Travel time information via VMS in Athens

by

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Abstract

This paper deals with the way that the link travel times - for both urban road with signalised intersections and freeways - are estimated by the Athens Traffic Management Center. The way the travel times are estimated and constantly fine-tuned by the calibration of specific algorithms is presented. In particular, the estimated travel times are regularly compared to the actual travel times of the vehicles traveling through the route, which are being monitored by the ATMC Operators with the use of the CCTV control cameras. In case of a higher than 20% difference between them, calibration of the travel time estimation algorithms takes place. The estimated travel times are used in conjunction with messages about possible congestion in the neighboring road sections for the information of road users via Variable Message Signs and hence, for the traffic optimisation of the most heavily roads of Athens.

1. Introduction

The Athens Traffic Management Center (ATMC) of the Hellenic Ministry for the Environment Physical Planning & Public Works was built in time for the Athens 2004 Olympic and Paralympic Games and is now in its second year of operation. The primary aims of the Athens Traffic Management Center are:

- Traffic optimization of the most heavily loaded urban roads of Athens
- Quick incident response
- Collection, analysis and use of the traffic quantities being collected from the about 500 monitoring sites (inductive loops and video-detection)

- Real-time intervention in the traffic signal programs of the about 900 signalized intersections connected to the Center
- Supply of real-time data to providers of real-time information to drivers
- Cooperation with other Traffic Management Centers

The Center operates 24 hours per day, 365 days per year. Its apparatus comprises around 500 monitoring sites, 208 CCTV control cameras, 24 Variable Message Signs, the Siemens SITRAFFIC CONCERT Traffic Control and Monitoring System (Siemens, 2001), Traffic Controllers at signalized intersections for the communication with CONCERT, a control room with 10 work stations, one video-wall and 42 monitors for the constant screening of the cameras.

2. Use of VMS

For the information of road users, 24 permanent overhead three-line Variable Message Signs (VMS) are installed throughout the main road system of Athens (Sermpis et al, 2006). VMS are used for three types of messages:

- Immediate and Advance Warning messages
- Travel-time Information messages
- Public Service Announcement messages

Immediate and Advance Warning messages provide information to the driver for incidents which are either unexpected (such as accidents, broken-down vehicles, road damages, and extreme environmental conditions) or planned (such as road closures due to construction and maintenance works, athletic events, demonstrations, etc.).

Travel-time Information messages provide real-time information to drivers about the time needed to reach a specific destination. Several routes are being monitored for each VMS, and the time needed for a private car to reach the specific destinations is being estimated by taking into account the appropriate traffic quantities collected from the loops and using specially designed algorithms. Furthermore, information about possible congestion at specific road sections, which are considered to be important for the drivers passing by each VMS, is also displayed.

The Public Announcement messages are “soft” messages, which are only used in special events (greetings on National Holidays) or within the framework of cooperation with other public authorities (road safety related messages in cooperation with the Ministry of Public Health).

There is a priority rule concerning the use of the above three types of messages. According to it, Immediate and Advance Warning messages have the highest priority, followed by Travel-time Information messages and last by Public Announcement messages.

3. Literature review

Travel times are important for the information of a driver, but are also an important parameter for a number of applications, such as estimation of delay (crucial for economical analysis), estimation of emissions, etc. The link travel time reflects the traffic conditions averaged over a fixed distance. It must be considered as a constant comparison between "expected travel times" and actual travel times. A possible difference between them must be compared to historical statistical data to indicate a possible incident.

Travel time can either be estimated or predicted. Traffic prediction approaches include statistical (Davis and Nihan, 1991) or macroscopic models, route choice models based on dynamic traffic assignment (Ben Akiva et al, 1992), spectral and cross-spectral analyses (Stathopoulos and Karlaftis, 2001), cusp catastrophe theory (Phshkar at al, 1995), time series models (Ahmed and Cook, 1982) and neural network techniques (Fu and Rilett, 2000). The main bias in these methods is that they use historical data from a given location to make predictions for future (usually short-term) traffic behaviour. Furthermore, these methods are mostly used for non-urban roads.

The methods that can provide travel time estimations can be divided into five categories:

a) Spot speed measurement methods
b) Spatial travel time methods
c) Probe vehicle technologies
d) Regression models
e) Neural networks

The spot speed measurement methods are based on the existence of inductance loop detectors (single or dual) for the provision of real time traffic information. Other techniques involve infrared and radar technologies. These systems only measure traffic stream speeds over a short road segment at fixed locations along a road. These spot speed measurements are used to compute spatial travel times over an entire trip using space mean speed estimates. New approaches that match vehicles based on their lengths have also been developed (Coifman and Cassidy, 2002; Coifman and Ergueta, 2003).

Spatial travel time methods use fixed location equipment to identify and track a subset of vehicles in the traffic stream. By matching the unique vehicle identifications at different reader locations, spatial estimates of travel times are computed. Typical technologies include AVI and license plate video detection systems.
Probe vehicle technologies track a sample of probe vehicles on a second-by-second basis as they travel through a link. These technologies include cellular geo-location, global positioning systems (GPS) and automatic vehicle location (AVL) systems. The use of probe vehicles enables a sample of the travel times experienced by all vehicles traveling through the link to be obtained. Previous research has examined how accurately probe vehicle travel times reflect the travel times of all the vehicles (Van Aerde et al, 1993; Turner and Holdener, 1995).

Regression models are the most commonly used method to estimate travel times and are based on regression analysis. Well-established regression methods include the Wardrop (1968), Takaba et al (1991), Sisiopiku and Rouphail (1994) and Zhang and He (1998) formulas. Due to the large number of factors influencing the traffic delay, there are no accurate mathematical models describing the relationship between the travel time and its influencing factors. Therefore, the estimation of travel time becomes a complex problem due to the large number of factors that could affect traffic dynamics. Most of the algorithms proposed in the literature are sufficiently accurate for low density and uniform traffic situations. Hence, they adopt well for travel time estimation on freeways, but not that well for urban arterials and streets. The main characteristic of urban arterials and streets is the unexpected growth and decay of queues. Such a travel time estimation algorithm should react quickly and accurately in the development of unexpected traffic problems when using dynamic data.

Artificial Neural Networks (ANNs) have been widely used in traffic engineering (Dougherty, 1995). They allow complex non-linear relationships between variables to be determined. Although the results of such techniques have been promising, they lack rigor and theoretical background.

4. Travel time estimation

Travel time estimation is divided into two categories:

a) Estimation for urban roads with signalised intersections
b) Estimation for freeways

The difference between the two methods is the existence of traffic lights, which is the primary reason for the growth and the decay of queues and hence, for the extra time needed for a vehicle to travel through a link.

4.1 Urban roads with signalized intersections

These are roads mainly in and around the city center. In these roads, the traffic is being controlled by traffic lights, which either serve considerable amounts of traffic through conflicting directions or serve specific purposes (such as heavy pedestrian movements). The basic characteristic of these roads is therefore, the existence of traffic lights, which control the vehicle movements and lead to the formation of queues when the red indication is shown.

To achieve efficient travel time estimation, two parameters of the route design are crucial: the identification of the critical traffic lights and the location of the loops. Each route is split into several road sections. To split the route into road sections, the traffic lights which are considered to be critical in terms of network performance are identified. Each road section begins downstream of the previous critical traffic lights and ends at the stop-line of its own critical traffic lights. Hence, each road section can comprise of more than one signal-controlled junctions, which are not considered to be critical.

Each road section has one set of inductive loops (one loop per lane), which is placed upstream of the critical junction. The location of the loops is of high importance, because it should reflect the growth and the decay of the queues. Therefore, the loops are placed at such a location upstream of the critical junction that they become constantly occupied only when the traffic flow of the road section is considered to be heavy and hence, the road section is considered to be congested. It must be noted that a traffic flow is defined as heavy when the last vehicle in the queue (when the traffic lights turn to green) needs more than two cycles to cross the stop-line of the critical junction.

The algorithm for the travel time estimation is based on Tannert's method (Siemens, 2001). This algorithm is applied to each route section and the travel time of the route is then calculated as the sum of the travel times of all road sections. According to the algorithm, the estimated travel time is the sum of three different travel times:

a) The time for a vehicle to travel through the uncongested (which is defined as not being part of the queue) part of the road section – t_1
b) The time for a vehicle to travel through the queue – t_2
c) The time that a vehicle needs to wait for the green indication of the traffic lights – t_3

The estimation of the travel time is given by the following formula:

$$t_R = t_1 + t_2 + t_3 = \frac{(L_{link} - L_{t,stau})}{v} + \frac{L_{t,stau}}{v_{stau}} + \left[t_{rot} * \frac{L_{t,stau}}{L_{ab}} + t_{vz} \right] \qquad \text{\{Formula 1\}}$$

where:

t_R : travel time (s)

L_{link} : length of the road section (m)

$L_{t,\ stau}$: queue length at time t (m)

v : free flow speed (m/s)

v_{stau} : speed at which the vehicles travel through the queue (m/s)

t_{rot} : red indication time (s) of the critical signal-controlled junction

L_{ab} : number of vehicles clearing the critical signal-controlled junction during a full cycle (m)

t_{vz} : time that a vehicle needs to wait for the green indication of all the signal-controlled junctions (s)

For the first term of the algorithm, the part of the road section which is uncongested is assumed to be free of any vehicle interaction effects and therefore vehicles travel at free flow speed. The free flow speed is set by the user by taking into account the speed/flow diagram of the loop upstream of the critical signal-controlled junction.

For the second term of the algorithm it is assumed that vehicles travel through the queue at a constant speed, which is set by the user and is also found by taking into account the speed/flow diagram of the loop upstream of the critical signal-controlled junction.

Finally, for the third term of the algorithm, two travel times are needed: the travel time for a vehicle to pass through the critical signal-controlled junction and the travel time for a vehicle to pass through all the signal-controlled junctions of the road section. For the estimation of the travel time for a vehicle to pass through the critical junction, it is assumed that the mean headway between vehicles passing through the critical traffic lights is constant. Hence, by knowing the green time indication it is possible to calculate the exact number of vehicles clearing the junction during each cycle. Then, by dividing the queue length by that amount, the number of cycles needed for a queue to dissipate is estimated and hence, the travel time. For the estimation of the travel time for a vehicle to pass through all the signal-controlled junctions of the road sections, the time that a vehicle is waiting in the queue for the green indication to be shown in all the traffic lights of this road section is needed. It is assumed that the time needed for a vehicle to wait for the green indication of a signal-controlled junction is equal to half of the red indication time. Hence, the time for a vehicle to pass through all the signal-controlled junctions is equal to the sum of the half red indication times of all (including the critical) signal-controlled junctions.

The most essential element in the estimation of the travel time is the accurate estimation of the queue length. The queue length is the only parameter in this algorithm, which is dynamic. At each time update (90s), the prevailing values of traffic flow and speed are compared to the previous ones. Moreover, the speed is compared to two characteristic speeds: the speed above which the queue starts to clear and the speed below which a queue starts to build up. This will indicate whether the queue is dissipating or clearing. Depending on this comparison, the appropriate formula is used:

$$L_{t,stau} = L_{t-1,stau} + A_t \qquad \{\text{Formula 2}\}$$

where:

$L_{t-1,\ stau}$: queue length at time t-1 (one update interval before the current time) (m)

A_t : increase or decrease of the queue length (m), where:

(a) Queue increase $A_t = \frac{(v_{ab} - v_t)}{v_{ab}} * q_t * stab * L_{fz}$

(b) Queue decrease $A_t = \frac{(v_{opt} - v_t)}{v_{opt}} * (q_{\max} - q_t) * stauf * L_{fz}$

where:

v_{ab} : speed above which the queue starts to clear, which is set by the user by taking into account the speed/flow diagram (m/s)

v_t : speed at time t (m/s)

stab : sensitivity parameter of the queue growth, which is estimated by the user

L_{fz} : length of a vehicle (m)

v_{opt} : speed under which a queue starts to build, which is set by the user by taking into account the speed/flow diagram (m/s)

stauf : sensitivity parameter of the queue decay, which is estimated by the user

4.2 Freeways

In the case of freeways, the routes are once again split into several road sections. To split a route into road sections, the positions where the geometrical (i.e. change of the number of lanes) and/or the traffic characteristics (i.e. ramps) change, are identified. In these positions, sets of loops (one per lane) are placed. Each road section begins at one set of loops and ends at the following one. Hence, one set of loops serves as entry loop in a road section and as exit loop in the previous one.

Once again, the travel time of the route is calculated as the sum of the travel times of all the road sections. For the estimation of the travel times of the road sections the Sachse method (Siemens, 2001) is used. In this method, the data from the two loops are used for the estimation of the amount of the queue length. By a simple subtraction between the traffic flow monitored in the exit loop and the traffic flow monitored in the entry loop, the number of vehicles that have not cleared the road section at a specific time interval are calculated and hence, the queue length. This queue length is used in Formula 1 (as in the case of urban roads with signalized intersections), with the only exception being that the Sachse method does not include the time that a vehicle needs to wait for the green indication of the traffic lights, since no traffic lights exist. Hence, the third term of Formula 1 does not exist in Sachse method.

4.3 Calibration of the algorithms

Before applying these algorithms for the estimation of the travel times in Athenian roads, they must be calibrated to cater for the specific characteristics of the Athenian road network. To monitor the accurateness of the algorithms' estimated travel times, the ATMC Operators carry out extensive measurements for each road section. These measurements deal with the identification of vehicles passing through the beginning of the road section, their monitoring until the end of the road section and hence, the recording of their travel time. The exact number of measurements required depends on the standard error of the average measured travel times. This standard error should not exceed 5%. These measurements are carried out for a variety of traffic conditions and time intervals to account for different traffic conditions and time intervals of the specific road section.

The average value of the measured travel times and its confidence interval are then calculated and compared to the algorithms' estimations. The aim is for these algorithms to estimate the travel times of each road section with a maximum of 20% difference to the actual travel times that the ATMC Operators measure.

To apply the algorithms to the Athenian roads, several parameters have to be estimated. These quantities can be divided into three categories:

- Parameters that can easily be measured, such as the link length and the red indication time of the critical traffic lights.
- Parameters which can be identified from the speed/flow diagram, such as the free flow speed, the speed above which the queue starts to clear and the speed under which a queue starts to build, and can be fine tuned during the calibration procedure. A characteristic speed/flow diagram for a loop is shown in Figure I:

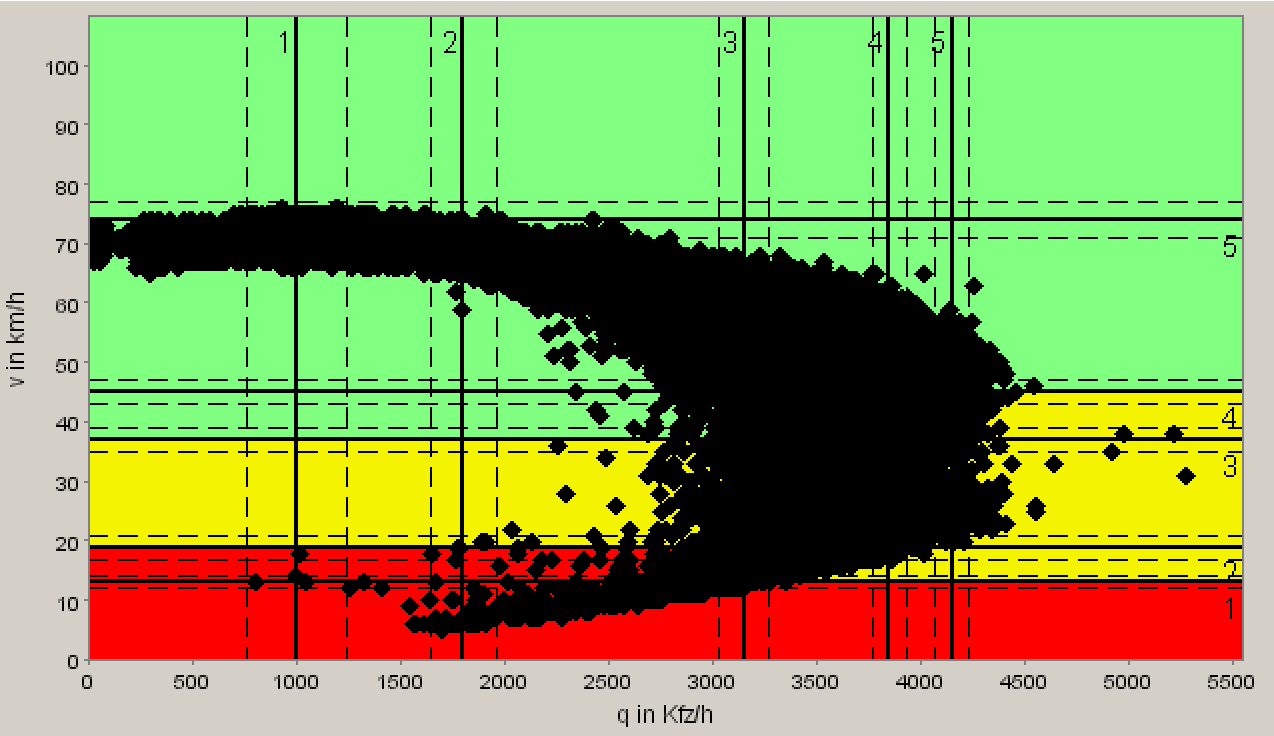

Figure I: Characteristic speed/flow diagram for a loop

In this diagram all the 90s (update interval) traffic flow and speed pair values are illustrated for a period of one month. The shape of this diagram is close to the fundamental speed/flow diagram that describes the relationship between traffic flow and speed. The three colors correspond to three different levels of traffic conditions; light, medium and heavy flow. The traffic condition of a road section is defined as light (green color) when the last vehicle in queue (when the traffic lights turn to green) clears the junction during the first cycle. The traffic condition of a road section is defined as medium (yellow color) when the last vehicle in queue does not clear the junction during the first cycle, but during the second. Finally, the traffic condition of a road section is defined as heavy (red color) when the last vehicle in queue needs more than two cycles to clear the junction. This categorization is not directly significant for the estimation of the travel times, but only indirectly in terms of identifying several parameters for the calibration of the algorithms. More specifically, the free flow speed is the maximum speed found at the diagram (74 km/h), the speed under which a queue starts to build (37km/h) is the limit between light and medium flow and the speed above which the queue starts to clear (19km/h) is the limit between medium and heavy flow. The values taken from this diagram are used as first input in the algorithms, but need fine-tuning for more accurate estimations.

- Parameters that need calibration (such as the speed at which the vehicles travel through the queue).

After the first input in the algorithms, the estimated travel times are compared to the ones measured by the ATMC Operators. An example of not-well matched values is shown in Figure II:

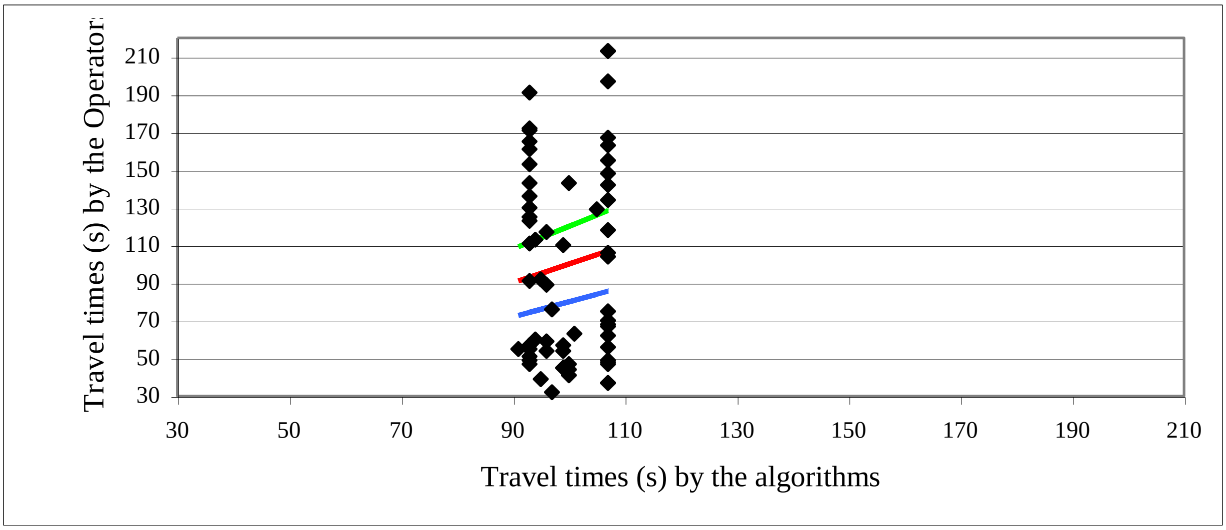

Figure II: Comparison between the estimated travel times (s) by the algorithms and by the Operators

In this figure, the red line indicates the 100% match between the values of the algorithms and those measured by the ATMC Operators, whilst the green and the blue lines indicate the 20% upper and lower confidence levels. Most of the values are not placed between the green and blue lines and hence, the difference between the two values is not acceptable. In these cases, and also in cases of fine-tuning, the algorithms need calibration. By calibrating the algorithms, several of their quantities are constantly being altered until the estimated travel time statistically matches the measured travel time by the ATMC Operators.

For the calibration of the algorithms, a simulation tool was developed, which takes into account all the values of traffic flow and speed of a specific loop, and estimates the travel times using these algorithms. In this tool, the alteration of a parameter of the algorithms leads to new estimated travel times. The results of the simulation program are illustrated in Figures III και IV:

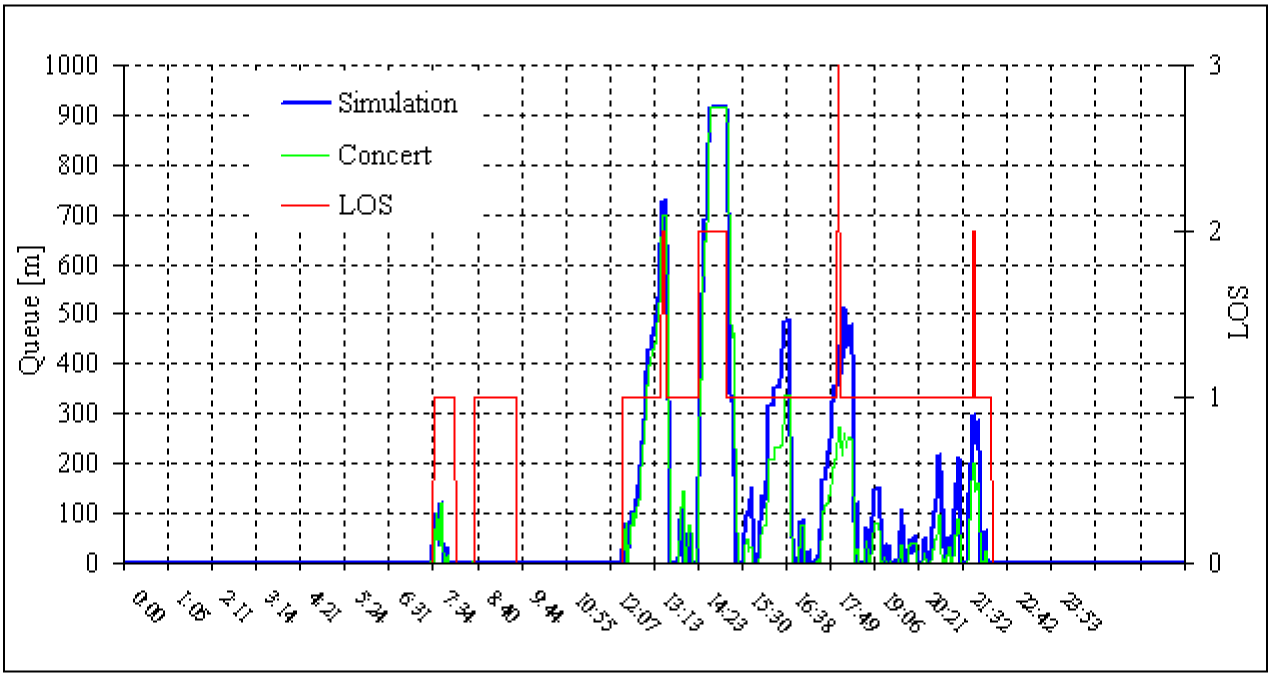

Figure III: Simulation of the growth and the decay of queues

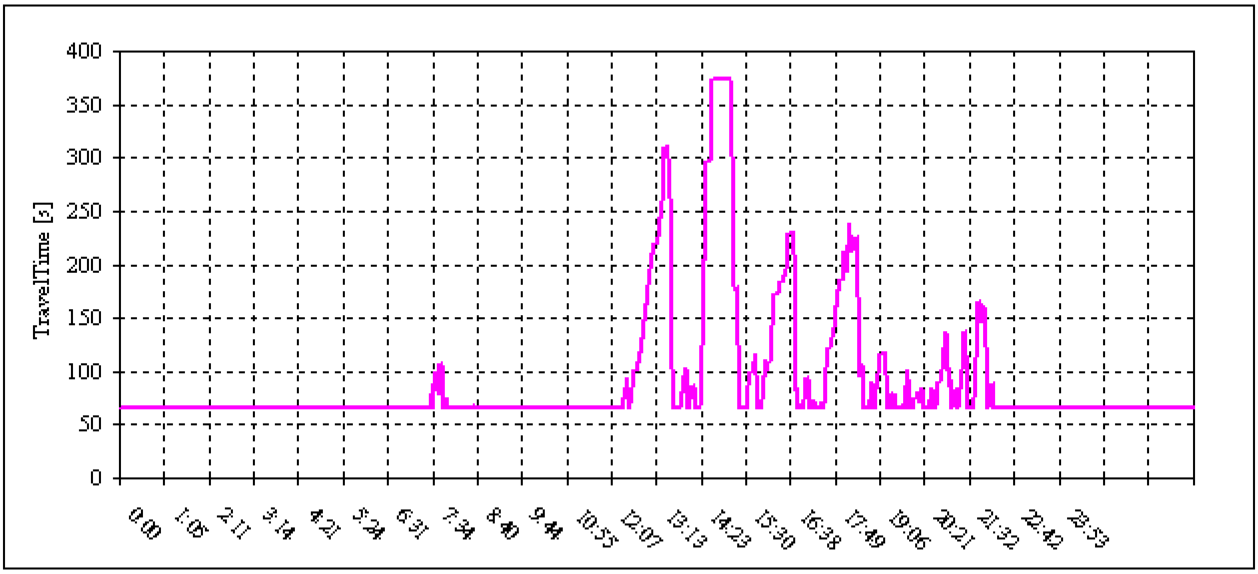

Figure IV: Simulation of the estimated travel times

Figure III must be seen in conjunction with Figure IV. In Figure III, the green line corresponds to the queue length that the algorithms produce (Concert). The blue line corresponds to the estimated queue length after the simulation (by altering the algorithms parameters), whilst the red line (LOS) corresponds to the traffic conditions of the road section (by 0, 1 and 2, the light, medium and heavy traffic conditions are indicated – value 3 indicates a measurement error). For the same time intervals and by taking into account the simulated queue lengths, the estimated travel times can be found in Figure IV. The red line corresponds in this example to the travel time estimation for urban roads with signalised intersections.

By comparing the estimated travel times with the algorithms to the estimated travel times measured by the ATMC Operators, the simulation tool is used to match the two values by calibrating the algorithms. In the calibration procedure of the algorithms, two parameters are of high importance. The first one is the identification of queue growth and queue decay. The algorithms must respond in time and accurately to the growth or decay of queues. The two important parameters for the queue estimation are the "*stab*" and "*stauf*" variables. These values correspond to the sensitivity of the algorithm in the growth and the decay of the queues. These two parameters are arbitrary and must be treated this way. This means that they do not have a theoretical background but are only indicators of the queue sensitivity. An effort has been made to categorize road sections in terms of their traffic and geometrical characteristics in order to use the same "*stab*" and "*stauf*" parameters for similar road sections.

The second important parameter is the speed at which vehicles travel through the queue. This speed cannot be directly identified from the speed/flow diagram, however this diagram can produce a rough indication by identifying the speed of the vehicles which is recorded in most cases when the traffic conditions are heavy. In the calibration process, the value of the speed is manipulated in order to match the estimated travel times measured by the ATMC Operators.

During the calibration of the algorithms, several of the other parameters of the algorithms are also manipulated, but mostly for the fine-tuning of the results.

This calibration procedure takes place for all the road sections and hence for the whole routes. An example of acceptably estimated travel times for a route is illustrated in Figure V:

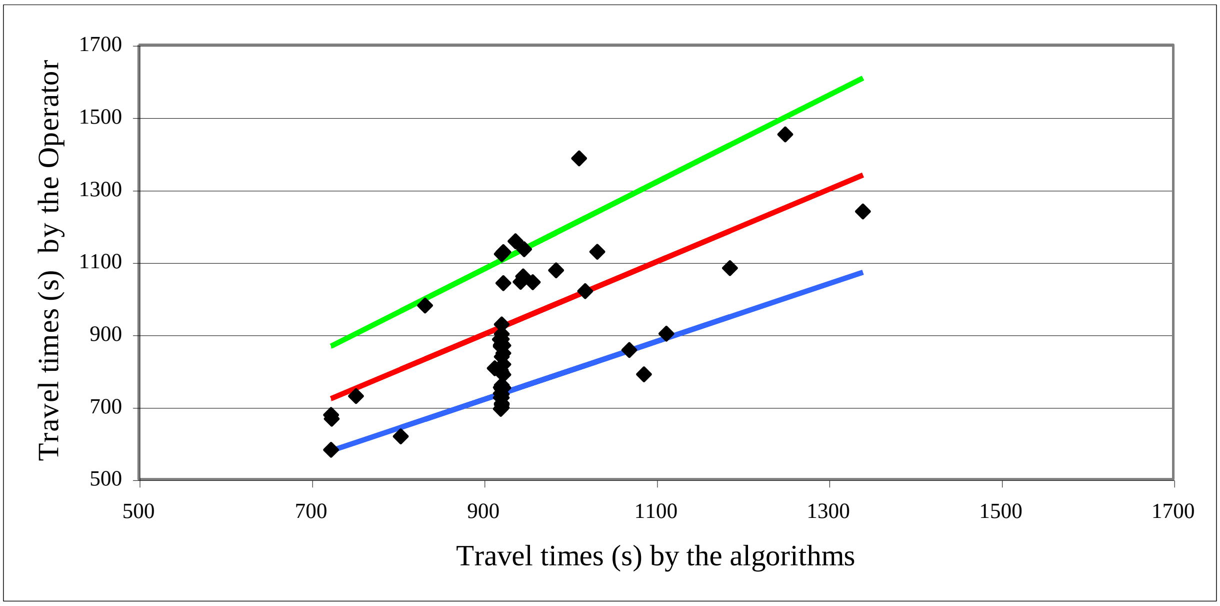

Figure V: Travel time (s) comparison between the algorithms and the Operators for the route of L. Mesogion - from Dynan Hospital to Stavros - (VMS19)

Once again, the red, green and blue lines indicate the 100% match, the 20% upper and the 20% lower limit of the estimated travel times. In this graph, most of the values are inside the desired area and hence, are acceptable.

5. Travel-time Information messages

The Travel-time Information messages are displayed automatically by the SITRAFFIC CONCERT System (which responds automatically to the current traffic conditions) and include the routes travel times and information about congestion in road sections upstream of the VMS.

For each VMS, the routes and the road sections which will be monitored and for which information will be provided are chosen. A logic chart referred to as STRAtegy MOdule (STRAMO) is designed, which assigns the appropriate Travel-time Information and/or traffic congestion messages (called programs) to the VMS.

Table I: Example of STRAMO Logic Chart for VMS

Variables															
RO171_TT	1		>0	>0	>0	>0									
RO172_TT	1		>0				>0	>0							
RO171_TT	1		<27	<27	<27	<27									
RO172_TT	1		<23				<23	<23							
VB048_VL	1						2		2	2	2				
SA481_VL	1			2					2			2	2		
ST212_VL	1				2					2		2		2	
DisableSign	1	1													
Met Conditions		1	4	3	3	2	3	2	2	2	1	2	1	1	
Program Number		Blank	1701	1702	1703	1704	1705	1706	1707	1708	1709	1710	1711	1712	Blank

The variables included in a typical STRAMO Chart are the route travel times (RO_TT) and the values for traffic conditions of road sections (Traffic Areas – VB's, Traffic Vectors – ST's or Traffic Vector Sections – SA's) associated with a VMS. STRAMO is designed to give higher priority to programs combining Travel Times in conjunction with possible congestions in road sections adjacent to the routes and lower priority to programs with combinations of traffic congestions without travel times.

The route travel times must always be greater than zero and smaller than a threshold defined specifically for each route to be considered valid by STRAMO. This threshold is the upper 95% value of all the route travel times' values. In this case, the VMS displays the travel time, in minutes, with or without information about congestion in traffic sections upstream of the VMS (see Figure VI).

The threshold is used in order not to display travel times which are rarely (5% of the cases) encountered, because they then account for unlikely heavy traffic conditions. When the travel time is above this threshold, it is considered that the route is congested and it is not advisable to show a travel time for it. Instead, the STRAMO chart checks whether one or more of the road sections examined at the specific VMS are congested (heavy traffic condition defined in STRAMO as value 2). If that is the case, a relevant program is executed, displaying to the VMS only combinations of traffic congestions.

There is only a limited amount of information that can be read and processed by a driver passing through the road section where a VMS is visible. Thus, it is preferable to display all the necessary information in a single constant frame. When this is not possible, a maximum of two consecutive frames are used, with a 3 to 4 seconds alternation period depending on the location of the VMS and the visibility of the drivers.

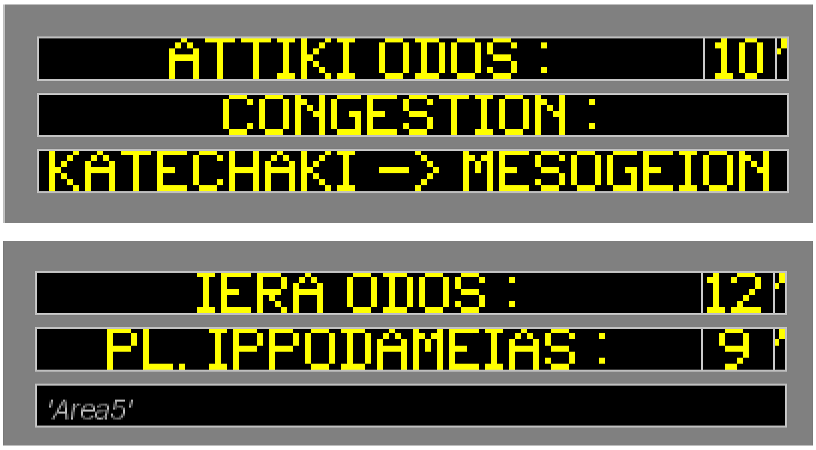

Figure VI: Two examples of Travel Time messages

6. Conclusions

The Athens Traffic Management Center became operational in July 2004 and its primary aim is the management of traffic in the heavily congested roads of the greater Athens area. For this purpose, 208 CCTV control cameras are used for the constant monitoring of traffic and 24 Variable Message Signs (VMS) for the provision of information to the road users. The 24 VMS are used for three types of messages: Immediate and Advance Warning messages, Travel-time Information messages and Public Service Announcement messages.

The way that travel times are estimated is divided into two categories: travel time estimation for urban roads with signalised intersections and travel time estimation for freeways, with their distinct difference being the existence of traffic lights.

In urban roads with signalised intersections, one set of loops is used for each road section placed upstream of the critical signal-controlled junction and the estimated travel time comprises three time components. These are: the time needed for a vehicle to travel through the uncongested part of the road sections, the time needed for a vehicle to travel through the queue and the time that a vehicle needs to wait for the traffic lights to turn to green. In freeways, two loops are used as entry and exit loops for the estimation of the queue length. The absence of traffic lights in such networks means that the time needed for the vehicles to wait for the green indication is omitted from the estimation of travel time.

The algorithms for estimating the travel times need constant calibration and fine-tuning in order to match the estimated travel times to the actual travel times as being measured by the ATMC Operators by monitoring the time needed for a vehicle to travel through the specific road section or route. The aim of the calibration is to succeed a 20% difference between the two sets of values.

The estimated travel times are used in conjunction with information about possible congestion in neighboring road sections (which are judged to be of interest) for the information of the drivers.

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