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Real Time Driver Information for Congestion Management

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16. Abstract

Traffic demand in the U.S. has grown substantially over the past few years because of the increase in population and urbanization in large cities. This causes traffic congestion to spread out over U.S. highways and arterials, and subsequently leads to deterioration in traffic networks in terms of operation, safety, and productivity. Therefore, congestion management strategies have become essential for addressing safety and operational problems. Recently, active traffic management (ATM) strategies have been recognized as efficient methods for managing widespread congestion, provided that a proper management strategy is identified and implemented. Any ATM strategy requires a systematic process that should work in a specific sequence starting from getting information from a congested road segment to dissemination of relevant information to travelers to help relieve congestion. This process starts with collecting traffic data from the roadways, screening the collected data to remove redundancies and erroneous data, synthesizing useful traffic information, and finally disseminating such information to travelers in real time. Based on the type of delivered information, travelers may alter their trip decision in terms of departure time, mode choice, and route selection in order to avoid congestion.

This report presents a review of the state-of-the-art and state-of-practice methods used to execute the steps taken to deliver accurate real time traffic information to travelers and the impact such information has on congestion management. The report sheds light on different technologies and methodologies used for data collection, screening, and dissemination in the United States. In addition, the report highlights the impact of disseminated information on drivers' behavior and transportation network operation and safety. More so, the report presents few case studies on different ATM strategies and shows the gained benefits from using these strategies.

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ABSTRACT

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IMPLEMENTATION STATEMENT

Active traffic management (ATM) strategies have been used over the past few years in order to provide an integrated real-time driver information system that can help in congestion management. This report highlights the state-of-the-art and state-of-practice of ATM strategies and procedures, from data collection to delivering information to travelers for better trip decision making purposes. The report presents different technologies used in data collection and shows the advantages and disadvantages of each technology, as well as some appropriate data screening methods. The impact of the delivered information to travelers on their driving behavior and trip making decisions is explained in the report with emphasis on congestion mitigation. Recent traffic management strategies are also presented with a few case studies. The technical content of this report provides an overview of the practical components associated with the implementation of active traffic management strategies and the vital role of real time traffic information in congestion mitigation. All procedures and methods presented in this report are practical and based on real implementations.

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INTRODUCTION

With traffic congestion growing where residents live and work, communities are demanding more efficient transportation systems to provide greater mobility, reduced delays, and safety. The utilization of Intelligent Transportation Systems (ITS) can improve operation, safety, and productivity of surface transportation. The U.S. Department of Transportation (DOT) depicts Intelligent Transportation Systems as an integrated system to improve safety and mobility and to enhance productivity through the use of advanced information and communication technologies. Intelligent Transportation Systems encompass a broad range of wireless and wire line communications-based information and electronics technologies. When integrated into the transportation system's infrastructure and in vehicles themselves, these technologies have the ability to relieve traffic congestion, improve safety, and increase productivity. The importance of ITS data has been long recognized by researchers and practitioners in the field. On one hand, traffic management agencies are constantly seeking new opportunities to improve real-time operation and management functions and advance the methods used to assess the impact of minor/major capital improvements. On the other hand, researchers continue to seek data to improve their capabilities to better understand the behavior of traffic under non-stationary transient stages, to identify certain factors or conditions that may impact safety, to distinguish between the traffic characteristics during recurrent and non-recurrent congestion, and to develop comprehensive and composite measures of the level of service. More importantly, research needs to better understand the impact of real time information on the behavior of travelers in terms of their trip planning decisions on departure time, route choice, and mode choice, as well as the impact of such decisions on the success of congestion management strategies.

As the backbone of ITS, information and communication technologies have substantially overcome the data acquisition obstacles through a wide spectrum of advanced data collection and communication devices such as points sensors (inductive loops, microwave sensors) and link based devices (Bluetooth, probe vehicles, etc.). This has tremendously increased the ability to manage and control major transportation system facilities in real time, as well as allow state DOTs to establish programs for real time traffic information on travel conditions. The real time information can now be relayed to drivers via variable message signs, websites, mobile phone apps, advisory radio, and 511 services, among others. However, significant changes to technology are occurring that may fundamentally alter the manner in which traveler information is generated and delivered to drivers. For instance, ongoing research on connected vehicles has made it possible for information transmission among vehicles using V2V (Vehicle to Vehicle) and V2I (vehicles to infrastructure). Such technology is expected to penetrate the market in a few years and will have a substantial impact on traffic operation and safety. Therefore, there is a need to better understand the capabilities and limitations of current and emerging technologies, the current state of research and practice, and the ultimate potential of such technologies in congestion mitigation through driver decisions.

Real time traffic information is vital to the traveling public in congested metropolitan areas where traffic conditions are operating close to or beyond capacity conditions. Such information is believed to have a significant influence on the traveler's decision-making process in terms of departure time, mode choice, and route selection. Altering the trip planning decisions for travelers had the indirect benefit of alleviating congestion by spreading the demand over time and space. Moreover, congestion avoidance has significant safety benefits in terms of crash reduction. As such, real time driver information has strong potential operational and safety benefits to both transportation system users and providers. The proposed synthesis report aims to address such benefits in detail using case study examples that demonstrate and quantify the user and system benefits. The synthesis report documents the current state of the practice by surveying successful efforts nationwide and in the southeastern region.

In a real time driver information system, there are some procedures to be followed in order to have an efficient system in which drivers are aware of the conditions of the transportation network and the agencies are able to operate and manage the network. This procedure is discussed throughout this report that is organized as follows. The data collection section discusses the first and foremost step in a real time driver information system. This is followed by a review of the data screening process to control the quality of information to be extracted from the data. Then, various data dissemination technologies and methods are presented and followed by an overview of how disseminated traffic information to travelers impacts trip planning decisions such as departure time, trip route, and travel mode, and subsequently congestion management strategies. Examples of case studies are also provided in the report, followed by conclusions and recommendations.

OBJECTIVES

The main focus of this synthesis report is to compile a technical summary of past and current research, as well as the state of the practice, on the role of real time information in congestion mitigation programs. The specific objectives are to:

1. Conduct a literature review on past and current research efforts on the role of real time information in the traveler's decision making process
2. Collect information on the current state of practice for gathering and disseminating traffic information in the southeastern region and other states
3. Review the current and emerging technologies for traffic data collection and dissemination and identify the potential use of each
4. Compile the reviewed materials from different sources and identify the current problems and challenges
5. Organize, evaluate, and document the useful information acquired, with emphasis on performance resulting from current practices, including new and unusual practices; research results and current practice, including implementation of research recommendations; current practices that appear to be working well and those that are not working well; current practices that are at odds with research findings; critical knowledge gaps that could be filled by additional research; and other actions—e.g., training, revised standards, and increased management attention that could improve the state of the practice in a given area
6. Make recommendations for needed research based on the reviewed case studies

SCOPE

The research was restricted to reviewing the state of the art and state of practice in real-time driver information systems and their benefits in congestion mitigation and management in the U.S.

DATA COLLECTION

The development of a reliable real-time driver information system, as part of the Intelligent Transportation Systems (ITS), requires high quality real-time traffic data collection. In such systems, a successful operation is highly dependent on the accuracy of the collected data; therefore, for several years, traffic data collection methods have been evolving in order to meet the requirements for developing a highly reliable ITS. In this context, traffic data collection methods and technologies have gone through many improvements and have been developed from traditional methods, such as inductive loops, through current technologies, such as video detection, to emerging technologies such as connected vehicle technology.

Real time traffic data collection methods can be categorized as site data, floating car data, and wide area data collection 1. The site data are collected by sensors located along the side of a road. The different methods used to collect site data are inductive magnetic loop, pneumatic road tubes, piezoelectric loop arrays, and micro wave radars. In addition, more developed technologies are included in the site data methods, such as ultrasonic and acoustic sensor systems, infrared systems, and video image detection method. The floating car data (FCD) collection method, on the other hand, is based on locating and recognizing vehicles at multiple points in a network, where real or virtual detectors are placed throughout the network, forming what is called 'point-to-point sensors'. The wide area data collection method is based upon multi sensors tracking methods such as photogrammetric processing, video analysis, sound recording and space based radar *[1]*.

Antoniou et al. established another classification method based upon the functionality of sensors: point sensors, point-to-point sensors, and area-wide sensors *[2]*. Point sensors, the widely used method, collect raw data from fixed sensors installed on arterial roads. Examples of this method that are commonly used include: video image detection [closed-circuit television (CCTV)], infrared, microwave, acoustic and ultrasonic sensors, as well as inductive loops radar *[2]*. Point-to-point sensors have the ability to detect vehicles at multiple locations in the network. This also offers the capability of providing travel times, route choice, and origin-destination (OD) flows. Automatic Vehicle Identification (AVI), vehicle identification without drivers, and license plate recognition are considered the three main examples of technologies using point-to-point sensors technique. AVI is based on vehicle recognition as they pass a sensor location using an electronic tag placed in the vehicle *[3]*. License plate recognition method is based on the CCTVs recording license plates and then, using special Optical Character Recognition (OCR) software to match the license plates and calculate travel times *[4]*. Area-wide sensors, (also called vehicle probing-based schemes), analyze raw data from collected fleet of probe vehicles and match the tracks using Geographic Information Systems (GIS) technology [*4]*. The most common vehicle probing technology is Bluetooth technology, used for vehicle tracking, point-to-point travel times, route choice fractions, paths, and origin-destination flows *[2]*.

There is a wide range of counting methods available. They can be classified as intrusive or non-intrusive methods. The former include counting systems that involve placing sensors in or on the roadbed; the latter involve remote observational techniques. Below, a thorough review of the different technologies used for data collection is conducted.

Manual Counts

Manual counts are one of the conventional non-intrusive data collection methods. It depends totally on a traffic data observer on the road side, in order to collect the required traffic data. Therefore, traffic data accuracy is not guaranteed as there are so many factors that control the accuracy including human error *[5, 6]*.

Pneumatic Tubes

Pneumatic tubes technology is one of the conventional intrusive methods. It is rubber tubes placed across the road that detects vehicles based on the pressure changes resulting when vehicle tires pass on the tubes. This technology has been used for a long time because of its simplicity; however, it has limited lane coverage and its efficiency is highly dependent on the weather, temperature, and traffic conditions *[5, 6]*.

Piezoelectric Sensors

Piezoelectric sensors are used for traffic volume, speed, classification and weigh-in-motion. They are one of the conventional intrusive methods, as they are placed in a groove made along the road surface of the lane(s) of interest *[5, 6]*.

Magnetic Loops (Inductive Loops)

Magnetic loops, or the well-known inductive loops, are the widely used conventional technology for traffic data collection. It is considered one of the conventional intrusive data collection methods as the loops are square formations embedded in the road. The main drawback of this technology is the short lifetime of the loops, especially when a heavy vehicle passes over the loop. This results from the weakened and rapidly deteriorating pavement due to the cuts that take place in order to install the loops, which makes the inductive loops prone to higher traffic stresses; however, it is not affected by weather conditions and is therefore considered weather resistant *[5, 6]*.

Passive and Active Infra-red

Passive and active infra-red technology is one of the conventional methods that can collect data on vehicle classes and speeds. This does not have any intrusive effect on the road pavement. The main disadvantage of this technology is that it does not work properly in bad weather, and is lane-specific *[5, 6]*.

Magneto-Meters (Passive Magnetic Sensors)

Passive magnetic sensors are placed within holes in the pavement or on top of the road pavement; therefore, it is considered one of the intrusive data collection methods. These sensors mainly collect traffic counts, speeds, and vehicle types. The main drawback of this technology is that it may not be able to differentiate between two vehicles following too closely *[5, 6]*.

Microwave Radar Detectors

Microwave radar detectors are one of the non-intrusive traffic data collection methods that have the ability to collect vehicle counts, speeds, and simplified vehicle classification. There are two main types of microwave radars: the frequency modulated type that is able to detect stopped and moving vehicles and have unlimited lane coverage, and the continuous wave type that cannot detect stopped vehicles and have limited coverage to one lane only. The main advantage of this technology is that weather does not affect its efficacy *[5, 6]*.

Ultrasonic and Passive Acoustic Devices

This non-intrusive technology emits sound waves in order to detect vehicles by measuring the time it takes for a signal to travel back to the devices. They are mounted over the lanes of interest or on the roadside. These devices collect vehicle counts, speeds, and vehicle classification. The main drawback of this technology is that it is sensitive to temperature and weather conditions *[5, 6]*.

Video Image Detection

Video image detection is based on cameras that record the vehicle volumes, type, and speed using different video detection techniques such as trip line and tracking; this technology is also affected by weather conditions *[5, 6]*. This method is widely used at intersections, more specifically, at signalized intersections to detect the presence of vehicles in order to distribute green times based on traffic demand.

Floating Car Data (FCD)

In floating car data (FCD), every vehicle is equipped with a mobile phone or Global Positioning system (GPS) that acts as a sensor. Examples for the data collected are: vehicle coordinates, speed, and direction of travel. This data is sent anonymously to a processing center where the data is processed in order to extract useful information such as traffic conditions and alternative routes. Such data can help improve safety and reliability of the transportation system, and hence play a great role in developing a highly reliable real-time information system. In FCD, there are three main types of technologies: (1) GPS-based FCD, (2) cellular-based FCD, and (3) Automatic Vehicle Identification (AVI) *[1, 7]*.

GPS Based Technology

GPS-based technology requires the vehicles to be equipped with GPS. In such systems, the accuracy of vehicle coordinates is high and reliable. Despite GPS becoming more affordable, not many vehicles are equipped with the system. Therefore, the vehicle types used for data collection differ according to the area type. In rural areas, private vehicles and trucks are more suitable for data collection, as these are primarily the vehicles that use the network. For urban areas, taxis are more dependable because of their high numbers as well as the communication systems they are equipped with, i.e. mobile phone or GPS *[5]*. The main issue about this technology is that DOTs have to purchase the data from third parties that collect and control data.

Cellular-Based Technique

Cellular-based techniques can be very efficient because of the vast number of cell phone users that makes it more probable that every vehicle will have at least one occupant using a cell phone. Cell phones can transmit location information on the network, which will enable travel times to be estimated on different road segments. However, this technique needs the phones to be turned on. Cellular-based technology is more accurate and efficient in urban areas than in rural areas because of the high number of cellular towers available. The main advantage of this technology is that it does not require special equipment specifications; therefore, it is less expensive than the GPS-based technology and the conventional technologies. In addition, it does not have coverage limitations as the conventional methods *[5]*. The main drawback of this technology is the error arising from multiple counts when multiple users are in one vehicle. However, this problem was overcome in the study conducted by Fao and Liu *[*8*]*. Similar to the GPS-based technology, this technique requires DOTs to purchase the data from a third party.

Automatic Vehicle Identification (AVI)

The AVI technique is based on tags placed on the windshield of the vehicle. The main idea of data collection with this technique is based on sampling probe vehicles at different locations in the network using the tags (electronic transponders) placed on the windshield of the vehicles that are read when vehicles pass the sensors *[5]*. This technology has the advantage that DOTs have access to the data, which is not the case with the GPS and cellular-based technologies.

Bluetooth Technology

The use of media access control (MAC) address, which is a unique number based on which devices are recognized and identified, found in Bluetooth-wireless-enabled devices in vehicles, has been proclaimed as a cheaper and more reliable alternative for collecting travel time data *9*. Bluetooth wireless MAC protocol now comes standardized in most devices such as cell phones, Personal Digital Assistants (PDAs), car radios, dashboard systems, laptops, printers, GPS navigation devices, headsets and most modern personal equipment. The MAC address is unique to each device and consists of a 48-bit address assigned by the manufacture of the device. There are no databases matching these MAC addresses to individuals, so there is no privacy issue with this system, unless a court warrant is obtained *[9, 10, 11, 12]*. MAC address matching involves time-stamping and tracking these Bluetooth enabled devices found in everyday passenger vehicles to derive travel times and origin-destination information. This offers a non-intrusive and cost effective (as no special onboard equipment is needed) way of collecting a vast amount of quality data on a roadway network without affecting the normal flow of traffic *[9, 10]*.

Emerging Data Collection Technologies

The discussed technologies used for real-time traffic data collection require an accurate estimation of current and predicted traffic on the roadway network. In addition, some issues arise in the accuracy of the real-time data provided due to spatial and temporal gaps in the network. Therefore, there is a significant effort to overcome these problems by developing more advanced technologies for data collection. In this context, this section discusses some of the emerging real-time traffic data collection technologies.

Lederman and Wynter developed a method for estimating traffic volumes over full-sized urban road network in real-time that utilizes historical and real-time traffic data *[13]*. Using their strategy, information is computed in two different phases: an offline calibration phase and real-time estimation phase. During the offline phase, link-to-link probabilities on traffic flow propagation are determined. Then, this information feeds into the real-time phase that takes current traffic data from different sources and then scales to full city-wide deployments.

The discussion of emerging technologies available to capture real-time driver information would be incomplete without the introduction of automated vehicles. The scientific community is in agreement that cars of the future that will eventually replace the standard vehicle are fully automated vehicles and connected vehicles. Fully automated vehicles are cars that are run and managed completely void of the driver's assistance. The technology that enables these cars to perform this feat includes a sophisticated combination of radar sensors, cameras, image-processing software, GPS units, accelerometers, ultrasound, wheel sensors, and laser range finder (Lidar) systems. Radar and ultrasound sensors are used to detect upcoming obstacles, while cameras aid in distinguishing between individual lanes and backup assistance. The image-processing software installed detects traffic signs, lights, roadway striping among other visuals that assist the essentially driverless car in following road restrictions and safety signage. GPS is used for location information as it is currently used in traditional vehicles in the market. The wheel sensors also keep track of vehicle location in the event the GPS satellite is ineffective and these sensors can be used in anti-lock braking systems as well as stability systems. Finally, Lidar technology is installed with the purpose of capturing horizontal distance measurements that eventually combine with the cameras and radar sensors and create a three dimensional "map" of the vehicle's surrounding *[14]*. Automated vehicles have the ability to run concurrently with the vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) technologies.

The V2V and V2I communications used in the automated as well as the connected vehicle environment can serve as a very efficient data collection method that has the capability to provide real-time traffic data such as traffic speed, traffic conditions, OD flows, route choice, incident locations, and many other data types, which can be helpful in traffic management.

DATA SCREENING AND INFORMATION SYNTHESIS

Most of the ITS implementation efforts were intended for major urban freeways to provide effective solutions to the perpetually escalating problems of urban congestion. Currently, several hundred miles of freeway in Louisiana are instrumented with traffic surveillance devices, all of which are primarily installed to improve the operation, safety, and productivity of the transportation system. As the ITS instrumentation efforts continue to pervade the urban freeway system nationwide, real-time information from hundreds of miles of freeways and arterials can be synthesized from traffic data at traffic management centers and then disseminated to road users via various communication devices. Currently, little information has been utilized from the tremendous wealth of information that can be extracted from this data. This is primarily due to the lack of advanced data mining methods that are specifically developed to maximize the utility of information from existing surveillance systems. Such methods must be capable of manipulating large amounts of data for the purpose of extracting the most useful information and removing information redundancies. In other words, this data needs to go through a refining and cleaning process in order to extract reliable traffic information that can be used in the traffic management process. In this section, a discussion of some research studies that dealt with data processing is conducted.

Data preprocessing is a combination of techniques applied to improve the quality of data. Bellemans et al. described a detailed procedure for data collection and pre-processing in order to make the data ready for modeling and prediction *[15]*. The authors presented three major steps for real time traffic data analysis that include data acquisition, interfacing, and pre-processing. These three stages are meant to result in a clean and complete set of data that can be used to extract traffic information. In the data acquisition stage, data are collected from different sources using different technologies. These data may contain errors or missing data due to data link errors, measurement errors, sensors failures, etc. Data interfacing, on the other hand, deals with transporting the data from different sensors to the main data collection computer system. As shown in Figure 1, the central database on the main computer polls the data from sensors at one-minute intervals and stores it in its memory or on a disk. After the data is collected, transported, and stored in the central computer, the preprocessing stages begins. In this stage, the data errors and the missing data are handled. For the data errors, the central computer validates the data using some basic assumptions, such as non-negative speed values, and based on those assumptions any detected data error is transformed into missing data. Then, all missing data are estimated through an interpolation-based method from historical data. In their study, Bellemans et al. found this method to be very efficient and sufficiently accurate to overcome missing data problems *[15]*.

Lopes et al. proposed a data preprocessing and cleaning technique that includes statistical data description and analysis *[1]*. In this technique, the collected data goes through a four-step process: data summarization, data cleaning for missing values, data cleaning for outliers, and data reduction. The objective of data summarization is to obtain some descriptive statistics that can give an overall picture of the collected data. These statistics include the mean, median, mode and midrange as measures of central tendency, quartiles, inter-quartile range and variance as a measure of data dispersion. The second stage, after having a complete picture of the data, is data cleaning, which aims to overcome missing values, data noise, outliers and data inconsistency problems. In order to fill in missing data, an important variable needs to be determined, which is the gap size. For missing gaps up to 15 minutes, a simple linear regression method was proposed to estimate the missing data with a straight-line. In case of larger missing data gaps (45 mins-120 minutes), they introduced estimation through interpolation based on the historical data along with the most recent observations.

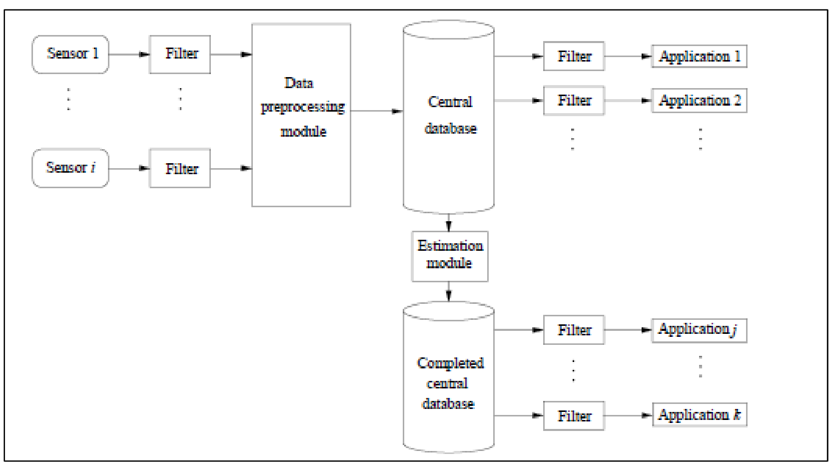

Figure 1
Data estimation module

In situations when the traffic pattern abruptly changes due to incidents or any other reason, then the missing data treatment technique becomes ineffective. In these situations, two statistical analysis methods are proposed: space-based similarity search and time based similarity search. After the missing data problem is overcome, outliers are dealt with in the second phase of the data cleaning stage. Outliers may result from sensor noise, instability in data acquisition, equipment problems, or human errors. Outliers are identified automatically, based on a predetermined threshold, and then they are isolated and labeled as missing values in order to be treated the same way as the missing data *[1]*. The vast number of data sources that feed into any system making the use of all the data obtained may lead to significant difficulty in accomplishing the anticipated result *[16]*. Therefore, data reduction techniques that can minimize the data size and complexity without affecting the integrity of the original data are required. A two-level data reduction approach was designed: at the data acquisition level (in which raw data are aggregated and summarized per regular periods) and at the data fusion level, in which diverse data sets are merged in order to obtain one single integrated data set *[1]*.

In order to monitor the data from traffic sensors, Chawathe proposed a new method with three major components: streaming query processor, stream viewer, and pattern matching and mining module *[17]*. The streaming query processor selects the data of interest from the incoming XML, which contains the traffic data from different sources, while the stream viewer is used to present a summary of the traffic data to the human analyst, and the pattern matching and mining module detects user specified patterns in the incoming data and mines the historical traffic data and matches it with any recurring patterns.

With the increasing traffic demands and unpredictable traffic fluctuations and incidents that may lead to long lasting congestion in road networks, many researchers have introduced different methods to forecast future traffic data and conditions in order to proactively react to the different traffic conditions. For instance, He et al. introduced a new artificial neural network (ANN) module to forecast traffic conditions based on data mining technology *[18]*. Figure 2 shows the developed module, where data mining is the basis for the decision support system module to perform the traffic information forecasting. Data mining is used when there are very large data sets to be processed as it is very difficult to process these big data sets using ordinary methods *[19]*. A self-organizing feature map (SOFM) and a GA-Chaos optimized Radial Basis Function (RBF) neural network are also applied for the data mining purpose, as shown in Figure 2. The RBF neural network is used in the module due to its highly efficient performance in non-linear mapping capability, which can help in traffic information forecasting. This module was found to be feasible and efficient in extracting and forecasting traffic information using ITS data.

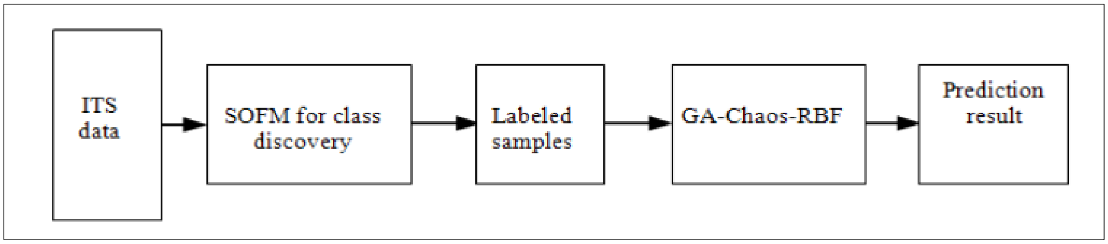

Figure 2
Data mining module

As discussed in the previous study , the traffic data analysis may be conducted in order to forecast traffic conditions, which was found to be very important in the traffic management process. In addition, traffic data can be analyzed in order to predict accident prone locations in the transportation network *[19]*. For instance, Pande and Abdel-Aty developed a framework using the randomly selected crash and non-crash real time traffic data in order to detect crash prone conditions. In the developed framework, loop detectors for crash and non-crash real-time traffic data were provided for every 30 seconds *[20]*. The collected data contain traffic speeds, vehicle counts and lane occupancy. The rear end crashes were classified into two different clusters based on the speed of traffic, and then the model was applied in order to find the crash prone condition. The results of the framework, which are the traffic prone conditions, are then used to create the proper traffic information that can be released to the drivers.

In his dissertation, Herring also presented three different models to forecast traffic conditions using real time traffic data: regression models, the Bayesian model, and the Probabilistic graphic model *[21]*. The author used regression models to determine the level of service based on the travel time and congestion states. The Bayesian model uses the historic traffic patterns of that network to estimate the current traffic condition. The probabilistic graphical model is flexible and extensible over the first two models.

Geisler and Quix developed a framework to manage and analyze the huge size of collected data in order to create useful traffic information that can be released to drivers *[22]*. The complete architecture of the framework, called the data stream management system (DSMS), is shown in Figure 3. The raw data from mobile sources are considered as a main source of data for the DSMS. The collected data are processed and integrated in the DSMS, and then the integrated data are analyzed through the data mining and quality assessment modules in order to derive useful traffic information.

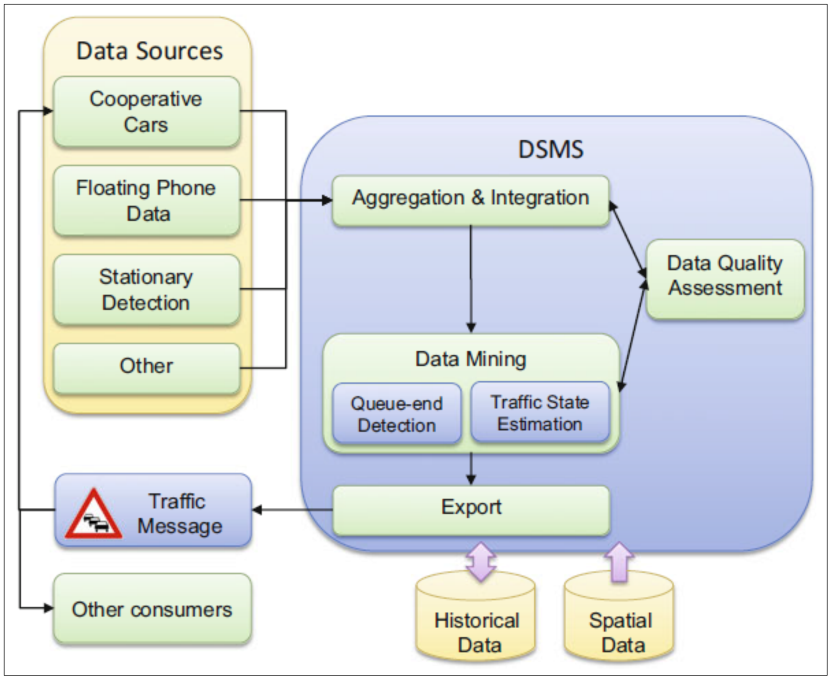

Figure 3

Overall architecture of data stream management system

Nakata and Takeuchi developed a technique to predict the travel time based on real time traffic data. Probe vehicles were used as the main source of data collection *[23]*. Their prediction technique was based on statistical analysis, and more specifically, the authors used the Auto Regression (AR) model. The newly developed technique was accompanied with a seasonal adjustment, minimum description length (MDL) criteria along with a state space model. As the AR model only works for stationary time series, the seasonal adjustment and state space model were used to control the periodicities in traffic data. The MDL criterion was used to select a pre-specified type of effective data from a big amount of data coming from the different data collection sources.

As shown in this section, there are different methodologies used for data cleaning, mining, preprocessing, and analysis that are used to improve data quality and to produce useful traffic information. Some of these methodologies are focused on producing real-time traffic information, and some are focused on predicting traffic conditions and accident prone locations based on the collected real-time traffic data. The significance and quality of the produced traffic information is not only dependent on the quality of collected raw data, it is also affected by the methods used for its mining, cleaning, preprocessing, as well as the used estimation and prediction models. Therefore, all the steps the data go through in order to produce useful traffic information should be carefully selected and conducted.

INFORMATION DISSEMINATION

Following on from the data collection stage where real time data has been collected, successfully filtered, and extracted from raw data into useful information, the data has to be disseminated or distributed to drivers who can actually use it. The ultimate goal of disseminating real time traffic information to drivers is to facilitate driver decisions concerning route choice, departure time, trip elimination, and other aspects of their personal travel characteristics that they have the ability to control. Advanced Traveler Information Systems (ATIS) have the opportunity to disseminate real time information that can help accomplish this goal. ATIS is defined as any system that acquires, analyzes, and presents information to assist travelers in negotiating a trip. Various ATIS strategies are currently being used as a popular means of real time data dissemination. The following sections detail the different technologies in use by state DOTs to disseminate real time information and the emerging strategies that will eventually be used in real time data distribution.

Conventional Technologies

As stated in a report prepared by the Washington State Transportation Center, every U.S. state deploys some form of ATIS. Whether only simple highway patrol reports or sophisticated technological systems are employed, ATIS is the most common strategy used to disseminate travel information. The most common dissemination methods used are highway advisory radio, variable message signs and telephone information services *[24]*. Also, as technology advances, state DOTs are now more widely using social media platforms in addition to these traditional techniques, as will be discussed at the end of this section.

Highway Advisory Radio

Highway Advisory Radio, often called Traveler's Information Stations, serves to distribute information by broadcast radio to travelers. These stations operate in the AM Broadcast Band and are not allowed to transmit any commercial information, as this service is only available to governmental entities and local park districts *[25]*. The Highway Advisory Radio transmitters are normally distributed throughout specific locations along a roadway in an effort to provide real time information or pre-recorded travel updates on the driver's car radio. Information broadcast may include traffic delays, emergency operations, and construction updates among other traffic details that can aid the driver in making informed travel decisions. Blue Highway

Advisory Radio signs are constructed along the roadway corridor using flashing beacons to indicate when drivers can hear the recorded messages *[26]*.

The Federal Highway Administration (FHWA) cites Highway Advisory Radio as an effective tool for providing timely traffic and travel conditions to the public *[27]*. The most advantageous aspect of using the ATIS strategy is that it can reach many travelers at any given time, i.e. all drivers that are within its broadcast range. Also, a large amount of information can be conveyed using this approach since the driver is simply listening to audio instead of having to read a sign while driving. However, since it is a radio broadcast, it is restricted to low power and often experiences poor signal quality normally due to weather. This strategy also requires the driver to take action (turn on the radio to the appropriate station), which can lead to low listenership *[27]*.

Dynamic Message Signs

Dynamic Messaging Signs (DMS) also commonly distinguished as either Changeable Message Signs (CMS) or Variable Message Signs (VMS), are the most fundamental technologies available for disseminating traffic-related information *[28]*. These signs can be programmed to display any combination of characters for the purpose of relaying messages to drivers. They have the flexibility to be either permanently fixed roadside, above the roadway or can be used as portable devices attached to a trailer or truck to be driven wherever desired. FHWA's Freeway Management and Operation Handbook stresses the importance of using these signs appropriately, because once they are implemented they become a part of the entire motorist information system *[28]*. In order to be effective, the message on a DMS must have these five elements: the problem, location, effect, attention, and action that can be taken *[29]*. DMS can be used to manage congestion and/or general traffic by displaying messages that either provide an early warning of an impending incident or slow-down, advise motorists on useful information like upcoming speed changes, and/or offer alternative routes available to a desired location *[28]*. It is important to note that in order to be deemed effective communication devices, the Manual on Uniform Traffic Control Devices (MUTCD) specifies that a DMS message must be able to be read at least twice while traveling at the posted speed limit *[29]*.

Telephone Information Services

In 1999, the U.S. Department of Transportation petitioned the Federal Communications Commission (FCC) to designate a nationwide three digit telephone number that exclusively provides traveler information *[30]*. This motion was approved and "511" currently stands as the

U.S. official traveler information telephone number. By dialing 511 on a telephone, a driver can obtain information on highway conditions, transit services and other travel information via pre-recorded messages. State and local transportation agencies are responsible for operation and implementation of individual 511 programs. Currently, 39 states actively use the national 511 model and have implemented their own local 511 services. As of now, all states with the exception of Arkansas have funds allocated to assist in the development and maintenance of a 511 program *[30]*.

Social Media

A method that has been gaining popularity in recent years is the use of social media as an avenue to disseminate current traffic states or transportation-specific alerts. In today's technology-driven society, most drivers have much of the information they need and use when deciding whether to make a vehicle trip at their fingertips. Although there are few studies detailing exactly how social networks influence driver behavior, it is clear that these sites have become a popular and widely used tool to inform the public of roadway incidents in real time. In addition, smartphone applications such as Way to Geaux, INRIX, Beat the Traffic, among others, are widely used by travelers to get information about traffic conditions. Gal-Tzur et al. explored the potential of social media in delivering transportation policy goals *[31]*. These authors defined the differences between social media platforms and noted social networks specifically exploit real time information and have the power to effectively deliver short real time information through statuses updated by users. Applications such as WAZE and Twitter are examples of methods through which the general public or transportation agencies can identify and mass distribute information on traffic conditions.

According to a report prepared by the FHWA operations division, state agencies are using several social media platforms to share information and the ways in which these platforms are distributing information constantly evolves. Agencies are also altering the use of social media tools in response to public interest and feedback received through these outlets concerning keeping content updated, providing more dynamic information and, in some instances, in response to comments about particular DOT policies. Social media serves as a method to explain to the public why and how DOT does what it does *[28]*. Figure 4 displays the usage percentages of 41 states (and Washington, D.C.) studied, that were using particular social media tools in 2012.

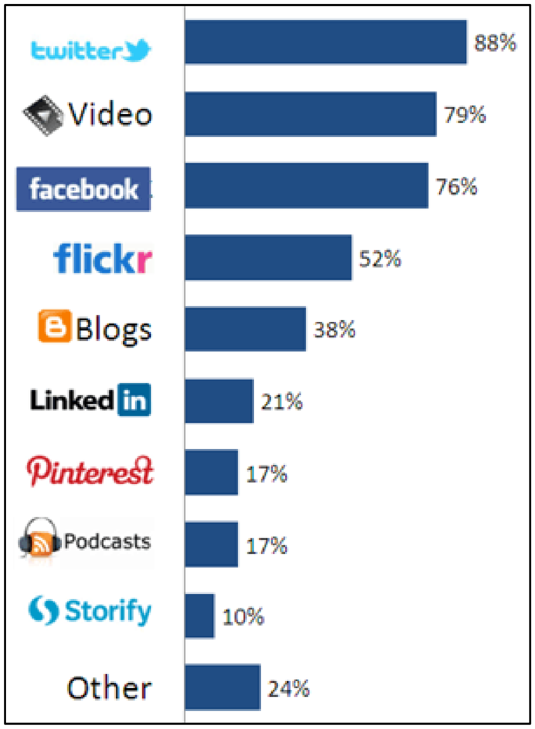

Figure 4
Percentage of 41 states and DC using social media tools in 2012

Emerging Data Dissemination Technologies

As discussed earlier, in-vehicle technologies and vehicle-to-vehicle technologies are emerging applications of sophisticated tools for traffic management. Although the technology equipped in autonomous and connected vehicles is of great interest, the actual dissemination of the data collected using that technology is expected to be very beneficial in congestion management. In these advanced environments, there are many factors that control the dissemination of traffic information, such as: market penetration, transmission range, traffic density, and dissemination protocol used. Therefore, some studies tried to study all these factors to come up with an optimal environment that guarantees its operability.

For instance, Nadeem et al. presented the Traffic View system, which is used to provide traffic and road conditions to a driver *[32]*. Traffic View is used to provide a dynamic view of the road and used to disseminate and gather information of the vehicle on the road, while GPS is used to show a static view of the map. The dynamic view and the information from the GPS receiver, when combined with the digital maps, show different real time traffic information like accident alert and road side e-advertisement in a Traffic View device.

In another study, Wenping used VANETs to disseminate the real time abnormal traffic information within a certain road segment among certain set of vehicles *[33]*. The protocol proposed to disseminate traffic messages was evaluated in a simulator environment and showed a fast and reliable dissemination. In yet another study, Fogue et al. introduced a new method, known as Enhanced Message Dissemination based on Roadmaps (EMDR) to disseminate traffic information to more vehicles by reducing the notification time *[34]*. They highlighted that their method was more effective in a situation with low market penetration rate and low vehicle density.

REAL TIME INFORMATION AND DRIVERS' BEHAVIOR

Traffic information is disseminated to drivers in order for them to react and consequently make decisions that will enable the smooth operation of the transportation system. As a driver receives a piece of traffic information, the overall driving performance may change in terms of route choice, trip time choice, travel speed, etc. With any decision a driver may make, the overall performance of the transportation network is affected which may lead to achieving the desired traffic management level. In this section, the effect of the disseminated traffic information on the driver's behavior is discussed.

Many researchers studied the impact of the traffic information on drivers' behavior as well as the overall performance of the transportation network. For example, Tseng et al. studied the impact of traffic information delivered via smart phones on the travelers' behavior *[35]*. They conducted an experiment on a sample of drivers where some drivers were provided with smart phones as a source of traffic information and the rest of drivers were allowed to drive without smart phones. The authors measured the variation in trip scheduling and travel behaviors for both drivers groups. They found that drivers provided with smartphones reacted to the daily variation in travel times, which proves the importance of traffic information in controlling drivers behavior and hence the overall network behavior.

Haghani et al. measured the effectiveness of the dynamic messages sign (DMS) *[29]*. The overall driving behavior and driving safety were tested with and without the DMS. Three different types of messages were projected for the drivers that were classified as Type I (Danger/Warning), Type II (Informative) and Type III (Regulatory/Non-Traffic Related). In their experiment, the authors found that drivers reacted to the messages, causing an overall speed reduction in the DMS area. The highest reduction in speed was found to be associated with Type I followed by Type II and Type III. For the safety analysis, the authors analyzed accident data on a 900-ft. segment based on the DMS maximum visibility distance. The statistical analysis results showed that DMS can participate in increasing driving safety by reducing crash rates. This can happen as drivers reduce speeds when required to react to an incident ahead. Overall, this study proves how efficient DMS can be to help operate and manage traffic. Further, Wang et al also found positive correlation between speed slow-downs and some of the messages they posted on DMSs *[36]*. As the authors tested the effect of the DMS on different age groups, they found that elder drivers showed better tendency to slow down through DMS messages. Similarly, Peeta and Ramos found high positive correlation between DMS and the overall drivers' behavior from the safety and operational points of view *[37]*. Similar results were obtained by Schroeder and Demetsky who found that a properly designed message can lead to higher diversion rates on suggested alternative routes when incidents take place *[38]*.

The effect of incident information on the drivers' behavior was studied thoroughly by different researchers. For instance, Christoforou et al. conducted a study on identifying crash type propensity using real-time traffic data on freeways including traffic management applications *[39]*. The author found that if a location is designated to have more instances of a particular crash type, warning messages could alert drivers of the potential dangerous areas. Variable speed limits (an example of an active traffic management approach) could affect driver behavior and reduce variations in speed *[39]*. Moreover, incident information can affect drivers' route choice *[40]*. The traffic incident information was provided through a DMS in urban expressway networks. A stated-preference survey was designed to obtain the route choice behavior of travelers with the incident information provided via the DMS. The results showed that based on the congestion information provided via DMS, travelers can assume the travel time of alternative route and take a good route choice decision. In addition to the information provided on a DMS, Zhou and Wu found that driving experience, network familiarity, and criterion of route selection also affected drivers' route choice *[41]*.

Janssen et al. studied the effectiveness of in-vehicle traffic information systems compared to the conventional congestion information broadcasting on radios *[42]*. The authors analyzed the driver behavior data with respect to the claim that in-vehicle traffic information systems are distracting and can negatively affect driving performance and compromise safety. The study compared the effect of different in-vehicle real time traffic information systems, such as Philips Carin 520, Renault/Sagem Carminat, and Volvo/Mitsubishi RTI systems, to congestion information broadcasting on the in-vehicle radio. The study showed that driving with an in-vehicle real time traffic information system is not considered less safe compared to the conventional traffic congestion information broadcasted on the radio, especially if the in-vehicle messages are properly designed not to be distracting (in terms of text size, and color). In addition, using in-vehicle traffic information systems can save travel time by 44.7% *[43]*.

Zhang used a micro-simulation approach to measure the effect of real time traffic information systems (RTTIS) on the overall traffic performance on different road networks defined as parallel, ring, and grid networks *[44]*. They defined two different traffic groups based on whether they use the in-vehicle RTTIS or not. The simulation results showed that the overall performance of both traffic groups improves as a specific percentage of RTTIS usage is achieved. However, the required percentage of RTTIS usage for a better network performance depended on the network type *[44]*. A study conducted by Buscema et al. further supported that real-time traffic information improves the overall performance of the road network they studied *[45]*.

As shown in the reviewed studies, real-time traffic information proved to be very efficient in influencing drivers' behavior. Therefore, a properly designed message delivered via a properly designed system can improve driving behavior in terms of trip scheduling, route choice, travel speed selection, etc. More so, a few studies showed that traffic information may not be as effective as researchers think and so the focus should dwell on what messages are delivered, how the messages are designed, and how they are delivered *[46 - 48]*. Answering these questions can show whether a traffic information system is effective or not. Therefore, successful real-time traffic information should be properly designed in order to gain the expected results of the drivers' behavior and hence on the overall network behavior.

Generally, studies demonstrated the effectiveness of traffic information in controlling the drivers' behavior and hence properly managing the entire transportation network, especially if the information is accurate and delivered in a proper way and at the right time so that the drivers can make the right decision at the right time. This is achieved even with information accuracy less than 100%, as discussed by Kantowitz et al. in their study that recommended real-time information accuracy of 70% or greater to guarantee a successful traffic management process *[49]*.

ACTIVE TRAFFIC MANAGEMENT (ATM) STRATEGIES

The Virginia DOT website contained a quote that summarizes why DOTs should strive to introduce technologies and distribute essential information that helps influence driver decisions: "When travelers are well-informed, they will be able to make intelligent choices about their travel options" *[50]*. When striving to manage congestion and prevent or delay the onset of congestion, helping drivers become "well-informed" should be a high priority. If drivers have information available to them prior to departing, they will be more prepared to successfully maneuver through traffic hurdles they are sure to encounter and help the overall transportation system move more efficiently. Some benefits of using real-time driver information include improved safety and system mobility. One option many DOTs have used to distribute real-time information is ATM. This concept utilizes real time information from vehicles, drivers, and the environment to adjust current roadway features to accommodate incidents that arise. The goal in utilizing ATM techniques is to become proactive and manage transportation systems prior to the onset of changing condition *[51]*. Thus by implementing active traffic management strategies, state DOTs can effectively influence a driver's decision on whether to make a trip, or how to alter a trip in progress, in order to successfully navigate an unexpected hurdle. In a synthesis report prepared for the Federal Highway Administration, active traffic management is defined as "an approach for dynamically managing and controlling traffic demand and available capacity of transportation facilities, based on prevailing traffic conditions, using one or a combination of real-time and predictive operational strategies" *[52]*. ATM strategies are useful in areas that have limited right-of-way and funding availability, common issues for state DOTs in the U.S.

In recent years, active traffic management techniques have been employed more frequently throughout the world, specifically in Europe and America. U.S. based strategies include adaptive ramp metering, lane management, variable speed limits, shoulder use, priced lane facilities, and variable message signs. European nations are utilizing speed harmonization/lane control, queue warning, hard shoulder running, junction control, and dynamic re-routing *[52]*. The following sub-sections provide detailed descriptions of ATM strategies including benefits, challenges, technology required, target markets, data needs, and complementary strategies that can be used concurrently.

Dynamic Lane Use (Shoulder Control)

Dynamic lane use or shoulder control is defined as the dynamic opening of a shoulder lane to traffic or dynamic closure of travel lanes temporarily (see Figure 5). Shoulder control can also be used to serve only transit vehicles if specific conditions call for this. Currently, some heavily populated regions of the U.S. use hard shoulders during peak congestion or under emergency situations. However, dynamic shoulder control is almost instantaneously opening a shoulder lane whenever deemed appropriate. Benefits of this strategy include a postponed onset of congestion, increased capacity, and improved trip reliability and travel times. Some challenges often experienced while utilizing dynamic shoulder control are informing the public when shoulder running is allowed and possible bottlenecks experienced during the area immediately prior to the termination of shoulder lane use. A target market that would most benefit from this strategy would be heavily congested freeways and freeways with high transit vehicle volumes. The required data that determines the shoulder use includes traffic volumes, travel speeds, incident presence and location, and shoulder availability. Finally, complementary ATM strategies that work well with shoulder running include variable speed limits and queue warning signs *[53]*.

Figure 5
Example of dynamic shoulder control

Dynamic Merge (Junction Control)

Dynamic merge (junction control) is the adjustment or closure of a lane or lanes upstream of an interchange. This strategy would be ideal for heavily congested roads and especially for roadways with high merging volumes. Benefits of junction control include delayed onset of congestion, increased capacity and improvement of traffic efficiency and reliability. However acquiring necessary right-of-way, gaining public support, design, and operation of the junction control area could be obstacles for implementing this strategy. Data necessary to provide a dynamic merge area would be the maximum capacity of upstream lanes, traffic volumes on general purpose lanes and merging ramps, travel speeds, and incident presence and location. An example of the dynamic merge strategy is shown in Figure 6. Other ATM strategies that would work well with junction control include variable speed limits, shoulder control and queue warning signs *[53]*.

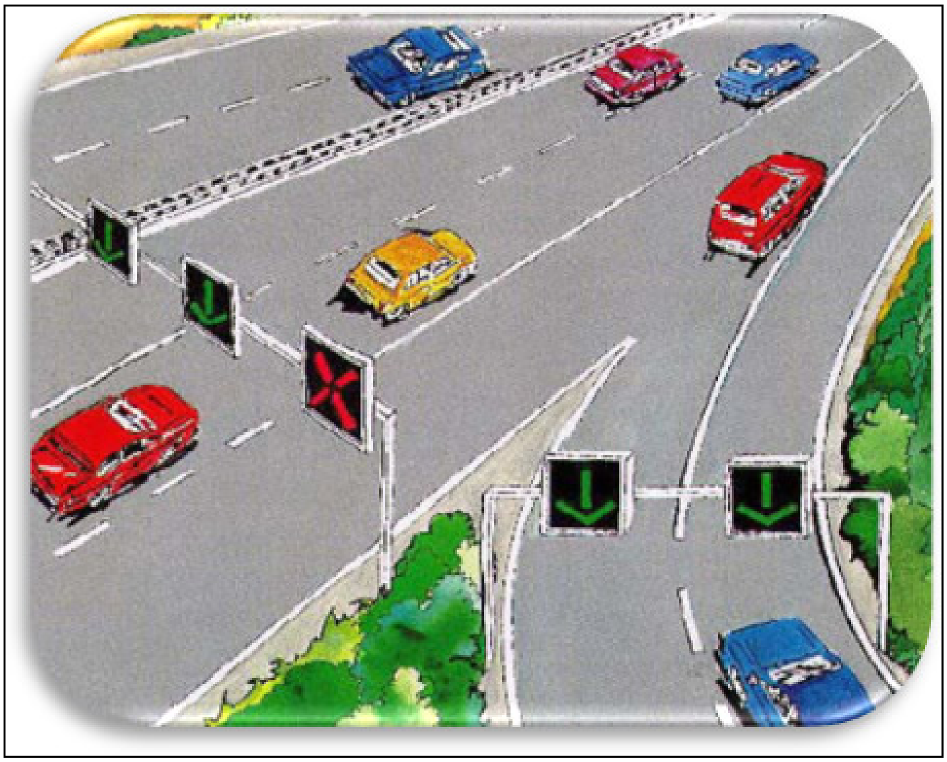

Figure 6
Example of dynamic merge

Variable Speed Limits (VSL)

Variable speed limits (VSL) are changeable signs that instantaneously reduce the speed limit in 5mph increments downstream. Technologies such as roadway or weather sensors would be useful when operating VSLs as the speed could be adjusted based on inclement weather or simply roadway conditions. Benefits seen from this method include improved traffic flow and uniform traffic slowing or speed harmonization. Speed harmonization has been used by DOTs to improve system mobility and corridor safety. Public support and operation of VSLs have proven to be challenges associated with their use. Enforcement issues have also arisen when DOTs have utilized these VSLs. Necessary data for this strategy's operation would be traffic volumes, travel speeds, local climate and weather conditions as well as incident presence and location. An ideal market would be any freeways, especially heavily congested roads as well as areas prone to adverse weather. An example of this strategy is shown in Figure 7. Shoulder control and queue warning signs would work well with variable speed limits as well *[53]*.

Figure 7
Example of variable speed limits

Queue Warning using Dynamic Message Signs (DMS)

Queue warning signs are used to alert drivers of queues or backups downstream and can also be used to estimate travel times. DMS can be used to update drivers on any and everything about the roadway including construction dates and times, accidents ahead, or major events that would hinder regular traffic operations, as shown in Figure 8. Loop detectors are often used to aid in the identification of possible queues. However, other sensors would also provide useful information with this strategy. Benefits include reduced congestion, reduction of rear-end crashes and improved driver safety, while challenges associated with these signs would be ensuring data quality and reliability, determining appropriate location for sensors, public awareness and operations and management. Any real-time information such as traffic volumes, speeds, travel time, and incident presence and location would need to be acquired so that information could be communicated to the drivers. Any freeway would be a target market for these signs and variable speed limits would serve as a complementary strategy to this method *[53]*.

Figure 8
Example of dynamic message signs (DMS)

Dynamic Route Guidance

In association with the queue (congestion) and travel times information provided in the previous strategy, dynamic route guidance (DRG) uses congestion and travel time data from the advanced traffic monitoring equipment to develop optimal real-time traffic distribution of traffic. Different algorithms are used in the DRG based upon congestion levels and real-time traffic conditions. Optimal routes are recommended to drivers via either DMS, as shown in Figure 9, or in-vehicle systems *[54]*.

Figure 9
Dynamic route guidance

Adaptive Ramp Metering

Ramp metering refers to a system where signals are placed on interstate on-ramps that control the rate of vehicles entering the freeway facility. Adaptive ramp metering is a specific case where real-time information such as vehicle volumes, speeds, ramp demand and geometry, and crash history dynamically alter the rate at which vehicles are allowed access to the mainline. An example of an adaptive ramp metering is shown in Figure 10. Benefits of ramp metering include decreased crash rates in controlled areas, increased traffic volumes and speeds, and relatively low construction costs. However, two major challenges transportation professionals experience with ramp meters are potential violations of the meters and negative public perception of ramp delay to local traffic. Target markets for adaptive ramp meters are freeways with recurring breakdowns, congested metropolitan areas and stop-and-go traffic conditions *[53]*.

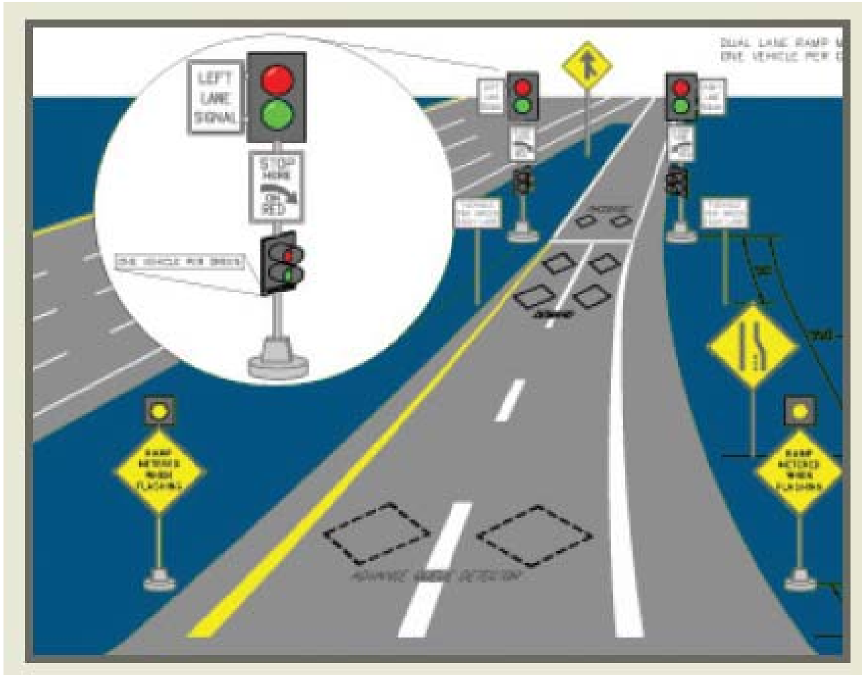

Figure 10
Example of ramp metering use

Advanced Arterial Control (AAC) System

The major benefit of this technology is to reduce travel time and congestion and increase safety by better managing the traffic flow throughout the arterial network including signalized intersections. Different sensors such as loop detectors are used at different approaches of intersections to detect the presence or passage of vehicles. Signal controllers use the data collected by the loop detector and control signal timing so as to minimize the delay at intersections. In addition, the systems work to allow a platoon of vehicles to pass through few intersections continuously. The further advancement in this system is adaptive traffic control where groups of signals are operated by a computer that dynamically alters times based on real-time demand. Different algorithms like SCOOT and SCATS are currently available for the system *[54]*.

Advanced Public Transportation System

This system deals with transit vehicles using information technology to increase the operational efficiency of the transit system. The system works based upon the real time positions of vehicles communicating with each other and uses the information to increase the operation efficiency and hence reduce congestion. To make the system more efficient for the users, the system also implements an electronic fare payment system rather than cash payment. In addition, transit information such as pre-trip information and terminal information is provided to travelers, allowing them to properly schedule and plan for their trips, which subsequently reduces congestion and travel times *[54]*.

Multimodal Traveler Information Systems

In these systems, real-time travel information for different transportation modes are coordinated. For instance, traffic information of freeways and incident management systems are coordinated with the transit information systems. Different sources for different data are used to collect enough data for successful coordination. Traveler information in these systems can be provided in real-time or before the trip to allow travelers to plan their trips *[54]*.

CASE STUDIES

State DOTs are currently using many forms of ATM strategies in order to effectively communicate real time information to drivers. This section details a few case studies that exemplify specific scenarios where ATM is best applied and the impact it can have on congestion management if used appropriately.

Smart Lanes: Minnesota DOT

In 2010, the Minnesota DOT employed dynamic lane use control, dynamic speed limits, queue warning and adaptive ramp metering strategies in the implementation of Minnesota Smart Lanes. Under their Smart Lanes program, during traffic incidents, digital overhead signs illuminate displaying relevant information to drivers such as whether a lane is closing ahead and when to begin merging. Green arrows indicate a lane is open, yellow arrows provide warnings to proceed with caution and a red X signifies the lane is closed and drivers should begin to merge out of said lane. Figure 11 shows the smart lanes with the signs displaying the green and yellow arrows. The smart lane technology has resulted in a 30% collision reduction and 22% increase in capacity for this roadway *[55]*.

Figure 11
Smart lanes in use on I-35 Minnesota

Multiple ATM Strategies: Virginia DOT

Virginia DOT (VDOT) is scheduled to complete a major project dealing with active traffic management on Interstate 66 by 2015. This project will involve the implementation of many active traffic management strategies and technologies concurrently. VDOT already allows vehicles to access shoulder lanes during weekday peak periods; however, upon the completion of this project, dynamic shoulder use will be allowed when congestion reaches a threshold defined by the Traffic Management Center (TMC) any time or day of the week *[50]*. VDOT will also implement dynamic message signs and lane control systems to alert drivers of delays, unusable lanes, incidents ahead and upcoming merges. Other ATM strategies and technologies that will be implemented include adaptive ramp metering, dynamic merging, enhanced detection and camera systems, and queue warning systems. The project area spans 34 miles along I-66 from the District of Columbia to Prince William County *[50]*. Figure 12 details the exact project layout and type of ATM strategy utilized in each segment.

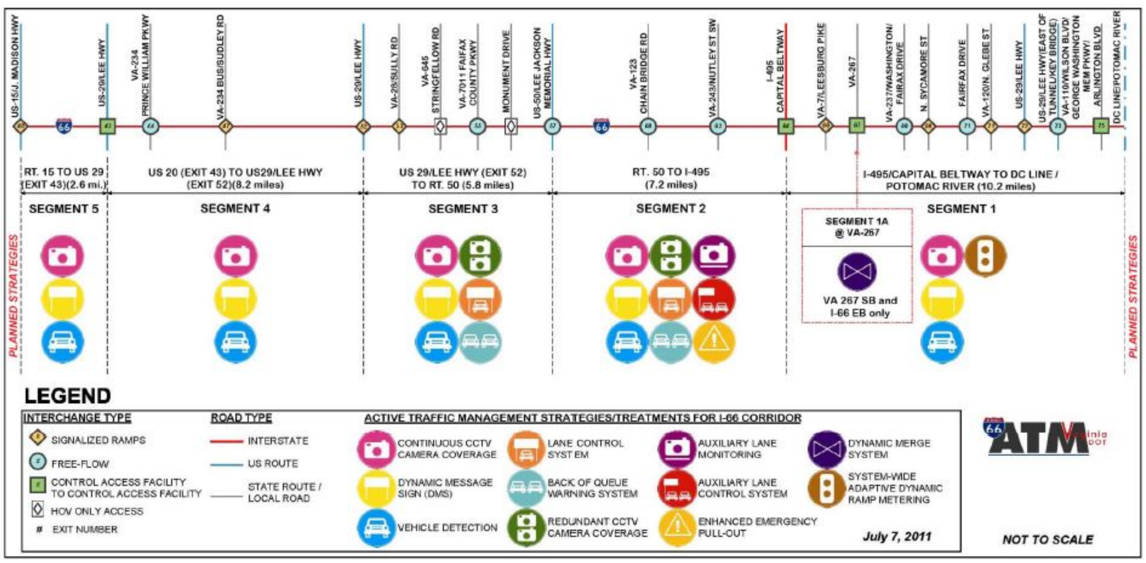

Figure 12
Virginia DOT ATM project layout

Variable Speed Limits: Missouri DOT

In 2008, Missouri DOT implemented variable speed signs along I-270 and I-255 in St. Louis, MO. After two years, a study was conducted to investigate how effective this strategy truly was on this corridor. The study determined that although the variable speed limits had aided in the reduction of crashes and some congestion, enforcement of these speed limits was challenging due to driver confusion. Therefore, in 2011 Missouri DOT decided to change their approach and convert the variable speed limits into variable advisory speeds. The actual signage consists of a yellow and black color stating Advisory When Flashing. The advisory speed range along this corridor increases from 10mph in extreme congestion, to 60 mph during very light traffic. This strategy is used to slow down or stop drivers in the event of upcoming congestion, inclement weather conditions, work zone lane closures or stopped vehicles ahead. Dynamic Message Signs are used in conjunction with these variable advisory speed signs in order to explain why the speed has been lowered *[56]*. Figure 13 illustrates an example graphic of the variable advisory speed signs used in Missouri.

Figure 13
MoDOT variable advisory speed sign

Multiple ATM Strategies: Texas DOT

The Center for Transportation Research at the University of Texas at Austin conducted a study using simulation software to analyze the effect of selected active traffic management techniques used by Texas DOT. They found variable speed limits harmonized traffic flow, reduced the amount of lane-changing conflicts and provided improved safety on the freeways. Variable speed limits also reduced the likelihood and severity of conflicts. Shoulder lane use reduced traffic density and increased operation speed in the middle of the shoulder-use segment. However, the speed at the end of the shoulder lane use segment decreased due to bottleneck conditions created. Although safety of the corridor was improved in the middle of the shoulder lane use segment, the end of the shoulder lane use segment provided unsafe conditions due to the lane-drop. Due to this finding, it is recommended that a comprehensive evaluation be conducted before implementing shoulder lane use over a corridor segment. The ramp metering strategy aided in the reduction of the average number of stops per vehicle and helped maintain a homogenous speed among vehicles. Corridor delay was reduced when using ramp meters as well, however overall network delay increased because of vehicles queuing during the peak traffic on ramps *[57]*.

On Interstate 610 in Houston, Texas, a queue warning system was implemented to combat the bottleneck issue at an interchange. A before and after analysis was conducted in 2008 and early 2009 to analyze speeds and crash rates. The queue warning system resulted in higher average speeds and reduced variance of driver speeds over all lanes. However, there was no change in the number of crash incidents. Researchers recommended a longer study be conducted in order to determine a more realistic effect of the queue warning system *[53]*. Middleton et al. discussed the importance of real time traffic data from the private sector in Texas area to fill the gap due to coverage problems of collected data from the government sectors *[0]*.

Camera and Sensor Technologies: New Mexico DOT

In New Mexico, the Intelligent Transportation System Bureau of New Mexico Department of Transportation maintained a number of cameras and sensors in Albuquerque metropolitan area along I-25 and I-40 *[0]*. It measured speed, lane count, and occupancy information and the collected data were used for traffic management and for emergency response. In order to improve the commercial vehicle operation, the New Mexico Department of Public Safety used the electronic screening systems based on recognizing license plates' images, USDOT number. The imaging system provides an alert to the road side inspector for any high risk vehicles on the roadway.

CONCLUSIONS

This report presents a review of the state-of-the-art and state-of-practice real-time driver information systems and the requirements for a successful integrated Intelligent Transportation System (ITS). Any agency that needs to establish a real-time traffic information system needs to answer some questions in order to have an integrated system: (1) what is the required traffic data accuracy? (2) what traffic data screening should be used? (3) what is the most effective way to disseminate the resulting traffic information to the drivers? Upon answering these questions, a follow up study should be conducted in order to assess the impact of the disseminated traffic information on drivers' behavior and the congestion management process of the highway network.

Most of the research studies conducted on data collection technologies focused on the data collection accuracy as the key element in determining the success of any real-time traffic information system. However, along with the accuracy, the ability of the technology to work in different weather conditions as well as its ability to integrate with the data collection in use are of great importance. Based on these factors, video image technologies and Bluetooth technologies are considered to be reliable data collection technologies. More so, connected vehicle technology can provide a very reliable data collection aid when implemented. More research is required to address some of the unanswered questions such as the minimum market penetration for an optimal environment.

When reliable data collection technology is used and accurate data are collected, the data need to be screened in such a way that guarantees reliable traffic information. The collected traffic data may have errors or missing data problems in addition to the amount that should be managed properly, which was the emphasis of most of the reviewed studies. Research studies showed different approaches for data management, cleaning, and estimation. According to the state-of-practice, a pre-specified logical reference is used to correct data errors, whereas, missing data is estimated according to the missing data intervals. Estimation methods such as simple linear regression, interpolation and different statistical procedures can be used to overcome the missing data problems. As traffic data are screened, the required real-time traffic information can be obtained. However, in some instances, and according to previous studies, predicting traffic conditions and traffic accident prone locations can be more useful for traffic management.

The importance of ITS data has been long recognized by researchers and practitioners in the field. Driver and network information, including travel times, speeds, delay, congestion, bottlenecks, queues, and collisions are all examples of real-time information that drivers want to know before making a trip. There is a range of technologies available to DOTs and other transportation authorities that have the ability to collect essential driver information in real-time. Yet, the issue many agencies face is how to effectively distribute or disseminate the required information to drivers. The main questions in any dissemination method, according to the reviewed studies, are: (1) in what form should the message be disseminated? (2) what is the reasonable message length? (3) when is the best time to disseminate a traffic information? and (4) what is the most reliable dissemination method to be used?

Highway advisory radio, DMS, telephone information services, and social media have been predominantly used to disseminate traffic information. However, DMS is recognized as the most used technology by different TMCs. Simultaneously, other dissemination technologies are being studied, such as connected vehicle technology, as a more reliable and flexible dissemination technology. More research is required to determine a communication protocol with minimal problems in order to have the message delivered to the drivers at the right time.

The traffic information delivered to the drivers is meant to affect their travel behavior so that the overall transportation network is managed, and existing congestion is relieved. The traffic studies reviewed in this report showed that traffic information can control drivers' trip scheduling, route choice, and travel speed. Accordingly, the overall travel behavior on the network is affected. Based on that, the entire traffic management process returns to the accuracy of the collected data and the disseminated information as key elements in any real-time driver information system as to help in congestion management. Accurate traffic data collection leads to accurate traffic information and successful traffic congestion management.

RECOMMENDATIONS

The problem of the effective management of real time traffic data is of major concern for responsible authorities. To extract more information from large sets of available data is a great challenge. The type of data and effective methods of dissemination are also major factors to be considered. In addition, road users are concerned with the accuracy of the real time traffic information they are receiving. Different research studies have discussed the importance of traffic information accuracy on traffic operation and safety. Finally, the effect of consuming massive amounts of real time traffic information instantaneously on the drivers' behavior also needs to be taken into account. Since recent technologies used for data dissemination may be a source of driver distraction, their direct effects and potential hazards need to be studied in detail.

Active traffic management strategies have been gaining popularity among state DOTs as a method of disseminating real-time information accurately, quickly, and reliably. Whether applied individually or jointly, ATM approaches are proven solutions to many everyday congestion management issues. Autonomous vehicles partnered with V2V and V2I frameworks are future solutions that DOTs will see implemented in the mass market in the future. Until then, however, an integrated approach of many active traffic management strategies can aid in reducing congestion and improving the mobility of national freeways and local arterial roadways.

The reviewed case studies display how some ATM strategies can effectively aid transportation professionals in congestion management. However, it is important to note that each individual ATM strategy has its own shortcomings that may limit its availability for use in certain conditions or may inhibit potential benefits. For example, when using dynamic merge control, dynamic shoulder, or ramp metering strategies, it is essential adequate right-of-way is available or these techniques cannot be properly implemented. Variable (dynamic) speed limits will be less effective if speed limits are not heavily enforced on the corridor in which they are used. Also, it is important to educate public and gain support before implementing a new highway strategy such as ATM. Finally, there can be data quality and reliability issues when using dynamic message or queue warning signs to communicate real time information to drivers instantaneously. Further research should be conducted to examine an accurate cost-to-benefit analysis for each individual corridor for which ATM strategies are proposed.

ACRONYMS, ABBREVIATIONS, & SYMBOLS

AAC	Advanced Arterial Control
ANN	Artificial Neural Network
AR	Auto Regression
ATIS	Advanced Traveler Information System
ATM	Advanced Traffic Management
AVI	Automatic Vehicle Identification
CCTV	Closed-Circuit Television
CMS	Changeable Message Sign
DMS	Dynamic Message Sign
DGR	Dynamic Route Guidance
DOTD	Department of Transportation and Development
DOT	Department of Transportation
DSMS	Data Stream Management System
EMDR	Enhanced Message Dissemination based on Roadmaps
FCC	Federal Communications Commission
FCD	Floating Car Data
FHWA	Federal Highway Administration
Ft.	Feet
GIS	Geographic Information System
GPS	Global Positioning System
ITS	Intelligent Transportation Systems
LTRC	Louisiana Transportation Research Center
MAC	Media Access Control
MDL	Minimum Description Length
MoDOT	Missouri Department of Transportation
MPH	Miles Per Hour
MUTCD	Manual on Uniform Traffic Control Devices
OCR	Optical Character Recognition
OD	Origin-Destination
PDA	Personal Digital Assistant
PRC	Project Review Committee
RBF	Radial Basis Function
RTTIS	Real-Time Traffic Information System

SOFM	Self-Organizing Feature Map
STC	Southeastern Transportation Consortium
TMC	Traffic Management Center
U.S.	United States
USDOT	United States Department of Transportation
VDOT	Virginia Department of Transportation
VMS	Variable Message Sign
VSL	Variable Speed Limits
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure

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