research needs statements were sorted under the headings listed below. In each case, the number of statements is indicated in brackets. While it is recognized that some TRB committees could be much more zealous than others, the relative number of statements may give some indication of the research topics which are currently of greatest interest.

1. Freight Data (11)
2. Policy and Planning (5)
3. Highway Operations (4)
4. Asset Management (8)
5. Safety (1)
6. Alternative Fuels (4)
7. Health (2)
8. Hazardous Materials (6)

In the interests of brevity, only the first five categories will be considered further in this paper.

Freight Data

There is a strong, connected set of proposals to significantly improve the availability and use of highway freight data. How can technology contribute to informed planning and investment decisions? What is the roadmap for using a range of current and new technologies for freight decision making? There is a dearth of freight data – the data that does exist is generated by the private sector and is needed and used by the public sector. There is a need to develop business models and protocols to encourage the availability of private sector data in the public sector and to facilitate the use of public sector databases by the private sector.

Data from many sources needs to be integrated into an appropriate architecture. Information on freight movements is needed to incorporate the goal of reduced energy consumption in planning decisions. Commodity flow data only covers domestic goods and does not properly identify imported goods. Relative to the rail and waterborne modes, truck movement data including commodity information is lacking.

Policy and Planning

What are the economic development consequences of productivity enhancements, especially those driven by new technology? For example, how does improved productivity impact traffic congestion or pavement condition? How do intelligent highway systems contribute to improved service delivery and utilization of scarce resources?

How should freight be dealt with in urban planning – there is currently a lack of definition, data and understanding. Important changes in decentralization of industries and distribution

manufacturing may lead to more and smaller truck movements – what are the impacts for transportation and land use planning, and intermodalism?

Highway Operations

There are several research questions concerning the more efficient use of existing highway facilities, as heavy truck travel increases at a faster rate than light vehicle travel.

Managed lane strategies are being increasingly used to increase the efficiency of highway facilities. These include high-occupancy lanes, tolled lanes and truck-only tolled lanes. Such facilities mainly cater to light-duty vehicles and the impact of these facilities on heavy truck operations is not known. This is especially important as heavy-truck travel is increasing at a faster rate than light vehicle travel. A range of options for incorporating heavy trucks into managed lane scenarios needs to be studied.

As traffic congestion in urban areas increases, important issues are arising with highway capacity and level of service. Research is proposed to understand the urban highway capacity consumed by heavy vehicles, as dependent on road type, traffic and land use. A growing need is identified to quantify the actual affects of trucks on our urban areas to support the ability to safely and efficiently move goods and people in areas where expansion of roadways is generally not an option. And how is level of service interpreted by truck drivers, as opposed to drivers of light-duty vehicles (who dominate current notions of highway capacity)? Similar research is proposed in environments where long-haul operations are combined with local commuter trips.

Trucking operations are a major current contributor to tolling revenues and there are many questions concerning the impact of expanding heavy truck tolling. Many of these questions relate to the trucking industry's perception of value in the transportation system; and such questions affect the whole chain of industry players including shippers. How do shippers perceive the value of reduced traffic congestion?

Asset Management

It is proposed that the relationship between highway surface condition (roughness) and vehicle performance – including ride, handling and durability – needs to be determined. A full range of vehicle types would need to be considered, from light-duty vehicles to heavy trucks. A methodology is proposed to determine sites where excessive roughness would lead to unacceptable error in WIM measurements. Also further work is proposed on multiple-sensor WIM systems, for improving accuracy with poorer approach surface quality.

It is proposed that there is a need to develop a mechanistic roughness model for flexible pavement design; this will take into account dynamic loading generated by heavy truck suspensions systems.

Refined vehicle classification algorithms are proposed to better deal with a wide range of axle configurations, and to incorporate vehicle weight information.

Safety

There are very few heavy truck safety projects proposed in the database. However, significant safety research programs are underway under the auspices of the USDOT's National Highway

Traffic Safety Administration (NHTSA), Federal Motor Carrier Safety Administration (FMCSA) and the Research and Innovative Technology Administration (RITA).

Pedestrian injuries and fatalities brought about by heavy trucks are a significant issue in urban areas. A best practice guide is proposed to suggest innovative engineering, education, and enforcement strategies that can be used to accommodate these two groups safely in urban areas.

3.3 VII as an extension of current heavy truck best practice

Relative to light vehicles, heavy trucks have often been early adopters of ITS technologies. In recent years, there has been significant deployment of telematics services in the trucking industry. Potential extension of telematics services using VII was considered by Woodrooffe et al (2007). VII could enhance current services relating to vehicle location, vehicle maintenance status and fleet management. Such services could be taken to a new level with comprehensive, reliable and accurate information on traffic flow, especially notification of non-recurring congestion and incidents. This would require extensive VII probe vehicle data, and trucks themselves could provide much of this data.

If deployed in a sufficient number of vehicles, VII could significantly enhance the effectiveness of driver assistance technologies like forward crash warning. Woodrooffe et al (2007) refer to positive experiences in reducing crash rates in a limited number of trucking fleets. However, there remain many barriers to wider usage across US trucking fleets. One significant technical issue is the tricky balance between reliable detection of real conflicts and false alarms. Current forward crash warning systems suffer from an inability to tell whether the slow-moving, rapidly-closing vehicle ahead is intending to continue in the current lane, or suddenly turn off. V2V communication would help resolve this dilemma for the truck-based forward crash warning system.

From an infrastructure perspective, VII is needed to transmit critical information such as weight and height to RSEs located well upstream of sensitive elements in the infrastructure, such as lower standard bridges and low overhead clearances. VII could also enhance weigh in motion (WIM) technology through improved identification and characterization of vehicles approaching WIM sites.

Truck size and weight has not been a major issue in recent years in the U.S., but new initiatives continue in other countries, including:

- Performance based standards (PBS) in Australia
- High productivity permits in Canadian provinces
- The modular transport concept in Europe.

These initiatives have several common elements, including larger vehicles, special management requirements and designation of appropriate routes. VII could play an important compliance role, especially where more route-specific technical data may need to be transmitted.

Trucks could also become part of the VII communication backbone by carrying mobile RSEs, mesh-networked between trucks and providing connectivity for all surrounding vehicles. While the economic case for deploying RSEs throughout urban areas is likely to be very

sound, there may be a need for alternative means of deployment in rural areas, and truck-mounted communication nodes could play a significant role.

3.4 VII as an enabler of an improved freight transportation system

How could the systematic potential of VII support and even transform our economy with respect to freight movement?

The ability of carriers to continue to provide a quality distribution and delivery service, in the face of traffic bottlenecks, incidents and urban change, is currently in doubt.

Truck-only facilities and lanes are being discussed; to the extent that these facilities become a reality, how should they operate in order to maximize level of service *from the truck driver's perspective*? There is minimal current knowledge base, and we must learn to design and operate such costly facilities quickly. VII not only offers accelerated learning through comprehensive data but offers real-time input to operational scenarios such as speed, headway, lane-changing, etc. Fitting of VII OBUs could well therefore be a pre-condition of access to truck-only facilities.

VII also offers the possibility of autonomous platooning of trucks under appropriate conditions. This may be a future consideration for a subset of truck-only facilities.

Managed lanes have been introduced to improve level of service for light vehicles, and may even negatively impact truck operations: this is not known. As managed lanes begin to admit trucks, data is needed to evaluate benefits for trucks, and impacts for light vehicles. In the case of truck-only toll (TOT) lanes, the requirement for OBUs on trucks, along with RSE's in the infrastructure, would contribute to improved operations as well as incisive evaluation of benefits.

Meanwhile, we need to improve the ability of trucks to negotiate the current road network. The safety data speaks to many of the key issues: wherever we have crash problems we have pervasive conflict issues which will impact on truck mobility. Key areas of concern include intersections, freeway ramps, merges, lane-to-lane movements and sudden slow-downs in traffic:

- One of the powerful gifts of ITS is adaptive traffic signals. There is a need to extend signal algorithms to maximize heavy truck throughput, using VII communication to characterize and improve the truck flows.
- Communication between ramps and platoons of trucks on freeways is needed to create gaps for vehicles entering the freeway; such platoons occur naturally when there is a high percentage of trucks in the traffic stream.
- Trucks need assistance in changing lanes, particularly when moving to the right as in preparing to exit a freeway. VII communication can provide the truck driver with presence and status information about adjacent vehicles, and potentially bring about co-operative gaps for efficient and safe lane-changing
- VII communication from slow-moving or stationary vehicles ahead, but out of sight of the truck driver, can help prevent rear-end crashes and eventually reduce the incidence and propagation of such traffic disturbances.

3.5 Implications for re-invigorated truck research programs

Much has been gained from past and current research programs which consider the truck-infrastructure interaction. It has been necessary to understand key aspects of truck impacts on the infrastructure, to ameliorate such impacts and to find the least intrusive ways to improve the productivity of trucks, and to manage trucks. Generally speaking, the focus has been on individual trucks of varying configuration, engineering and technology. This research has created significant productivity improvements, in a manner reasonably acceptable to society, and has developed improved monitoring methods such as WIM.

Part of the aim was to bring about more specific and informed consideration of trucks in transportation planning, road design and traffic management. This has been very slow to occur. We now face severe challenges to the highway system as it is negotiated by increasing numbers and mileages of heavy trucks carrying freight. These challenges not only relate to impacts created by individual trucks, but speak to the ability of large numbers of trucks to flow with any degree of freedom.

The truck impacts we have been studying affect not only safety and road costs, but also resistance to mobility. It is one thing to ask whether a truck can get around an intersection from a geometric perspective; we now need to understand how readily large numbers of trucks can negotiate networks of intersections. We have long been concerned about the acceleration and braking performance of trucks, particularly deficiencies relative to cars; we now need to understand the behavior of naturally-occurring mixed platoons of cars and trucks and the extent to which they could and should be separated. When separation is warranted, how should truck-only facilities be designed? What will be the effect on truck flow of removing traditional geometric resistance created by existing lane widths, turning radii, etc which were basically designed for cars and modified incrementally to accommodate trucks?

VII offers many things, but the most powerful possibilities for heavy trucks appear to be:

- Enhanced situation awareness for the truck driver
- Platform for co-operative car-truck behavior in traffic
- Reliable route guidance for avoiding delays
- Improved truck level of service at intersections, ramps, multi-lane facilities and exits
- Rapid learning curve for designing and operating truck-only facilities
- Enhanced truck management and monitoring at WIM sites, weigh stations, inspections and border crossings.

Important areas of truck research needed to support such VII-related developments include:

- Truck driver needs for situation awareness
- Effect of truck (and car) dynamic performance on co-operative traffic behavior
- Truck driver needs for improved level of service at intersections, ramps, multi-lane facilities and exits
- Effect of truck dynamic performance on the design and operation of truck-only facilities
- Effect of larger trucks (and alternative energy sources and powertrains) on truck performance (affecting all of the above).

4. Conclusions

VII offers a new level of systematic safety and efficiency in the highway transportation system, as well as requiring major commitments on behalf of the automotive industry and transportation agencies. Potential VII-related opportunities for freight transportation tend to differ from the light vehicle case and could have a positive impact on the economy, as well as truck safety.

Whether considered as an extension of current heavy truck best practices, or as a disruptive technology for the freight industry, VII offers a powerful array of applications for relieving current pressure points being experienced by trucks operating in the highway system. Such relief could have far-reaching effects on the ability of carriers to maintain current quality of service in freight transportation, distribution and delivery.

Irrespective of the vicissitudes of the deployment of VII and other forms of co-operative systems, supportive heavy truck research is needed. Such research should reach beyond current interests in individual heavy truck impacts to consider the broader effects of these impacts on the ability of increasing numbers of trucks to continue to flow safely through the highway network. A major effort is needed to investigate the dynamics of high-density traffic having a high percentage of trucks: truck platoons, platoons of cars and trucks, truck driver needs for level of service and truck driver needs for situation awareness.

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