Exploiting Motor Vehicle Information and Communications Technology for Transportation Engineering

Burcu Akinci, M.ASCE¹; Chris Hendrickson, M.ASCE²; and Itir Karaesmen³

Abstract: Technology already exists to capture and communicate a variety of information from motor vehicles. Automobiles are equipped with sensors and can reliably report their location, velocity, and condition via cellular telecommunications. Truck location tracking with global positioning systems is common, and prototype systems exist for characterizing surrounding traffic and roadway conditions. Given these advancements, we expect that future motor vehicles will be capable of reporting a wide variety of information about their own condition and the local environment, including the condition of the infrastructure on which they travel. Many uses exist for the vehicle- and infrastructure-related information that can be transmitted from motor vehicles. For example, fleet operators can take advantage of this information for better management of their own fleet, subject to privacy agreements with their own drivers. Similarly, this information can be used for traffic control purposes to improve travel times and safety. Even though it is becoming technologically feasible to use motor vehicles to transmit a variety of information collected through sensors, social, technical, and organizational barriers exist currently that limit the availability of this information mostly to the private use of the motor vehicle and drivers. In this paper, we describe our vision of how motor vehicle information and communications technology can be exploited for transportation engineering. We also discuss the social, technical, and organizational barriers that need to be overcome to achieve this vision.

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Introduction

The numbers and capabilities of sensors and computer processors onboard motor vehicles are growing rapidly. New features such as moisture sensors (to turn on wipers automatically), traction system control (to control power and braking at all wheels), or adaptive cruise control with short-range radar and stereo video (to detect vehicle surroundings) (Bosch 2001a) are increasingly available as options or standard features. Databases for onboard communication are standard on some production vehicles, and their use is expected to grow. Cellular telephones with packet-switched or traditional circuit-switched systems and global positioning system (GPS) receivers connected to the dynamic navigation systems are common options for vehicles (Bosch 2001b). Entertainment systems are also becoming more capable. Fig. 1 shows the estimated numbers of microcontrollers for different classes of automobiles over time as estimated by R. Bannatyne of Motorola Automotive (Bannatyne 2001).

As an example of the improvement in capability of sensors and computer processors, Table 1 shows the rapidly growing capability of the General Motors event data recorders over the past 10 years. In addition to providing information about accidents, the General Motors system will notify emergency response (911) groups of the location and expected severity of accidents, speeding up emergency response (Chidester et al. 1999).

Given these advancements, we expect that future motor vehicles will be capable of reporting a wide variety of information about their own condition and the local environment. Applications such as personal telecommunications, navigation aids, and accident response systems will motivate motor vehicle owners to purchase these capabilities. Once the initial telecommunication system is installed on the vehicles, the cost of additional onboard processing and transmission of vehicle information would be very low. Hence, the same data collection and communications technologies can be used to transmit not only additional vehicle-related data, but also infrastructure-related data collected from sensors embedded in the infrastructure.

Currently, gathering field data is often limited to a single application type and relies upon dedicated resources such as trace cars. For example, traffic volumes are commonly gathered with counters placed manually on roadways and returned after use. Our approach is similar to that used in multipurpose telecommunications networks or the Internet. There are no dedicated sensors or communications channels, but a multitude of information can be gathered inexpensively.

Vision for Exploiting Motor Vehicle Information and Communications Technology

Many uses exist for the vehicle- and infrastructure-related information that can be transmitted from motor vehicles. For example,
fleet operators can take advantage of this information for better management of their own fleet, subject to privacy agreements with their own drivers. Similarly, this information can be used for traffic control purposes to improve roadway capacity, travel times, and safety.

Fig. 2 illustrates our vision of how motor vehicle information and communications technology can be exploited for multiple purposes:

1. Private vehicles traveling on public roadways could report their location, speed, and environmental data on a regular basis to a data storage facility. This could be done via devices on the vehicles.

2. Private vehicles would also serve as relay communication hubs for sensors embedded in roadways, bridge decks, or other infrastructure items.

3. A variety of applications could draw useful information from the data storage facility. An existing application is information relevant to vehicle maintenance and response to accidents. Travel speeds and local weather on roadway links could provide good information for planning trips for travelers. Travel speeds and volumes could aid traffic control systems. Congestion information and vehicle tracking could improve fleet management for delivery vehicles, taxicabs, public transit, and so forth. Weather forecasters could have very detailed information about surface precipitation and temperatures. Finally, roadway surface roughness and potholes could be identified to aid maintenance planning.

Most of these applications could work with only a fraction of the private vehicle fleet enrolled in the system. A filter could be put in place to prevent identification on specific private vehicles to protect individual privacy, when necessary. If such communication and data gathering systems became universal, then numerous economies could be achieved. For example, loop detectors at traffic signals would no longer be needed. Waiting vehicles would communicate their location to the traffic signal directly.

Table 2 lists major applications, information inputs, and relevant vehicle sensors for important transportation engineering applications of motor vehicle information and communications technology. The effective use of this information should significantly improve the efficiency of the transportation infrastructure and operations. Cost savings from avoiding alternative information collection methods can also be realized. The use of improved location information for truck fleet control has been estimated to result in savings of $75 billion annually in the United States (Litan and Rivlin 2001).

As an example, traffic control could benefit in many ways from comprehensive real-time data on traffic density, speed, and volume by link. Even without improved control, such data can indicate traffic and ramp metering signals that are misadjusted, directing attention to the most critical changes needed rather than relying on a fixed review schedule. More sophisticated uses would alter signal timings or parking policies to reduce congestion. Real-time data might also contribute to enhanced incident detection and response.

Similarly, infrastructure monitoring, maintenance, and construction processes can benefit greatly from infrastructure- and location-related information. Vehicles traveling over particular infrastructure provide an opportunity to collect information about the infrastructure, such as strains at critical locations, more frequently and accurately. This infrastructure information can be used to make active decisions on scheduling of maintenance and construction operations, which are currently made when infrastructure deterioration becomes apparent, resulting in a reactive scheduling of construction and maintenance work that can potentially lead to higher-cost solutions to the problems. Continuous monitoring of the infrastructure by using vehicle communication technologies creates an opportunity for early diagnosis of problems and effective scheduling of infrastructure maintenance programs.

Given the variety and economic significance of the possible uses of motor vehicle information and communications technology, currently technical, societal, and organizational barriers exist that limit the availability of the information collected mostly to the private use of the motor vehicle owner.

**Scenario for Exploiting Motor Vehicle Information—Usage of Travel Time Information**

Several types of technologies, such as onboard microprocessors and microelectromechanical (MEMS) based sensors, exist within automobiles for collecting trip and travel information (for example, weather conditions, location, speed, and so forth). Intervehicle communication is also becoming a reality. For vehicles

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**Table 1. Parameters Available from General Motors Event Data Recorders at Different Stages of Development (Chidester et al. 1999)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1990</th>
<th>1994</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>State of warning indicator when event occurred (on/off)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Length of time warning lamp was illuminated</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Crash-sensing activation times or sensing criteria met</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Time from vehicle impact to deployment</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Diagnostic trouble codes present at time of event</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ignition cycle count at event time</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Maximum velocity change ($\Delta V$) for near-deployment event</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Velocity change ((\Delta V)) versus time for frontal airbag deployment event</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Time from vehicle impact to maximum velocity change ((\Delta V))</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>State of driver’s seat belt switch</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Time between near-deploy and deploy event (if within 5 s)</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Passenger’s airbag enabled or disabled state</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine speed (5 s before impact)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle speed (5 s before impact)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brake status (5 s before impact)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throttle position (5 s before impact)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
without factory-installed sensors, some add-on technologies, such as the E-Z Pass toll payment system, exist for reporting location information.

Once observations of speeds and locations are obtained from these systems in vehicles, they can be related to individual roadway links. A fraction of vehicles supplying trip and travel information would be enough to supply real-time travel time information. A number of methods, such as radio broadcasts, cellular telephones, and map systems within motor vehicles, can be used for delivering real-time travel time information.

Fleet operators, private motorists, emergency services, roadway agencies, and broadcast stations would be possible users of this information. Fleet operators can link this information with their fleet tracking software to have a better assessment of travel time information and to pay the drivers accordingly. Private motorists can benefit from this information when planning for their trips and also when they need to make route decisions while on a trip. Emergency services can use real-time travel time information in routing emergency vehicles, and roadway agencies can use this information for improved real-time traffic control and planning of maintenance activities. Finally, broadcast stations, which often provide traffic congestion reports assembled from stationary reports or helicopter patrols, can use real-time travel time information.

Two different business models could be used in exploiting real-time travel time information. One model would involve a private firm being the information supplier, which can form an alliance with a set of motor vehicle manufacturers to offer real-time travel time information as an option for new car purchasers. In return, the company would charge the customers a monthly subscription fee to access the data. In a second model, a government agency or nonprofit organization, such as the American Automobile Association, would provide this information free of charge in return for collecting data from motorists.

Table 2. Major Applications, Information Inputs, and Vehicle Sensors

<table>
<thead>
<tr>
<th>Applications</th>
<th>Major information inputs</th>
<th>Typical vehicle sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic control</td>
<td>Traffic density, speed, and volume by link</td>
<td>Speedometer, GPS receiver, inertial navigator</td>
</tr>
<tr>
<td>Traveler information</td>
<td>Travel times, transit vehicle arrivals</td>
<td>Speedometer, GPS receiver, inertial navigator</td>
</tr>
<tr>
<td>Asset management, maintenance, and construction</td>
<td>Travel volumes and times, infrastructure condition</td>
<td>Speedometer, GPS receiver, inertial navigator, traction control sensors, suspension control sensors, embedded roadway sensors</td>
</tr>
<tr>
<td>Weather and environmental modeling</td>
<td>Precipitation, temperature, air quality</td>
<td>Windscreen sensor, thermometer, visibility</td>
</tr>
<tr>
<td>Fleet control</td>
<td>Network travel times, fleet location</td>
<td>Speedometer, GPS receiver, inertial navigator, vehicle ID</td>
</tr>
</tbody>
</table>

Fig. 2. Illustration of Possible Applications Exploiting Motor Vehicle Information
Present State of Knowledge

Automobiles are already used as sources of information for maintenance and accident-event reporting (Chidester et al. 1999). Floating cars are used for travel time measurements. Transit vehicles have been monitored to provide arrival time predictions (Lee et al. 2000). As noted previously, the technology already exists to capture and communicate a variety of environmental factors and traffic and vehicle conditions. Golob and Regan (2001) note that new information technology opportunities mean that many aspects of travel demand modeling, and fleet operations need to be reexamined. McNeil et al. (2000) identify associated research issues.

Numerous studies and modeling efforts also exploit new transportation data. For example, Fletcher (2000) envisions a scenario in which automatic event-reporting system reports populate an accident geographic information database that is used for planning maintenance or safety improvements. Ygnace et al. (2000) estimate that cellular telephones and GPS receivers tracked in only 5% of a traffic stream would provide relatively accurate and useful traffic flow data. Economic assessments of intelligent transportation systems also exist [for example, Lee (2000); Peng and Beimborn (2001)].

Real-time information is being used in fleet management for updating information about vehicle locations and conditions as well as routes and sequences of stops (Brown et al. 1987; Cleary 2000). Decision support systems are being used by courier companies for dispatching, routing, and scheduling of vehicles as well as performing other business functions (for example, confirming delivery of a parcel, printing receipts, and so forth), or by other industries to improve operations [see Naresh and Jahren (1997) for tracking of construction vehicles]. Vehicle routing and dispatching problems are known to be very difficult to solve (mathematically), and the focus of scientific research, and in particular of operations researchers, is on finding good and practical decision rules with a reasonable amount of computation time and power [for instance, Cheung and Muralidharan (2000); Ichoua et al. (2000)]. The economic benefits of real-time information, however, have been somewhat neglected. Exceptions include Button et al. (2001), who studied the effectiveness of dispatching software on the productivity of drivers, Eisele et al. (2001), for multimodal uses, and Litan and Rivlin (2001), who report an estimate of $75 billion in annual savings due to information technology efficiencies contributing to improved scheduling and higher load factors.

Much of the existing work is focused upon a particular application of vehicle data, without an attempt to identify synergies or multiple clients. Moreover, business plans for the use of motor vehicle data do not yet exist. For example, considerable effort has been extended to assess and model systems of dedicated “floating” or “probe” vehicles to gather travel time data [for example, Chen and Chien (2000); Levinson and Chang (2000)]. The use of the entire population (or at least a significant fraction thereof) would reduce costs and improve data accuracy.

The use of embedded sensor systems for monitoring infrastructure health is not as widely adopted as sensing on motor vehicles. However, many research efforts have started demonstrating the technical feasibility of using embedded sensing for monitoring the conditions of the infrastructure. Different types of embedded sensors have been successfully used for concrete testing (Sackin 1999), to monitor and measure strains in precast concrete components (Steinberg et al. 2001), to accurately determine the strength of cast-in-place concrete components (Digital Site Systems 2001), and to monitor curing of concrete (ASTM 2001; Germann 2001). The most recent use of embedded sensors in construction involves radio frequency identification tags (RFID tags) for tracking structural components during fabrication, shipping, storage, and placement in the field (PipeTech 2000). In addition, commercially available microtransmitters, which are required to collect information from embedded systems, can now power and read multiple external sensor types (for example, strain, temperature, humidity, displacement sensors) and transmit the data collected for distances ranging up to hundreds of feet. These devices can transmit data while being embedded in up to 10 in. of concrete (Sackin 2000). In all of these cases, collection of data from these systems requires a separate crew dedicated to the task; hence, the economic feasibility of collecting information from these systems has not been fully demonstrated. The technical advancements in embedded sensing technologies for infrastructure health monitoring provide an opportunity to use motor vehicles to collect and communicate infrastructure-related data without the requirement of an additional crew for data collection purposes.

Many transportation applications are developed to automate certain management decisions. For instance, examples of predictive and analysis models of infrastructure deterioration and maintenance can be found in the literature, such as Scherer and Glagola (1994); Omar et al. (1995), and Kim and Haas (2000). Privacy concerns and suggested standards for electronic toll collections are discussed in Ogden (2001). These application-specific models do not fully address the value of a variety of information that could be collected continuously from sensors embedded in the motor vehicles and/or infrastructure.

Issues Related to Exploiting Motor Vehicle Information and Communications Technology

As demonstrated by the previous research studies described above, it is technologically feasible to use motor vehicles to transmit a variety of information collected by sensors. However, there is currently no necessity for motor vehicle information to be available for anything other than the private use of the motor vehicle owner. We are limited in our understanding of how this new stream of information might have various social and decision-making uses and how the current processes can be reengineered to benefit highly from this new venue of information. In addition, examples of technical and organizational barriers to the greater use of motor vehicle information include privacy, data storage, and broadcasting issues.

For privacy reasons, vehicle drivers may be unwilling to broadcast their specific locations and velocities. For example, traffic violations might be automatically charged, with comprehensive position and velocity information available to authorities. In contrast, for applications such as fleet management, vehicle owners might wish to know and use the location information for the different vehicles in the fleet. Some form of privacy filters will be essential to use motor vehicle information widely. Examples of such filters already exist for electronic toll collections purposes (Ogden 2001).

There is the potential to have large amounts of information available from a fleet of vehicles. We expect information exchanges to be undertaken at the instigation of either the individual vehicle or as part of a location-specific survey for a particular application. In either case, only vehicles willing to be enrolled for
particular applications would provide data. An efficient and effective data management strategy will be necessary to exploit motor vehicle data widely.

The possibility of embedding sensors to improve infrastructure management is a novel use of motor vehicle communications technology. Essentially, passive sensors could use passing motor vehicles to communicate information about the roadway infrastructure. By collecting data from many different vehicles passing over the infrastructure system, the problems related to the volume of material to be sensed will be addressed. If most of the sensors are still onboard a vehicle, then they will be updated on a much shorter cycle, which may bring up other issues associated with the consistency of the data collected over time. Finally, if some of the sensors are embedded, it may be possible for the vehicles to power the sensors via inductive coupling technologies similar to those used by RFID tags.

With the exploitation of motor vehicle information and communications technology, there will be multiple uses for the information collected, significantly increasing the potential benefits of the information in various vehicle transportation and infrastructure management areas. This creates an opportunity to reengineer the current processes and develop new business models to make our vision of the social uses of real-time motor vehicle data a reality.

Conclusions

New motor vehicle sensing, processing, and communications technologies promise to have a revolutionary impact on the amount and accuracy of information available for transportation engineering. To exploit this information, research should be under way on appropriate data management schemes, privacy filters, and users. Most importantly, a business plan for inducing automotive companies and drivers to make such data available is needed.

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