HIGHLY-DYNAMIC, PERVASIVE MONITORING OF TRAFFIC CONGESTION LEVELS

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ABSTRACT

The characteristic requirement that Intelligent Transportation Systems have for information on the transport network can often be satisfied by the wealth of available data gathered by statically deployed sensors, such as induction loops. Data derived from dynamically deployed sensors, for example, GPS sensors mounted on probe vehicles travelling on the network, can capture additional information aspects, especially in areas where no static sensors are deployed, and may complement such static sensor data. In this paper we present an intelligent transportation service for highly-dynamic and pervasive monitoring of traffic congestion levels based on information derived from dynamically deployed sensors. We outline how context information of probe vehicles can be statistically analyzed to extract information on the state of traffic within the transport network at any given time. Our service uses scheduled public transport vehicles as probe vehicles to monitor the traffic congestion levels within the national road network. The service can provide detailed, up-to-date traffic congestion information in a pervasive manner and even in areas that are not sufficiently augmented with static sensors. This approach enhances the accuracy and reliability of the provided congestion information and is expected to improve the service quality form a user's perspective. Ultimately, we expect to integrate this service with other user services, for example, for real-time passenger information or for multimodal travel planning.

Keywords: Intelligent Transport Systems, Probe Vehicles

1 INTRODUCTION

Obtaining information on traffic congestion levels within a transport network is an essential element of most applications of Intelligent Transportation Systems (ITS). Traffic congestion data collection techniques can be divided into two groups: roadside techniques and vehicle techniques. Roadside techniques employ static sensors physically embedded within the transport network while vehicle techniques use mobile sensors that are carried within vehicles. Much of the research to date has focused on measuring congestion levels using roadside techniques. The installation and maintenance of the required static detectors (such as induction loops and traffic cameras) can however be quite expensive. Vehicle techniques tend to use wireless technologies such as GPS, RFID, and GPRS or 3G cellular networks to gather and transmit traffic congestion data. These technologies provide an accurate, dynamic, pervasive means of measuring traffic congestion. Vehicles equipped with such data gathering technologies are known as probe vehicles. Traffic data gathered from probe vehicles has huge potential for improving the level of traffic congestion level awareness, particularly in locations where no static sensors are installed. Many public (and private) transport organizations in Ireland (e.g. Bus Éireann, Dublin Coach, Urbus, and Global Taxis) have outfitted their fleet with Automatic Vehicle Location (AVL) systems, which regularly transmit the location of each vehicle in the fleet. Though the main objective of any AVL is to improve transit operations these systems do also provide valuable information regarding the congestion levels throughout the transport network. The use of public transport vehicles as probe vehicles comes at little or no extra cost to the public transport organization as the vehicles are outfitted with GPS for estimating arrival times. Many of these vehicles also run on the most used roads in the transport network and often run at higher frequencies during peak periods. Thus public transport vehicles are ideal candidates as probe vehicles.

The traffic congestion data that is gathered by probe vehicles includes instantaneous speeds, travel times and levels of delay at any point in the transport network without the need for roadside equipment. These categories of data are important for a range of both off-line and real-time ITS. ITS that might use such traffic data include, but are not limited to: Advanced Traveler Information Systems, Advanced

Traffic Management Systems, Advanced Public Transport Systems and Advanced Vehicle Control Systems. Many such systems currently provide static information based only on the length of a road segment and its assigned speed limit. In practice, congestion levels can vary significantly during the peak and off-peak periods, thus the soundness of static information becomes questionable in many situations. This information could however be augmented with traffic congestion data from probe vehicles.

In this paper we present an intelligent transportation service for highly dynamic and pervasive monitoring of traffic congestion levels based on information derived from dynamically deployed (mobile) sensors. We outline how context information of probe vehicles can be statistically analyzed to extract information on the state of traffic within the transport network at any given time. Our service uses scheduled public transport vehicles as probe vehicles to monitor the traffic congestion levels within the national road network. The service can provide detailed, up-to-date traffic congestion information in a pervasive manner and even in areas that are not sufficiently augmented with static sensors. This approach enhances the accuracy and reliability of the provided congestion information. This service can be integrated with other ITS so as to provide them with access to the analyzed traffic congestion level data. Such ITS might include real-time passenger information systems or multimodal travel planning systems.

The remainder of this paper is organized as follows. Section 2 presents a review of the literature on the use of probes for providing traffic congestion data. Literature related to alternative data gathering techniques and relevant methods, as well as uses for such data is also reviewed. The design and implementation of a prototype congestion monitoring service is presented in section 3. We discuss initial results obtained from our prototype in section 4 and conclude with future research in section 5.

2 RELATED RESEARCH

The problem of estimating traffic congestion levels within a transport network has been a topic of research for a long time. Many researchers have investigated the use of probe vehicle data in estimating a transport network's traffic congestion levels. In this section we will review the work of the researchers that have used similar approaches in tackling this problem. We will also review the work of the authors that took alternative approaches in accomplishing this task. We will conclude this section by reviewing literature regarding the variety of ITS that might integrate with our proposed service and discuss how they might use the provided data.

Chakroborty and Kikuchi [3] investigated the use of AVL equipped buses as probe vehicles to gather travel time data throughout the transport network. Their work included an examination into the relationship between the travel times of a regular automobile and of a transit vehicle. The travel times of both were measured simultaneously along the same stretches of road in Delaware. The differences in travel time were found to be relatively stable, thus giving confidence that transit vehicle probes could be used in estimating travel times for non-transit traffic. A functional form that predicts automobile travel time based on bus travel time is thus suggested. This work does however ignore the effects of time-of-day and other local factors on travel time estimation.

Song, Li and Nakamura [11] and Pu and Lin [25] also investigate the use of buses as traffic probes in urban situations. The former focuses on the use of Bus Rapid Transit as opposed to local buses while the later focuses on the added element of real-time data as opposed to archived AVL data. Both papers confirm that a bus-car conversion is required produce reasonable speed and travel time estimates for general vehicles.

Coifman and Kim [9] investigated the use of transit vehicles as probes to monitor freeway traffic conditions. The results obtained in this investigation were validated using loop detector data.

Harrington and Cahill [17] presented a system which took into account not only probe location, speed, time of day and day of week but also additional categories of context such as weather conditions and events such as road maintenance and accidents. This extended context model allowed for a deeper exploration into complex relationships in the data that were not immediately apparent.

Jintanakul, Chu, and Jayakrishnan [20] investigated the use of hierarchical Bayesian models to estimate freeway travel times using small probe samples gathered under similar traffic conditions over several days. This idea allows for dependability of travel time estimation under varying levels of data availability.

Kalman filtering has been investigated extensively in estimating travel times [2, 5]. Kalman filtering has also been used to incorporate probe vehicle data with static detector data to improve travel time estimations [7, 24, 14]. Fuzzy regression and Bayesian pooling have also been used for the same purpose [8], as have neural networks and linear regression [6].

The fusion of multiple sources of traffic data can help manage situations where there are insufficient numbers of probe vehicles to accurately monitor traffic congestion levels within the transport network. Much research has also been put into determining the minimum number of probe vehicles required to accurately monitor traffic congestion levels [4, 21, 16, 19]. These works of research range in the proportions of vehicle population that should be designated as probe vehicles. These proportions vary based on congestion level, traffic volume, and quality of traffic information required.

Although the main alternative method to using probe vehicle data in monitoring traffic congestion levels that has been significantly researched is that of using induction loops there have been some other methods presented. One such method is that of tracing a virtual probe vehicle in a simulated environment as proposed by Liu and Ma [22] and by Cortés et al. [10]

Smartphone and E-Z Pass based approaches have also been employed in monitoring traffic congestion levels [18, 26].

Gomez et al. record many of the Advanced Traveler Information Systems that could benefit from traffic congestion data [15]. Such systems include in-vehicle information systems, passenger information displays (PIDS), passenger information at bus stops (PIBS), automated trip planning systems, passenger information on the internet e.g. [12] multimodal traveler information systems.

Lund and Pack show how probe based data can be used not only to monitor congestion but also to monitor incidents within the transport network [23]. An example of this concept will be illustrated in section 4.

Research performed by Berkow et al. [1] illustrates how similar data can be visualized and statistically analysed as part of an Advanced Public Transport System.

Doan et al. also shows how similar information can be used as part of an online Advanced Traffic Management System [13].

3 FUNCTIONAL OPERATIONS

In this section we present the design and implementation of an intelligent transportation service for highly dynamic and pervasive monitoring of traffic congestion levels. This service derives its traffic congestion data from information received from scheduled public transport probe vehicles. It can be easily integrated with other ITS so as to provide them with access to the analyzed traffic congestion data.

The proposed service has three main conceptual components, namely the Traffic Congestion Monitor system, a server and clients.

3.1 Traffic Congestion Monitor

The heart of the proposed service is the Traffic Congestion Monitor system. This system analyzes a wealth of probe vehicle data and deduces the traffic congestion levels within the transport network. The dataset that we used in conducting this research is that of a number of public transport vehicles (coaches) that run on an hourly schedule from Dublin Airport to Portlaoise and back. Thus each road along the route should be traversed on average once every hour during operating hours (4.30 am to 11.15 pm). The number of probe vehicles running within the network at any time would need to be higher in order to have a finer grained knowledge of congestion levels throughout the network, but for the purposes of our prototype system this dataset is sufficient.

Initialization

When the Traffic Congestion Monitor system is first initialized it reads in the records that each probe vehicle has gathered over the past month. Although the dataset contains data that dates back to 1st January 2010 only one month worth of data is maintained within the running program at any one time. As the data for each vehicle is read into the system numerous variables are calculated and stored, including the vehicle's average speed, acceleration, and distance travelled between GPS readings. These variables will be used to calculate information such as travel times. As new probe vehicle updates arrive into the live dataset the Traffic Congestion Monitor system reads them into memory, thus keeping the system aware of the real-time activities of the probe vehicles.

Requests

When the Traffic Congestion Monitor system has loaded the past month worth of data and is in a state of constantly updating this data with real-time probe readings it can then handle requests passed on to it from the server. Upon request the Traffic Congestion Monitor system can calculate average speeds, delays and travel times along chosen roads within the network. A typical request includes as parameters a representation of a stretch of road within the transport network, day of week, time of day, an indication as to whether the request is for real-time or non-real-time data, an indication as to the type of speed to be used (time mean speed, average running space mean speed, or average travel space mean speed), and an indication as to what variable is being requested (average speed, delay or travel time).

Stretch of Road

Within the request two coordinate points (two sets of latitude and longitude) represent the stretch of road in question. A simple request to Google Maps returns the shortest route between these two points, thus no definition of transport network infrastructure such as road layout need be explicitly defined on either client or server side. As an example stretch of road we selected a segment of the M50 going northbound as can be seen in Figure 1.

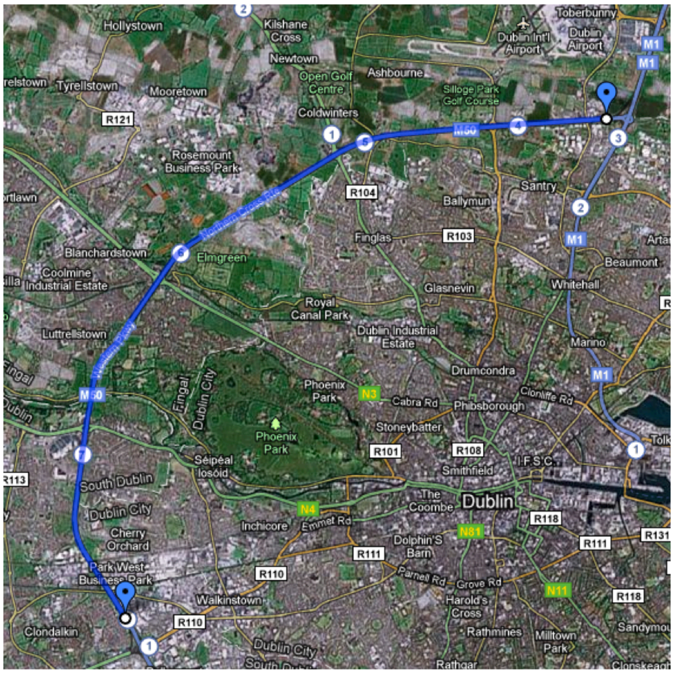

Figure 1. M50 Northbound Sample Road Segment

Free flow Speed

Once the Traffic Congestion Monitor system discovers the stretch of road in question it calculates the free flow speed along this stretch of road. Free flow travel time is basically the travel time used for static information and in many cases can be seen as a function of the speed limit. The free flow speed tends to slightly exceed the speed limit when traffic is light. Though it would be reasonable to use the speed limit our approach uses historic probe readings from times of little to no congestion in order to calculate the free flow speed. This overcomes issues such as frequent changes in road speed limits due to road works.

Average Speed

Once the free flow speed has been calculated the Traffic Congestion Monitor system selects the data from all traffic probes that were gathered over the past month along the given road segment on the given day of the week. If real-time data is requested then only the current days data will be used. The Traffic Congestion Monitor system then calculates the average speed (time mean speed, average running space mean speed, or average travel space mean speed as indicated by the request) during each hour of the selected day/s. If the request is for real-time data and no real time data is available at the given timeslot then the average speeds for the chosen day over the past month are used. If the particular timeslot for the chosen day does not have sufficient numbers of probe vehicle readings to provide an accurate average speed then the Traffic Congestion Monitor system calculates average speeds based on all weekdays or all weekend days over the past month (depending on if it is a weekday or weekend day that has been specified). Figure 3 shows the average running space mean speeds along the stretch of road depicted in Figure 1 from the 15th June to the 13th July 2010 divided into weekdays and weekend days.

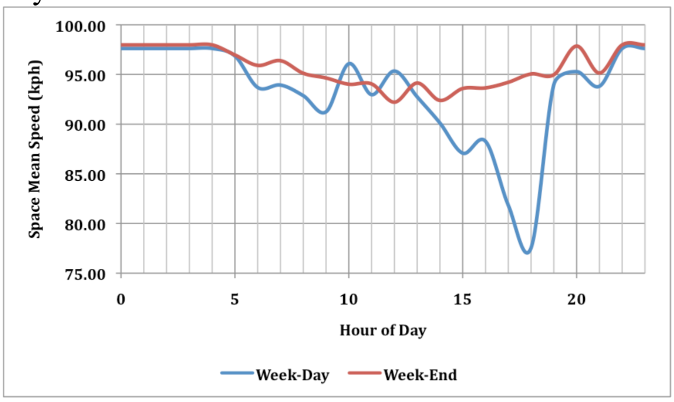

Figure 2. Average Space Mean Speed by Week-Day/End and Time of Day

It can be seen that weekend speeds tend to drop to their lowest at about midday while weekday speeds tend to drop to their lowest during morning and evening rush hours (9am and 5-6pm).

If these calculated average speeds still do not contain sufficient probe readings during the given timeslot then average speeds for all days throughout the past month are calculated. In the rare event that this last set of average speeds does not contain sufficient probe readings during the given timeslot then the free flow speed is used.

This concept is similar to that of the TeleAtlas speed profile concept [27] with the exception that the speed profile or traffic congestion patterns in our system are dynamically generated for client-defined stretches of road.

Travel Time

Now that the average speeds are known for the given stretch of road travel times can be calculated by dividing the length of the stretch of road by the average speed and multiplying by 60. A breakdown of times by day of week is given in Figure 3.

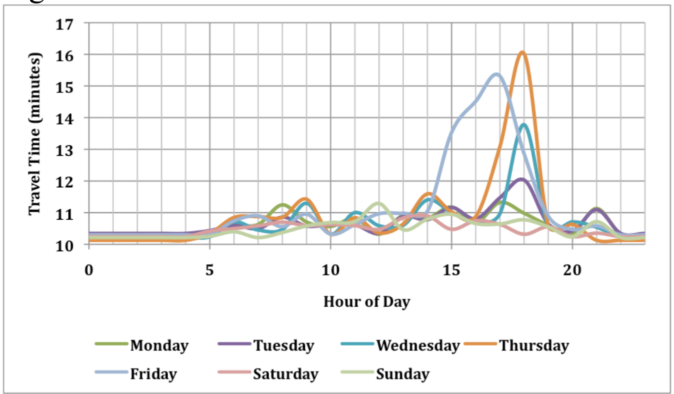

Figure 3. Average Travel Times by Day of Week and Time of Day

It can be seen that the highest travel times are on Thursdays, Wednesdays and Fridays at approximately 5 pm or 6 pm. These extremely high peaks might be caused by non-recurrent traffic e.g. road works or traffic accidents. To handle these peaks future versions of the system will not include non-recurrent traffic congestion readings in the calculations of average speeds for any day with the exception of the current day in real-time mode.

Delay

Having calculated the average travel times based on average speeds it is then a matter of subtracting these values from the free flow travel time in order to obtain the levels of delay, as seen in Figure 4.

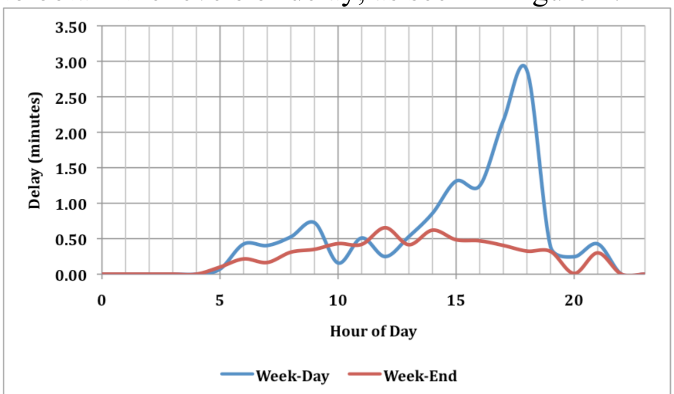

Figure 4. Average Delay by Week-Day/End and Time of Day

As an example, a request that is made for our sample stretch of road on a Thursday at 2pm would return a travel time of 11 minutes 40 seconds (an average delay of approximately one minute and 40 seconds) at an average speed of approximately 90 kph. If the same request was entered into Google maps a static travel time of 9 minutes is returned, with a static speed of 110 kph over the 16.7 km.

3.2 Server

The server passes any request made to it on to the Traffic Congestion Monitor system, and then returns any reply to the requesting client. Thus the server converts the Traffic Congestion Monitor system into an accessible service.

3.3 Clients

The clients can be any kind of application that uses the appropriate protocol to make requests to (and receive replies from) the server. In order to make a request a client must provide a start and end location along any stretch of road, as can be seen in Figure 1. The client must also state whether the result should be based on real-time or non-real-time data. The day and time must also be provided. This allows for estimates of past and future traffic conditions to be requested. The client also states what type of traffic congestion data is being requested. The currently supported requests that can be made on any one stretch of road are: the travel time, the average speed, the delay and the length of the given stretch of road. Client applications can range from Real-Time Passenger Information applications to Automatic Incident Detection applications.

4 RESULTS

Though in the previous section we used the entire length of the M50 northbound as a test length of road, we found that the results were more accurate if smaller sections of road were chosen. This is partly because the state of traffic congestion over a large stretch of road will simply be an average of numerous smaller congestion patterns along this road, e.g. at the different junctions along the M50 there will be different levels of traffic congestion throughout the day. As the traffic congestion patterns are dynamically calculated for client-defined stretches of road it becomes the client's responsibility to select appropriate road lengths. These will of course depend on the specific purposes that the client has for the requested information.

In our example we use average space mean speeds along a motorway. It is up to the client to decide whether average running space mean speed or average travel space mean speed is more suitable for smaller national roads (the former removing stopping delays while the latter includes them in the calculations of average speeds).

Flow vs. Delay

The Central Statistics Office (CSO) 2007 Transportation report summarises much of the information gathered by roadside sensors along the M50 and other major roads throughout Ireland. Figure 5 displays the hourly traffic flow at the Blanchardstown junction of the M50 that can be found in this report.

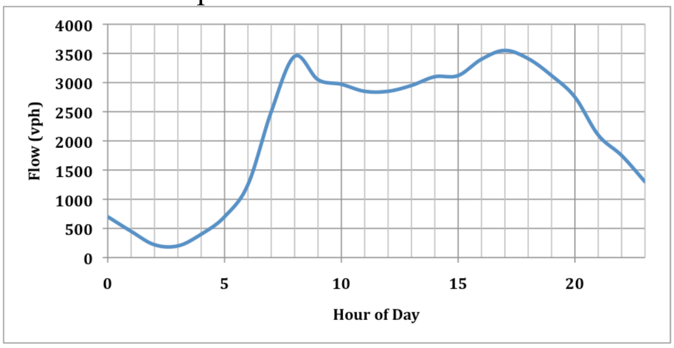

Figure 5. Average Weekday Traffic Volumes at Blanchardstown (M50 Northbound), 2007

In an investigation to observe the relationship between the hourly flow and the average delay on this junction we queried the Traffic Congestion Monitor service giving as parameters the stretch of road depicted in Figure 6.

Figure 6. M50 Northbound Road Segment at Blanchardstown Junction

The returned delay statistics are given in Figure 7. Comparing Figure 5 and Figure 7 we can observe that traffic on this stretch of road travels at free flow speeds until the traffic flow exceeds a certain level (approximately 7500 vph). At this point optimum flow is reached. Above this point increases in traffic flow result in increased delay (hence decreased speed). This relationship is given on the congestion branch (the upper half) of the well known fundamental speed flow diagram (Figure 8).

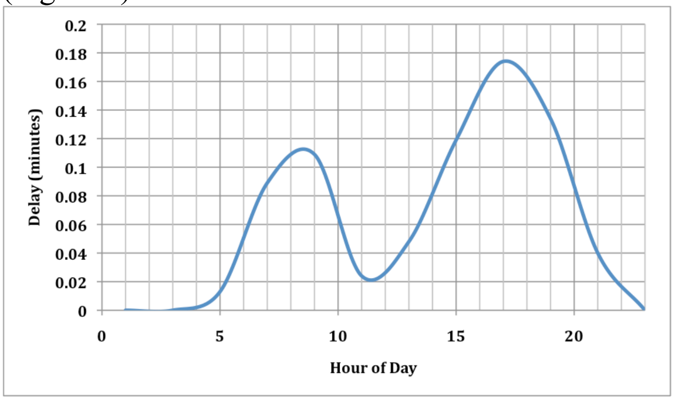

Figure 7. Average Weekday Delay at Blanchardstown (M50 Northbound)

This example illustrates how the Traffic Congestion Monitor service can provide useful data that may be used in both academic and industry based research. Thus civil engineers, city traffic officials, planners and research students can access data that may assist in conducting traffic congestion studies at different levels of resolution ranging from area wide studies down to congestion studies at local intersections.

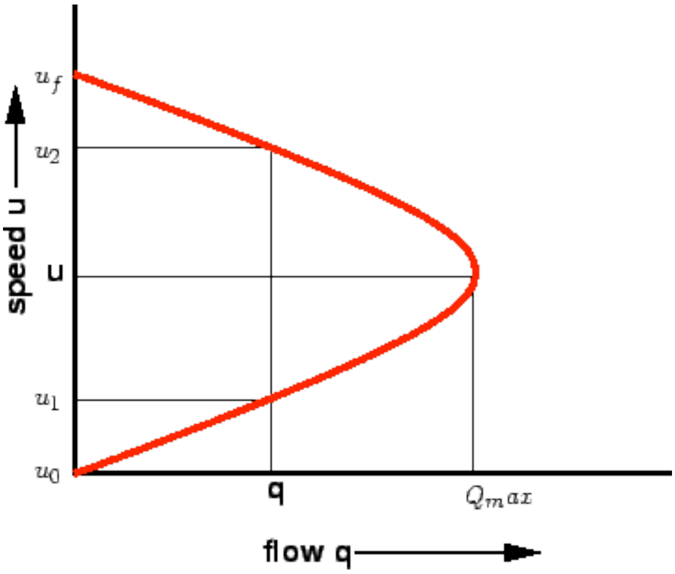

Figure 8. Fundamental Speed Flow Diagram

Real-Time and Automatic Incident Detection

The Traffic Congestion Monitor service provides a useful real-time function that can be used not only to provide real-time data on traffic congestion levels but can also be used to automatically detect traffic incidents. To emphasise the usefulness of this feature we investigated a day on which there was unusually heavy traffic on the northbound M50 (Figure 1). This non-recurrent traffic was caused by an accident at the Ballymun junction as can be seen in the alert retrieved from BreakingNews.ie in Figure 9.


BreakingNews.ie « Previous Next »

M50 crash delays Dublin traffic

27/05/2010 - 08:06:29

A collision on the M50 is causing a headache for Dublin motorists this morning.

The collision occurred on the northbound off ramp at the number four Ballymun junction.

It is closed now until further notice while efforts are made to clear the scene.

As a result, traffic is very heavy from the Finglas junction.

Motorists are being advised to continue on to the interchange of the M1 and M50 to access the M50 southbound, and then exit at Ballymun.

« Previous Next »

Share:

Figure 9. BreakingNews.ie Collision/Congestion Alert (M50 27/05/2010)

Figure 10 compares delays on this stretch of road on this particular Thursday to average Thursday delays on the same stretch of road.

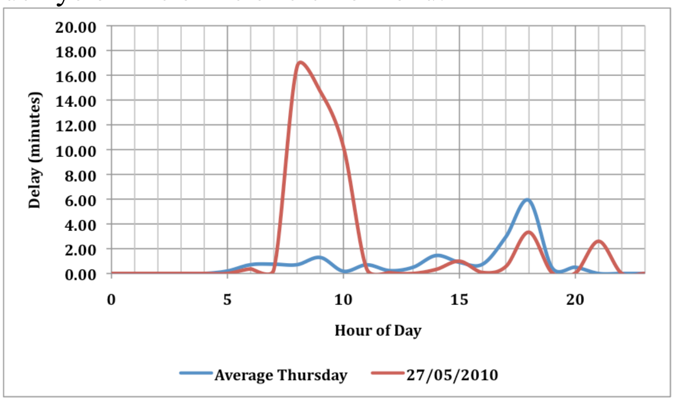

Figure 10. Average Thursday Delay vs. Average Delay on 27/05/2010 by Time of Day

It can be seen that the accident occurred at about 8 am and was fully cleared by 11 am. Queries to the Traffic Congestion Monitor service in real-time mode between these times would have returned the higher delay levels for that particular day as opposed to the average Thursday delays.

5 CONCLUSION & FUTURE WORK

This paper described an intelligent transportation service for highly dynamic and pervasive monitoring of traffic congestion levels. This service derives its traffic congestion data from information received from scheduled public transport probe vehicles. It can be integrated with other ITS to provide access to the analyzed traffic congestion data. It has been shown that this data can be used for real-time congestion monitoring and real-time passenger information as well as for automatic incident detection.

Although the initial results obtained from our experiments are encouraging, issues remain for future research. As the number, frequency and area of coverage of transit traffic probes increases the Traffic Congestion Monitor service becomes more accurate and useful to client applications. We would therefore consider incorporating additional sources of transit vehicle probe data, such as taxi probe data, from public transport organizations to further advance our service.

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