INTELLIGENT VEHICLE / HIGHWAY SYSTEM: A SURVEY

Part 1

Alberto Martin, Hector Marini and Sabri Tosunoglu
Florida International University
Department of Mechanical Engineering
Miami, Florida 33199
E-mail: tosun@eng.fiu.edu

Abstract- *Traffic congestion in the largest cities of the world is a growing problem that has to be taken into account seriously, not only by governments, but also by the private sector. After an extensive survey in the field of Intelligent Vehicle / Highway System (IVHS), different alternatives are analyzed to solve this dilemma and the concept of Intelligent Vehicle / Highway System is proposed as the best solution. This work analyzes the latest trends in this area and compares the different options. In addition, comparisons between Europe, Japan and United States, highlighting the advancements in this field of each one of them was conducted. Ideas and procedures are unified while developing a well-structured concept of Intelligent Vehicle / Highway System which contains separate fully-functional units with their own characteristics interrelated to each other to conform a flexible system that can respond in an effective way to solve the problem of traffic congestion. Some of the most relevant efforts in this area and their role in the great scale implementation of IVHS are described.*

INTRODUCTION

It is a well-documented fact that highway traffic congestion in the metropolitan areas of the world is becoming a major concern for governments, scientists, private sector, transportation consulting firms, and international environmental organizations. According to statistical data of U.S., the average travel speeds at rush hour in the larger U.S. cities drop to about 36 miles per hour. Annually, this leads to some 5 billion collective hours of delay and estimated productivity losses of $50 billion nationwide. In addition, all vehicles caught in traffic jams consume more fuel. Everybody, without exception, has experienced the frustration of being captured in a traffic jam. The traffic congestion is, to a great extent, responsible for the increased accident rates and their consequences--human life losses lost time, increased air pollution and expensive repairs.

Several solutions have emerged to solve this problem, but the concept of "*Intelligent Vehicle / Highway System*" appears to be the most attractive one.

HISTORICAL BACKGROUND

Traffic congestion is not a new problem. In the 1930's, the introduction of affordable mass-produced cars provoked a rapidly increasing population of drivers demanding paved city and rural roads. This fact quickly expanded the scope and intensity of the traffic problems. The increase of automobiles and trucks during several decades after the car boom has resulted in the construction of more and more highways. In the United States, the massive 30-year construction of the nationwide interstate highway is only now nearing completion [18].

The relief from traffic congestion through the construction of highways has only been temporary, because new commercial and residential growth follows the path of the project.

The traditional solution has been to construct more and larger highways. However, due to the high financial, social, and environmental costs of such projects, that is no longer seen as a viable option. Many innovations have come to use in a more efficient way the existing infrastructure, such as: improved traffic-signal controllers, changeable highway signs, rerouting rush-hour traffic, creation of traffic-control centers that monitor and display gross traffic conditions, use of preplanned alternative traffic solution based on repeated daily traffic patterns, etc.

The more efficient use of the existing road network using the emerging advancements in technology seems to be the most acceptable answer. However, there is not a consensus of how to face the problem. It is necessary to find the way to operate the existing system more effectively and efficiently, but this system does not respond dynamically to traffic congestion. It is unable to change traffic-handling rules rapidly in response to actual traffic conditions. In that sense, it is indispensable to create the basis for a new generation of vehicles and highways that will interact intelligently as a unit. This new concept to face the growing traffic problems and its

consequences is called Intelligent Vehicle / Highway System (IVHS).

THEORETICAL BACKGROUND

What is an Intelligent Vehicle / Highway System?

It is an intelligent transportation system, in which vehicles and highways will exchange information through a two-way communication system. The automated highways will have a set of lanes on which vehicles with specialized sensors and wireless communications systems could travel under computer control at closely spaced intervals. This type of arrangement is called platoons. The vehicles could continuously exchange information with other vehicles and traffic-control centers about speed, acceleration, braking, obstacles, road conditions, etc. Sensor data can be processed and sent back to each vehicle guaranteeing a continuous exchange of information.

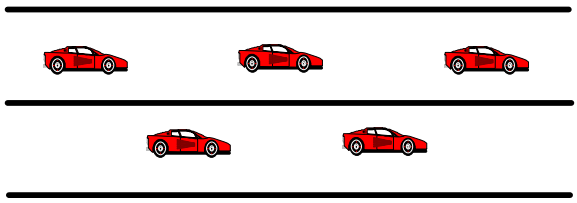

Figure 1. Platoon concept.

The highway system will know the destinations and planned routes of individual vehicles. In that way the system can coordinate traffic flow more efficiently, reduce speed fluctuations, monitor unsafe vehicle operation, and traffic shock waves, maximize highway capacity and minimize avoidable traffic congestion. In addition, the system will respond rapidly to changing highway conditions.

The vehicles might use several types of devices to sense its environment, such as magnetometers, visual sensors, infrared sensors, laser sensors, accelerometers, etc. Each vehicle has to have a powerful computer to process sensory data and the information that come from the traffic-control centers.

What are the factors that have contributed to the development of IVHS?

Some factors are listed below [2] [18]:

- The traditional solution of constructing more and larger highways is no longer seen as a viable option due to the high financial, social, and environmental cost of such projects.
- The more efficient use of the existing road network using the emerging advancements in technology does not guarantee a complete solution of the problem of traffic congestion.
- During the last two decades, the electronic content of cars and trucks that sense the vehicles' conditions to provide better vehicle operation and control has increased significantly.
- In the last decade, there was a notable increase in computer technology and advanced software techniques, which permit computers to assimilate large quantities of data and arrive at conclusions using rules based on analogous human experience (artificial intelligence).
- The microelectronic revolution has also provided the basis for major improvements in sensors and communications devices. The infrared sensor technology has been improved considerably. Greater advancements have also been made through military research on computer-based machine vision.
- With the Global Positioning System (GPS) for civilian purposes, the world of communications changed dramatically. GPS is a Satellite Navigation System funded and controlled by the U. S. Department of Defense (DOD). GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity, and time. The introduction of the GPS system and the recent advances in mapping and tracking make it possible to locate a car's position via a computer model of all roads. Because the location of every road in the United States fits in one CD-ROM, cars can be located to within a few feet. Navigational assistance is a reality and it is implemented in some high-end car models all over the world.

Today, society is getting closer to the science fiction image of cars and light trucks: driverless cars on automated highways may soon be everyday sights. High-tech devices that were only concepts a few years ago are now becoming reality due in part to the transfer of advanced technology from aerospace and the military.

Figure 2. BMW's new On-Board Navigation System. [4]

Devices and systems such as *Global Positioning System* (GPS), *Automatic Vehicle Monitoring* (AVM), *Incident Management System* (IMS), *Intelligent Transportation System* (ITS), *Vehicle Navigation System* (VNS), and *Driver Assistance System* (DAS), are very common today.

There is a single name under which most of these systems are lumped: Intelligent Vehicle / Highway System (IVHS). IVHS consists of a number of diverse technologies, including information processing, communications, control and electronics. These technologies, when joined with the surface transportation system, can reduce congestion, save lives, and enhance productivity. Among other devices, IVHS technologies have potential to:

- Collect and transmit information on traffic conditions and transit schedules, allowing travelers to avoid hazards and delays before and during trips,
- Decrease congestion by reducing traffic incidents, clearing them more quickly when they occur, re-routing traffic flow around them, and automatically collecting tolls.
- Improve the productivity of commercial, transit and public safety fleets with the use of automated tracking, dispatch and weigh-in-motion systems.
- Assist drivers in reaching desired destinations with in-vehicle navigation system and provide for their personal safety and security en route with collision avoidance and distress signaling technologies.

IVHS has an immediate market. Everybody has experienced the frustration of being caught in traffic jams or being lost on a road trip. In fact, non-consumer navigation products have been available in the U.S. for years. Automatic Vehicle Location (AVL) systems have been installed in numerous commercial vehicles and a number of companies are using GPS-based products in rental cars. Car locating services utilizing GPS for retrieving stolen vehicles are also common.

Surveys reveal consumers have specific expectations from IVHS. The systems must provide quick and reliable route guidance, offer easy-to-understand driving instructions delivered in a timely manner to reduce driving stress and increase travel safety, be easy to operate, provide alternate route recommendations to bypass traffic congestion, contain information on potential destinations like ATMs, hotels, restaurants and service stations, and sell at an acceptable price.

Intelligent Vehicle / Highway System has been called by different names depending on the developing area and the application purposes. Intelligent Transportation System (ITS), Intelligent Cars and Automated Highways Systems (AHS), Automated Vehicle / Highway System (AVHS), Smart Cars / Smart Highways are different denominations for the same concept.

INTERNATIONAL ANALYSIS OF IVHS

The Intelligent Vehicle / Highway System activities are being developed in different countries. They involve people in government, industry, academic institutions and professional organizations. The work of different groups occupied in different projects gradually merged into a concept of viewing advanced vehicle systems and highway systems as integrated vehicle-highway systems. By application of artificial intelligence to this concept, Intelligent Vehicle/Highway System emerged.

The IVHS concept seems to be strong in Japan and Europe. In Japan, the progress in this area is more advanced than in the U.S. and Europe. In 1973, Japan's Ministry of International Trade and Industry started a project related to IVHS. The purpose of this activity was to develop and test an on-board dynamic route guidance system. The Japanese government has promoted different projects to develop and evaluate intelligent vehicle and highway systems, working in conjunction with the private sector in different areas. All this work was unified in 1990 in a project called the Vehicle Information and Communication System (VICS) [18].

With all these projects under way, Japan has moved ahead in a number of areas. In 1994, Japan formed its Vehicle, Road, and Traffic Intelligence Society (VERTIS).

In Europe the first activities in the IVHS area can be identified with the two programs, PROMETHEUS and DRIVE. The multimillion Dollar European PROMETHEUS Project (Program for European Traffic with Highest Efficiency and Unprecedented Safety), which aimed to develop intelligent highways and vehicle systems, is an example of how serious the European Community is taking this challenge. The European

Community is participating in this type of research focusing initially on enhancing the mobility of freight. The Dutch Ministry of Transport is working with Daimler-Benz, BMW, Fiat, Renault, Volkswagen, to name a few, in the Automated Highway System European Analysis. France and England are also working in this direction.

There are other important European Projects such as DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe), a major initiative begun in 1988 to apply information technology to the improvement of road safety and the reduction of environmental pollution by road traffic, and CHAUFFEUR, a wireless radio link between two trucks, where only the first of which will be operated by a driver and both trucks will drive very close to each other at highway speeds, using video imaging to keep lanes as well as video registration and infrared signal to maintain a safe distance.

PROMETHEUS and DRIVE have been working for about 12 years to demonstrate the necessity of viewing vehicles and highways as an integrated system. PROMETHEUS was oriented toward vehicle technology and DRIVE toward highway and traffic control technology. To unify these two separate activities into one, the European Road Transport Telematics Implementation Coordination Organization (ERTICO) was created in 1991 as a private-public organization. It was designed to coordinate and control the research, development, and implementation of intelligent highways and vehicles in Europe.

In the U.S., the first efforts in the IVHS were undertaken by individual states and cities. In 1987 Mobility 2000 was created to promote the creation of national programs in the field of IVHS. This organization temporarily assumed the role of advising policy makers and the U.S. Congress on IVHS matters. Mobility 2000 was a main factor in the completion of a set of planning documents to guide national support for the development of an IVHS program. In 1990 Mobility 2000 sponsored the National Workshop in IVHS in which representatives of federal and state government agencies, industry and the academic community participated. There, the U.S. Department of Transportation (USDOT), through its Federal Highway Administration (FHWA), mobilized federal support for a nationally coordinated program. Representatives of the major automobiles, communications, information systems, transportation equipment, and consulting companies in the United States also attended the workshop [18].

Mobility 2000 promoted the formation of the Intelligent Vehicle Highway Society of America (IVHS America). This society is composed of people from federal, state, and local government, from industry and from academic institutions. IVHS America is the Federal Advisory Committee to the USDOT. This organization has prepared and submitted to the USDOT a strategic plan to implement a national IVHS program.

IVHS America has become the coordinating and planning entity in which the individual activities of state and local authorities, companies, and universities have a central orientation for constructing a national IVHS program.

VERTIS in Japan, ERTICO in Europe and IVHS America in the United States perform similar activities as major coordinators of the Intelligent Vehicle / Highway System Programs.

LONGITUDINAL COLLISION AVOIDANCE[1]

Collision Avoidance Systems (CAS) denote the first step towards accomplishing fully automated highways. However, the development and near-term implementation of CAS is driven by the system's role in preventing rear-end vehicle collisions.

The development of CAS represents a change of focus in dealing with the consequences of accidents. Traditionally the emphasis has been on injury mitigation for those involved in a collision, for example by providing stronger vehicle frames, seat belts, and airbags. Starting with the development of antilock brakes, the focus has now shifted to collision avoidance. Most CASs are currently in experimental stage; before they can be implemented on a wide-scale basis, several technical and political questions need to be answered.

A collision avoidance system operates, generally, through a sensor installed at the front end of a vehicle, which constantly scans the road ahead for vehicles or obstacles. When found, the system determines whether the vehicle is in imminent danger of crashing, and if so, a collision avoidance maneuver is undertaken. Most CASs are non-cooperative, that is, detection is independent of whether other vehicles on the road are equipped with collision avoidance devices.

An alternative technology relies on vehicle-to-vehicle communications to exchange information on vehicles' presence, location, lane of travel, and speed among other factors. In addition to the front-end sensor, vehicles

[1] The National Highway Traffic Safety Administration (NHTSA) estimates that that about 88% of rear-end collisions in the U.S. are caused by driver inattention or by vehicles following too closely [8].

require a rear-end transponder as well, since communication, and therefore detection, only occurs among equipped vehicles.

The criteria to activate the collision avoidance system are [8]:

The time-to-collision criterion*:* the system decides whether a collision is likely to occur at prevailing speeds and distances, within a certain time interval. In a car-following scenario, the time-to-collision is the time taken for the two vehicles to collide if they maintain their present speed and heading.

The worst-case criterion*:* the system infers that the vehicle preceding the CAS-equipped vehicle could brake at full braking power at any time. Basically, it operates on a "critical headway distance," that is, the minimum distance necessary for the CAS-equipped vehicle to come to a stop in the event the leading car abruptly brakes.

Collision avoidance maneuvers:

Headway distance control: the system alerts the drivers when their cars are following the leading car too closely. Some systems include automatic speed control, in such a way, the car could automatically reduce its speed in order to maintain a safe headway with the leading vehicle.

Hazard warning: the system alerts the driver of an object (moving or stationary) within its projected path, so that the driver has enough time to avoid a collision.

Automatic vehicle control: the system controls the vehicle's brakes and steering wheel, and applies them automatically when it determines it necessary.

Warning devices:

Visual head-up displays*:* warnings are displayed on the windshield in the driver's field of view, so that their content can be assimilated in conjunction with the driving scene ahead. These displays are intended to minimize distraction from driving tasks, in addition to ensuring that the warning does not go undetected.

Audio/Voice signals*:* in comparison to visual signals, auditory signals appear to be less intrusive on driving tasks. They are also insensitive to external conditions such as poor light, bad weather, or a dirty windshield. Two different auditory warnings have been developed: speech (synthesized voice) or non-speech (buzzer) displays.

Haptic devices*:* They provide redundant information via alternative sensory modalities, given that the primary visual or auditory channel may be degraded or overburdened. Research suggests that one possibility is to increase the force needed to push the gas pedal.

External sensors:

These sensors achieve the tasks of headway control and obstacle detection, which are the basis of CAS sensing techniques, and can be classified in three main groups:[2]

Optical techniques (Passive infrared, laser radar and vision)*:* they have the disadvantage of being sensitive to external environmental conditions. Passive infrared and vision cannot provide a direct measurement of distance to an object. Laser radar appears as the most useful of these techniques, despite its high cost.

Electromagnetic techniques (FMCW radar, impulse radar and capacitive)*:* unlike the optical techniques, they perform well under adverse environmental conditions. Despite its relatively high cost, FMCW radar (Frequency Modulate Continuos Wave) seems to be the best technique for long-range distance measurement. It could also be utilized at short and medium range, rendering it a quite flexible technique.

Acoustic techniques (ultrasonics)*:* well suited in applications where only short distance measurements are required because they are able to provide high resolution for a relatively low cost.

CONCLUSIONS

After years of planning, implementing and improving in small scale, Intelligent Vehicle / Highway System (IVHS) is starting to be an attractive and necessary alternative to alleviate the traffic congestion in the major cities of the world. Pioneer projects and organizations such as PROMETHEOUS, IVHS America, DRIVE, and ERTICO have established the basis to go one step further in the introduction of this concept in a larger scale.

The development of a theoretical support, in conjunction with the application, of the latest advances in the microelectronic, computer science and communications have definitively placed IVHS as the foremost option to solve this problem.

There is an international competition between U.S., Japan and Europe in this area. There is also a competition between private companies, universities and various government agencies. However, there is also vast

[2] Source: Storbart and Upton 1995.

evidence that international cooperation goes beyond this rivalry. All the factors involved in these efforts all over the world recognize that the principal adversary in this fight is the traffic congestion and its consequences.

REFERENCES

[1] Alireza, M., "Smart Sensors", Centre of High Performance Integrated Technologies (CHIPTEC), http:// www.eleceng.adelaide.edu

[2] Ashley, S., "Smart Cars and Automated Highways", Mechanical Engineering Magazine, May 1998.

[3] Bruman, "Technologies for Intelligent Vehicle Highways: Technology Tutorial Series, V.2, Boston, Massachusetts, November 1994.

[4] Circle Bavarian Motor Works New Car Department. http://www.cirlcebmw.com/new/obn/obn.htm

[5] Drane, C., Rizos, C., Positioning Systems in Intelligent Transportation Systems, Artech House, 1998.

[6] Elliott, S., D., Wireless Communications for Intelligent Transportation Systems, Artech House, 1995.

[7] ERTICO, Editor, "Toward an Intelligent Transport System", Proceeding of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems, Vol. 1-6, Paris, France, December 1994.

[8] Fariborz, F., (Editor) "Intelligent Cars and Automated Highways System (AHS).

[9] http://releases.twoten-press.net/releases/date/1995/10/13/MOTORING-Technology.html.

[10] http://www.fas.sfu.ca/css/update/vol8/8.1-smartcars.html, "Smarter Cars Means Cleaner Air".

[11] http://www.ittautomotive.com, ITT Web Site.

[12] Klein, L., A., "Vehicle Detector Technologies for Traffic Management Applications", Part 1, http://www.itsonline.com/detect_pt1.html

[14] Martin, A., Marini, H., Tosunoglu, S., "Intelligent Vehicle / Highway System: Design of a Blind Spot Detector Using Proximity Sensors." Department of Mechanical Engineering, Florida International University, February 1999.

[15] McCraw, J., "Smart Car is Smart Enough", http://www.thecarconnection.com/cc_Smrt1.htm

[16] Nwagboso, C., O., Advanced Vehicles and Infrastructure Systems: Computer Applications, Control and Automation. John Wiley & Sons, April 1997.

[17] Parkes, A., M., Frazen, S., (Editors), Driving Future Vehicles. Booknews, Inc., 1993.

[18] Saunders, N., "Smart Cars, A Proposal for a Radically new Transport System," http:// www.newciv.org/GIB/BOV/BV-395.HTML

[19] U.S. Dept. of Transportation, National Highway Traffic Safety Administration, "Examination of Reduced Visibility Crashes and Potential IVHS Countermeasures Microform", pp. 663-678, 1995.

[20] Whelan, R., Smart Highways, Smart Cars. Artech House, Boston-London 1995.

[21] Zhao, Y., Vehicle Location and Navigation System. Artech House, 1997.