Highway congestion in the United States is a nationwide problem, costing drivers over 60 billion dollars in delay time and wasted fuel annually. In addition to the economic implications, there are direct correlations between highway congestion and an increase in vehicle emissions. Highway expansion is not the most practical solution to this growing problem of congestion. One cost-efficient way to manage highway congestion and the resulting vehicle emissions is through the use of intelligent transportation systems (ITS) applications. The presented research will discuss the freeway management aspect of ITS, success stories involving ITS applications in congestion management and emissions reduction, and an overview of Federal support of ITS in the most recent transportation funding legislation.
INTRODUCTION

Traffic backup occurs during the morning commute, vehicles idle in the parking garage trying to get out after the big game, or an accident on the freeway which blocks the left lane. What do all of these situations have in common? They all cause roadway congestion. Experienced by millions of commuters each weekday, congestion can almost be considered a way of life for residents of large cities like New York, Los Angeles, Chicago, Houston, or Atlanta. The effects of highway congestion are numerous: increases in delay, travel time, and vehicle emissions mark this nationwide problem. There is no clear solution to highway congestion. Many believe that highway expansion is the solution. This solution is quickly becoming impractical because of all the costs and effort that go into a highway expansion project. However, the proper implementation of a freeway management plan as a part of a regional intelligent transportation system provides an economical way to effectively manage increasing congestion on America’s highways.

WHAT IS CONGESTION?

Highway congestion can be simply defined as the point at which the vehicle flow demanded of the roadway exceeds the roadway’s capacity. Congestion is characterized by decreasing free flow speeds, increasing point to point travel time, decreased vehicle spacing, and a heightened driver discomfort level. There are two basic causes of congestion: deficient roadway capacity and traffic-influencing events.

The physical capacity of a roadway is how much traffic it can hold. It is a function of the number and width of traffic lanes, the design of intersections and interchanges, and side clearance widths. Congestion occurs when the capacity of a highway stretch cannot hold the number of vehicles that are trying to use it. This phenomenon, often called a “bottleneck,”
accounts for 40 percent of American highway congestion. The most frequent locations of bottlenecks are the intersection of two or more major freeways or places on a highway where the number of vehicle lanes decrease. This congestion is often referred to as “recurring” congestion, because it is tied to problems with the design of the road and not a specific incident. America’s drivers are very familiar with bottlenecks as they have been given nicknames ranging from Atlanta’s “Spaghetti Junction” to Chicago’s “Hillside Strangler.”

Traffic-influencing events are the second cause of congestion. Termed “non-recurring” congestion, such events include accidents, vehicle breakdowns, construction zones, bad weather, poor signal timing, and special events. These activities will typically increase demand congestion on a roadway, but only for a relatively small amount of time. The national causes of congestion are shown in Figure 1.

![Figure 1: Sources of Urban Congestion](image)

**IMPACTS OF CONGESTION**

Due to its variety of causes, it is often very difficult to find a single way to quantify congestion. Instead, planners and researchers use several different indicators to measure
roadway congestion. The Travel Time Index (TTI), a ratio of peak period travel time to free
flow travel time, shows how much extra time a trip would take the user during a peak period\(^2\).
Another way of measuring congestion is by the amount of time delay per traveler, which is the
total delay experienced by an urban driving population divided by the total number of drivers.
Finally, the monetary costs of congestion can be measured by the value of the time delay plus
any additional costs incurred during congested periods, most notably the cost of wasted vehicle
fuel.

The costs of congestion are staggering. The 2005 Urban Mobility Study conducted by
the Texas Transportation Institute is an annual report of congestion in America. Study results are
summarized in Figure 2.

<table>
<thead>
<tr>
<th>Roadway Congestion Indicator</th>
<th>1982</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time Index</td>
<td>1.12</td>
<td>1.37</td>
</tr>
<tr>
<td>Delay (Billions of Hours)</td>
<td>0.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Fuel Wasted (Billions of Gallons)</td>
<td>0.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Total Cost of Delay (Billion 2003 $)</td>
<td>12.5</td>
<td>63.1</td>
</tr>
</tbody>
</table>

Figure 2: Costs of Congestion\(^3\)

The last 20 years have seen significant increases in the cost of congestion in America.
The increase in the Travel Time Index means that a 20 minute commute in 1982 took 22 minutes
during rush hour, while that same trip under 2003 peak hour conditions would take 27 minutes.
The continuously increasing per gallon price of auto fuel adds an even greater value to the
estimated costs of congestion.

In addition to economic implications, increases in vehicle emissions can also be tied to
congestion. As a vehicle runs, it emits several of the United States Environmental Protection
Agency’s (EPA’s) criteria pollutants. The three “criteria pollutants” emitted by vehicles are
carbon monoxide, volatile organic compounds, and nitrogen oxides\textsuperscript{3}. An additional pollutant of automobile engines is the “greenhouse gas” carbon dioxide. Studies have shown that the emissions of these pollutants are much lower from a free-flowing traffic stream than from a “stop and go” traffic condition. Figure 3 shows a graph of the emissions of several pollutants with respect to vehicle speed.

![Figure 3: Graph of Vehicle Emissions vs. Speed\textsuperscript{4}](image)

Carbon dioxides are emitted into the air from the burning of automobile fuel in internal combustion engines. As Figure 3 shows, the emissions of CO\textsubscript{2} will steadily decrease until around 80 km/h (50 mph) before rising again. However, speeds above 60 km/h (40 mph) will cause an increase in the amount of nitrogen oxides emitted into the air. Therefore, a free flow speed of 50 mph will result in the lowest possible emissions of CO\textsubscript{2} but not NO\textsubscript{x}. This situation is often referred to as “The NO\textsubscript{x} Dilemma\textsuperscript{5}.” The figure also shows that slower speeds, such as
the speeds experienced by drivers in congested areas, will result in higher emissions of the criteria pollutants.

There are further consequences of congestion on America’s highways, including an increase of traffic accidents, slow and inefficient emergency response abilities, and a negative psychological effect on the driver. What all the effects add up to is a problem that has been increasing on America’s highways for decades unchecked, while local transportation agencies struggle to find answers.

A driver, stuck in congested traffic on their way to work, may be led to believe that a logical solution to their morning traffic jam is the expansion of the roadway capacity by adding traffic lanes or having less interchanges. After all, additional lanes would distribute the traffic such that a free flow speed could be attained, resulting in less congestion. Although highway expansion is needed for many bottlenecks which suffer from outdated designs, construction is not always the answer to congestion problems. One phenomena observed by highway planners is known as induced travel, where travelers are more likely to take trips or use the roads if new ones are built. An example of induced travel would be if a commuter who had previously used public transit because their commute was too congested now decides to use a personal vehicle due to an improved or expanded highway. Additional pressures on right-of-way availability, planning and construction costs, and opposition from community groups have made highway projects very formidable tasks.

INTELLIGENT TRANSPORTATION SYSTEMS

With highway construction and expansion being so difficult in today’s world, planners must turn to more creative ways of managing and reducing congestion on America’s highways. One strategy of getting more from existing highways for less is the deployment of intelligent...
transportation systems (ITS). Intelligent transportation systems integrate current technologies in information processing, communications, and electronics to help solve surface transportation problems. The technologies and components of intelligent transportation systems are called the ITS architecture. The ITS architecture is divided into numerous categories, with each playing a specific role in the success of the entire system.

The most relevant component of the intelligent transportation systems architecture that aids in the reduction of congestion is freeway management. Freeway management consists of the use of traffic surveillance, ramp control, lane management, incident management, and information dissemination in an attempt to maintain free flowing highway operations. All of the freeway management architecture is controlled by the use of a central facility known as the transportation management center (TMC). Together, these components play a major role in the success of a freeway congestion reduction strategy.

The primary source of data in a freeway management program is through traffic surveillance. Traffic on the freeway is monitored via pavement-embedded sensors and overhead cameras. The data gathered by the embedded sensors include traffic speed and volume, as well as information on air temperature and pavement moisture. Changes in speed and volume often indicate the formation of a congested section of the freeway, which can then be confirmed visually using the overhead cameras. Additionally, data collected from the sensors can aid in calculating travel times as well as track the location of emergency vehicles. Weather information can be used to report possible ice and snow conditions on the roadway. Sensors located on the overhead cameras, in addition to collecting weather data, can be used to monitor vehicle emissions of carbon monoxide, volatile organic compounds, and nitrogen oxides. All of
the information that is collected by the traffic surveillance program is processed at the transportation management center and reported to the public by various means\textsuperscript{7}.

Ramp metering is a part of the freeway management program where flow onto the freeway is regulated by the use of a traffic signal or a timed gate. Flow rates, usually set between 4 and 15 vehicles per minute, control the amount of vehicles that can enter the traffic flow at a ramp. Ramp metering prevents large groups of vehicles from entering the freeway, which can often interrupt the flow on the highway as well as cause accidents. The flow rate for the ramp can be fixed but also can vary with the time of day or be adjusted instantaneously as volumes on the freeway warrant\textsuperscript{7}.

An urban freeway often has a lane or two built inside its median. Through the process of lane management, traffic coordinators can use the extra lanes to control the wide variety of both recurring and non-recurring congestion that can occur during the day. One primary use of the extra lane is to provide additional lanes in the high-demand directions during peak hours. During normal operations, the extra lane can be utilized by both transit vehicles to allow for improved transit operation and high occupancy vehicles (HOV) to encourage ride sharing or carpooling. The extra lanes can also be used to divert traffic around an accident or a work zone, or allow emergency vehicles to quickly access the scene of an accident\textsuperscript{7}.

Incident management is another concept that is quickly catching on for urban freeway management. Incident management is the effective response and coordination of all the agencies responsible for clearing a traffic incident and reestablishing unimpeded traffic flow. These agencies include law enforcement, fire and rescue, emergency medical services, and towing/recovery vehicles. Often the incident management program will include an “incident response vehicle,” which can assist motorists before other agencies arrive. These vehicles have
flashing lights on the back to warn oncoming traffic of an impedance as well as tools to help an initial response to an incident. Collaboration and coordination are keys to the success of an incident management program; many incident management plans contain instructions on which agency has jurisdiction over a traffic incident, which cuts down on response times.

The other components of the freeway management system would be ineffective without the dissemination of the collected data in usable form. The information can be distributed via changeable message signs on the highway, a dedicated phone information line, a highway advisory radio frequency, local broadcast media, and the internet. There are two categories of information: pre-trip and en-route. Pre-trip information tells the traveler about roadway and traffic conditions before the trip starts, with the goal of giving the user as many choices as possible with regard to modal choice, routes, and travel times. En-route information provides the user with real time data about the trip and can give the user a better idea about changing roadway conditions. For example, a changeable message sign on a highway can inform drivers of an accident and advise the use of an alternate route. Because the success of the entire freeway management system depends on the data being useful to the user, convenience is extremely important when creating an information dissemination plan.

The installation and application of intelligent transportation systems architecture is known as ITS deployment. The United States Federal Highway Administration maintains a survey of more than 2400 state and local highway agencies on their deployment of intelligent transportation systems. This survey predicts that within five years, the number of freeway miles monitored by real time data collection is expected to be approximately 50 percent of the available miles, more than three times the 1997 value. During that time, the number of freeway miles patrolled by an incident response vehicle is expected to more than double from 25 percent
to 57 percent. Additionally, freeway condition dissemination is expected to quadruple over the 8 year span, from 12 percent coverage to 48 percent. These numbers indicate a healthy expansion of freeway management systems in the United States.

ITS AND CONGESTION MANAGEMENT SUCCESS STORIES

The benefits of intelligent transportation systems deployment on both congestion mitigation and pollution reduction have been very positive. The Texas Transportation Institute reports that “operational treatments” such as ramp metering and incident management can, at the present time, reduce annual delay by over 330 million hours. The same study estimates that if the same operational treatments were applied to all roads, the delay reduction would be over 610 million hours, representing a significant increase. Consider the following success stories:

Although freeway surveillance plays more of a supporting role to the other divisions of freeway management, its direct benefits can still be measured. The Institute of Transportation Engineers (ITE) reports that a deployed traffic monitoring system in Houston, Texas has saved travelers an estimated 21,000 annual vehicle-hours of recurring delay. To mitigate this delay with new construction, ITE reports that 150 additional lane-miles of highway would have to be built. The ITE also reports that a sophisticated highway surveillance system would increase vehicle throughput by 12 to 20 percent and yield benefit-cost ratios between 10:1 and 12:1.

A ramp metering study performed in the Minneapolis-St. Paul, Minnesota metropolitan area was conducted in 2000. The results showed that under metered conditions, there was an estimated savings of over 25,000 hours of travel time, a reduction of 2.6 million annual hours of delay, and an annual savings of more than 1,160 tons of vehicular emissions. In addition, the number of peak period accidents was decreased by 26 percent when the ramp meters were in use. The resulting savings was approximated to be 40 million dollars, with a benefit-cost ratio of 5:1.
for the entire system and 15:1 for the ramp metering system alone\textsuperscript{10}. The overwhelming success of ramp metering in the Twin Cities makes it a very feasible option for other metropolitan areas.

A study in San Francisco, California showed that a reduced incident response time by 35 percent could be attributed to their incident response and management program. The benefit-cost ratio of the Bay Area’s incident response was estimated to be 3.4:1 and an estimated annual reduction of emissions as follows: 77 tons of carbon monoxide, 19 tons of nitrogen oxides, and 7.6 tons of hydrocarbons\textsuperscript{9}. In San Antonio, Texas, an incident management system was effective in saving more than 2,600 gallons of fuel yearly\textsuperscript{11}. In addition to improving public safety, both the San Francisco and San Antonio incident management systems were very effective in reducing the amount of vehicle emissions.

THE FUTURE OF ITS

The future of intelligent transportation systems deployment is promising. On August 10, 2005, President George W. Bush signed into law the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). SAFETEA-LU provides policy and financing guidance for all Federal surface transportation programs. Included with SAFETEA-LU are provisions to encourage states to employ real-time transportation monitoring and expand the use of HOV lanes. Research funding for intelligent transportation systems has been allocated at $550 million under the provisions of SAFETEA-LU. The congestion mitigation and air quality (CMAQ) program, which is designed to give funding to projects that improve air quality in non-attainment areas, has $8.5 billion of authorizations programmed in the new legislation\textsuperscript{12}. With the authorization of SAFETEA-LU, the future of intelligent transportation systems and related congestion management programs is secure for years to come.
Congestion is a nationwide problem, expanding at a rapid rate of growth. Consequences of congestion include travel delay, additional fuel costs, and increased emissions. Transportation agencies do not have the resources to continue building additional highways and infrastructure to keep up with the growing congestion problem. Intelligent transportation systems offer an economical way to help mitigate the problems of congestion on America’s urban highways while also reducing the amount of vehicle emissions associated with slower speeds and higher traffic volumes.

Bibliography


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Ben is currently pursuing a Bachelor of Science in Civil Engineering and a Bachelor of Science in Engineering Management from the University of Evansville in Evansville, Indiana and plans to graduate in May 2006. His past work experience includes internships at the Evansville Urban Transportation Study, Patriot Engineering, and the Texas Transportation Institute.

At Evansville, Ben is an active member of the American Society of Civil Engineers student chapter and the Chi Epsilon Civil Engineering honor society. He is also employed at Evansville’s campus radio station. Upon graduation from Evansville, Ben plans to attend graduate school and study Transportation Engineering.