REAL TIME INTERVENTION IN TRAFFIC SIGNALS USING FIXED-TIME AND TRAFFIC RESPONSIVE SIGNAL CONTROL STRATEGIES

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ABSTRACT

The aim of this study is twofold. First, to describe the interventions in the traffic signal programs using fixed-time signal control strategies and to estimate the effect of these off- and on-line changes on traffic and on the messages being displayed on the Variable Message Signs. The second aim is to describe the traffic responsive operation that has been developed by the ATMC by using the specific characteristics of the hardware at its disposal (detectors, traffic controllers), how this has been applied to intersections that present substantial variation in the incoming traffic flows and the effect of these traffic responsive signal control strategies on traffic in terms of traffic flow, average vehicle speed and resulting traffic conditions. Finally, the implications of the travel times being displayed on VMS due to the adaption of traffic responsive signal control strategy are considered.

Keywords: signal control strategy, traffic responsive, on-line signal control changes, VMS, travel times

INTRODUCTION

The city of Athens comprises about 5.000.000 citizens (which corresponds to 50% of the total Greek population) and it is estimated that there are about 8.000.000 trips generated daily, of which 39% is being made by private cars and 33% by Public Transport Modes making the city of Athens heavily car-dependant. There are three peak-hour periods identified; the morning peak-hour period ranging from 07:00 to 09:30 involving people from both the public and the private sector going to their work, the afternoon peak-hour period ranging from 14:00 to 16:00 involving people from the public sector returning home and the evening peak-hour period ranging from 17:00 to 20:30 involving people from the private sector returning home and people going to and returning from the shops. Moreover, the estimated average travel time per trip is 45 minutes and there is a 6% to 8% annual traffic flow increase resulting in heavier congestion and also peak-hour period extension.

The Athens Traffic Management Centre (ATMC) started its operation in July 2004 and is currently at its 6^{th} year of operation. The primary objectives of the ATMC involve:

1. Traffic optimization of the most heavily loaded urban roads of the road network
2. Quick incident response
3. Real-time intervention in traffic signals
4. Collection, analysis and use of the traffic data
5. Provision of real-time traffic data to private companies for the development of telematic applications

The main apparatus of the ATMC consists of 576 measuring stations – 75% of which correspond to single inductive loops and 25% of which correspond to Video-Detection loops, 210 CCTV control cameras, 24 Variable Message Signs (VMS) and connection with 850 traffic controllers.

The 24 VMS are scattered through the road network of Athens and are placed at locations upstream of critical intersections where drivers have to choose between alternative routes. They are used for three types of messages, namely; Immediate and Advance Warning messages, Travel-Time Information messages and Public Announcement messages.

Immediate and Advance Warning messages involve messages providing information to drivers about programmed (road closures, maintenance works, etc) or unexpected incidents (broken-down vehicles, accidents, etc). Travel-Time Information messages involve messages providing information to drivers about the time needed to reach specific destinations and possible traffic congestion in neighboring road sections. Public Announcement messages involve messages which do not provide any kind of traffic information to drivers, but are “soft” messages which are used in special events such as public holidays.

For the estimation of travel times (which are displayed in case of Travel-Time Information massages), each route is split into several road sections which are identified either by the existence of critical traffic lights (in case of urban roads with signalized intersections) or by the existence of significant traffic or geometrical changes (in case of highways). Hence, in the case of urban roads with signalized intersections the identification of the critical traffic lights is of vital importance for the accuracy of the travel times’ estimation.

The estimation of travel time for each road section is made by the use of algorithms which take into account the collected traffic data of traffic flow and average vehicle speed and also several traffic and signalization characteristics (Sermpis et al, 2006). More specifically, the travel time for each road section consists of three parts, namely; the time needed for a vehicle to travel through the uncongested part of the road section, the time needed to travel through the congested part of the road section and the time needed to wait for the green indication. Hence, the most crucial factor is the estimation of the queue length, which splits the road section length into its congested part and its uncongested part.

SIGNAL CONTROL STRATEGIES

There are two main methods of signal control, namely; fixed-time signal control and traffic responsive signal control. The field of fixed-time signal control has been a field of rapid evolution since the introduction of automatic signals in 1926 and since then much work has been done on methods for setting traffic signals, the most important of which were those of Webster (1958), Allsop (1971), Tully (1976), Improta and Cantarella (1984) and Gallivan and Heydecker (1988).In fixed-time control, the signal timings are pre-calculated according to the expected flows in the examined intersections. This method applies better to intersections where the mean rate at which traffic arrives at the intersection is roughly constant throughout the examined time period and within the range that the intersection can absorb. Therefore, variations in the arrivals are considered as random effects. For this method, the analysis is based on the assumption that a single cycle is typical for all cycles and that the mean of the random effects can be estimated.

Traffic responsive signal control of signal switching depends mainly on the principle that the signal timings are not pre-calculated, but are directly influenced by the traffic flow which is being observed at the intersection. There are two kinds of traffic responsive methods:

1. Non-optimizing traffic responsive methods (Department of Transport, 1984 and Van Zuylen, 1976)

2. Optimizing traffic responsive methods (Miller, 1963 – Robertson and Bretherton, 1974 – Bang, 1976)

The basic concept behind non-optimizing traffic responsive methods is the clearing of the queues in the streams having right of way during the current stage. For the purpose of these methods, vehicle detectors are placed at specific points on the approaches of the examined intersection. These detectors estimate the time when the traffic flow falls below the saturation level (which is characteristic of queue dissipation).

For the optimizing traffic responsive methods, three factors need to be known, which are the vehicle arrivals (being considered for a specific amount of time), the vehicle departures and the current queue lengths. There are a number of states of the controller that can be taken into account. These are the signals which are green, any changes that are underway and the times of expiry of any minimum or maximum durations. One basic problem of the optimizing traffic responsive signal methods is that although vehicles can be calculated for the future by taking into account the future arrivals, it is not certain that the decisions planned will in fact be implemented. The second major problem is that although many methods have been implemented in order to reduce the number of possible states to be examined, the number of states remains high and therefore the analysis is computationally expensive.

Signal control strategies in the city of Athens

Currently, the vast majority of the traffic lights in the city of Athens operate under fixed-time signal control strategy. Usually, there are four different fixed-time signal programs carried out involving four different time periods of demand for each intersection, namely:

1. Signal program 1 (SP1) involving heavy incoming traffic flow entering the centre of the city – heavy entry traffic flow
2. Signal program 2 (SP2) involving heavy incoming traffic flow exiting the centre of the city – heavy exit traffic flow
3. Signal program 3 (SP3) involving balanced incoming traffic flow between the two directions
4. Signal program 4 (SP4) involving light incoming traffic flow towards both directions

The time periods for which each one of the four signal programs is switched on are predefined in what is called as Weekly Automaton according to off-line traffic counts. Hence, a Weekly Automaton consists of a schedule for the changing between the different signal programs for each day (weekdays, weekends, public holidays, etc). The Weekly Automaton is updated when specific traffic or geometrical changes take place. A typical Weekly Automaton for an intersection is illustrated in Figure 1:

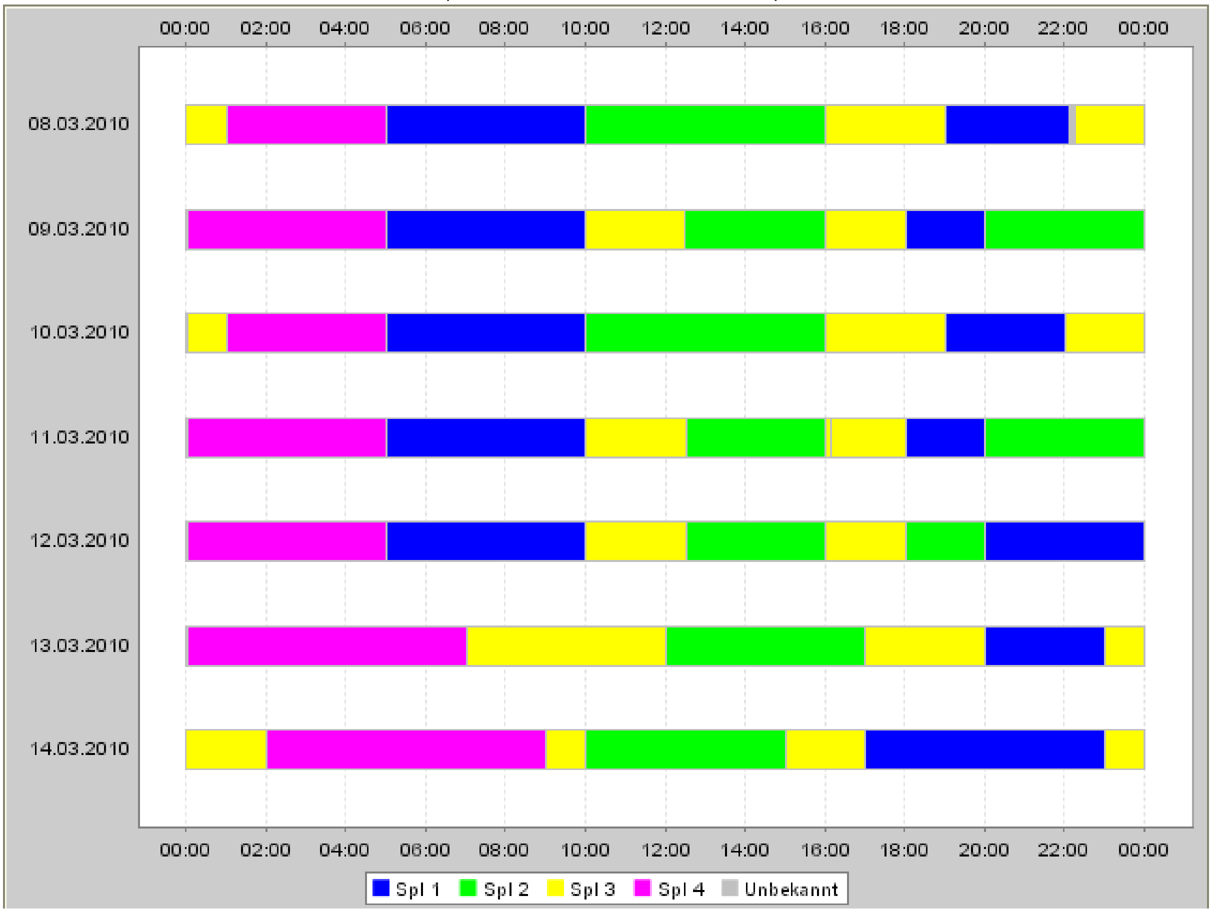

Figure 1: Typical Weekly Automaton of an intersection in the city of Athens

In several intersections, a specific non-optimizing traffic responsive signal control strategy is adopted, according to which either a specific stream (or approach) gets right of way only if a vehicle is being detected by a loop close to the stop-line or a specific stream (or approach) gets the right to extend its green indication for up to a specific amount of time (ranging usually from 5 to 10 seconds) if the queue (which is estimated as a threshold of the time occupancy value) of this stream (or approach) has not cleared during its pre-calculated green indication (which is defined in a fixed-time signal program).

INTERVENTIONS IN THE SIGNAL CONTROL PROGRAMS

The ATMC intervenes in the signal control programs of Athens in three different ways, namely:

1. Off-line interventions
2. On-line interventions
3. Implementation of optimized traffic responsive signal programs

The aim of the next chapters is to describe each one of the above methods and the impact that these interventions have on traffic.

Off-line interventions in the signal control programs

The off-line interventions in the signal programs take place in case where the signal programs of the Weekly Automaton in specific intersections or networks do not correspond to the prevailing traffic conditions on a constant basis.

The dynamic character of traffic means that the four predefined signal programs that comprise the Weekly Automaton might not correspond to the prevailing traffic conditions. This means that either the Weekly Automaton should be changed to cater for the current traffic conditions or new signal programs should be developed to correspond to the new traffic conditions of the intersections or networks.

The ATMC has updated the Weekly Automaton of 6 major arterial roads in the city of Athens by taking into account only the four predefined signal programs and by changing the time intervals for which each one of these four signal programs is switched on. At the same time, the ATMC has proceeded in the development of new signal programs for several intersections or arterial roads in cases where the already existing four signal programs did not account for the current traffic conditions.

In both cases (update of Weekly Automaton and development of new signal control programs), the ATMC firstly proceeds in the pilot implementation of these changes. This means that these changes take place for a pilot period of 2 weeks and the effect that these changes might have on traffic is monitored by two means, namely; the use of the CCTV control cameras and the analysis of the measuring stations. If the effect is considered to be positive and substantial, these changes become permanent; otherwise new changes are made and tested.

The pilot testing of the changes has proven to be significant since signal programs which are not traffic responsive do not always have a positive effect on traffic in reality for unforeseen reasons (such as coordination during congestion). So far, several pilot tests have taken place for off-line interventions in signal programs, some of which have resulted to added changes.

On-line interventions in the signal control programs

The dynamic character of traffic means that the four predefined signal programs that comprise the Weekly Automaton might not correspond to the prevailing traffic conditions. The ATMC has the capability of intervening on-line in the signal programs. This capability is very important in case of unexpected incidents that have a significant effect on traffic (such as road closure), but should be used very carefully since the vast majority of the intersections in a city centre is coordinated with neighbouring intersections and thus, an on-line intervention in one intersection might initially only have an effect on the traffic conditions upstream of the specific intersection, but after a while it might result in a deterioration of the traffic conditions of the whole network.

The ATMC has taken advantage of this capability in very few occasions and none of them – so far – involved an intersection which was coordinated with others. In cases of isolated intersections, the ATMC has intervened on-line in the signal programs by altering the green timings of the streams.

The effects of these on-line intersections on traffic conditions were monitored on-line primarily by the use of CCTV cameras and also by the analysis of the traffic counts. The CCTV cameras were preferred because the analysis of the traffic counts could not be made sufficiently fast.

Finally, it must be noted that the time between the forwarding of the command to change the signal program on-line and the actual implementation of the new altered signal program is 3 to 5 minutes and corresponds to the time needed for the communication between the central computer of the ATMC and the traffic controller of the intersection plus the time needed between the acceptance of the command by the traffic controller and the switch over point of the signal programs.

Implementation of optimized traffic responsive signal programs

In cases of isolated intersections, an optimized signal control strategy has been developed which takes into account the particularities of vehicle movement in the city of Athens as well as the technical capabilities of the traffic controller C800 of Siemens which is widely used in Athens.

The aforementioned particularities of vehicle movement in the city of Athens make it extremely difficult to use the variable of traffic flow in the optimisation algorithm. The reason is the way that vehicles use the provided pavement and more specifically the everyday on-street parking and the movement of the vehicles between the authorised lanes to allow for more vehicles to pass through the intersection (a characteristic example is the movement of the two-wheel vehicles). Hence, it has proven to be extremely tricky to use the traffic flows provided by the measuring stations for algorithms of this kind (optimisation of traffic signals).

The aforementioned technical capabilities of the traffic controller C800 imply the data that could be stored in the memory of traffic controller, the way that the data is transmitted and also the way that the optimisation procedure should by developed to be implemented in the specific traffic controller (for example in the case of the C800 traffic controller, there are 2 programs that should be used to allow for the optimisation algorithm to be implemented – one for the actual optimisation of the splits and one for the actual testing of their implementation).

The philosophy of the adopted optimisation algorithm was to minimise delays and hence, an appropriate algorithm was developed which mainly takes into account the variable of density (in the form of time occupancy) to account for the current traffic conditions. The developed algorithm took advantage of the traffic counts of two measuring stations for each critical stream. The first one (called strategic one) was placed upstream of the intersection (about 150-180m) to account for the demand of the critical stream and the second one (called front one) was placed upstream of the intersection (about 20-30m) to account for the departure rate of the vehicles leaving the critical stream. The philosophy of the applied algorithm is presented in the following steps:

1. Identification of the critical streams and identification of the measuring stations (both strategic and front one) that provide data for each critical stream

2. Preparation of a fixed-time signal control program with the minimum desired cycle period

3. Use of the measurement of the smoothed value of time occupancy given by the strategic measuring station for each critical stream

4. Estimation according to the developed algorithm of the ideal extension of the green timings of each critical stream (which ranges between pre-defined values) according to traffic policy criteria

5. Distribution of the ideal extensions of the green timings to each stage

6. Estimation of the ideal (as it emerged from the sum of the ideal extensions) cycle period

7. If the ideal cycle period is greater than the value of 160s (set as a threshold by the Hellenic Ministry of Infrastructure, Transport and Networks), reduction of the ideal extensions according to weight criteria

8. At the time of implementation of the extension, examination per second by the use of the variable of gap (being provided by the front measuring station) to check whether the given extension should be applied or not depending on the departure rate of vehicles

9. In case of high values of gap (usually greater then 4s), termination of the extension.

This philosophy was used in 6 grade separated intersections in L. Kifisou, which is a highway involving ramps for entering and exiting traffic flows. The specific intersections involved heavy congestion during the vast majority of the day time. The results of the implementation of the optimized traffic responsive signal programs were obvious even by the use of CCTV control cameras and they were testified by the examination of the prevailing traffic conditions as estimated by the ATMC.

The ATMC specifies three levels of traffic conditions, namely; light, medium and heavy. Light traffic conditions are defined as the traffic conditions when the last vehicle in the queue when the traffic lights of the stream under consideration turn to green clears the queue during the next cycle period. Medium traffic conditions are defined as the traffic conditions when the last vehicle in the queue when the traffic lights of the stream under consideration turn to green clears the queue during the second cycle period. Finally, heavy traffic conditions are defined as the traffic conditions when the last vehicle in the queue when the traffic lights of the stream under consideration turn to green needs more than two cycle periods to clear the queue. Hence, diagrams are produced which indicate the evolution of the traffic conditions during the day (in time intervals of 15 to 60 minutes). It must be pointed out that such diagrams could be produced – on an average basis - for a time period longer than a single day (for example for all weekdays of a month). In that case, for the desired time intervals (15 to 60 minutes) the traffic conditions for the whole period are gathered and then the corresponding percentages of light, medium a and heavy traffic conditions are calculated for the specific time interval.

For the illustration of the effect of the aforementioned optimized signal programs on traffic, these diagrams were used in order to compare the traffic conditions before and after the implementation of the optimized signal control strategy. In the next four diagrams (two diagrams per approach), two different approaches were chosen (of the same intersection) and the appropriate diagrams were produced to illustrate the traffic conditions before and after the implementation of the optimized traffic responsive signal control strategy.

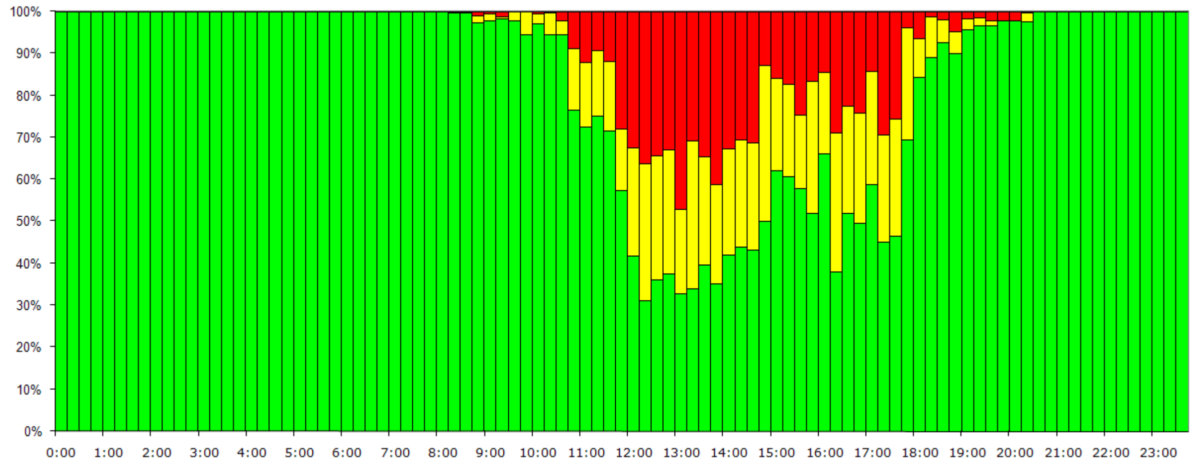

Figure 2 – Traffic conditions of approach 1 (before the implementation of the optimised traffic responsive signal control)

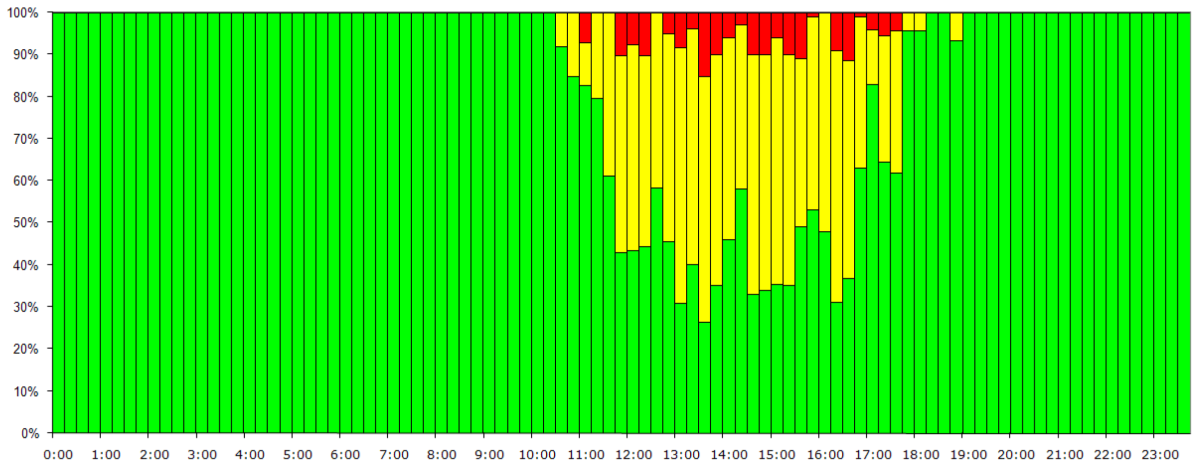

Figure 3 – Traffic conditions of approach 1 (after the implementation of the optimised traffic responsive signal control)

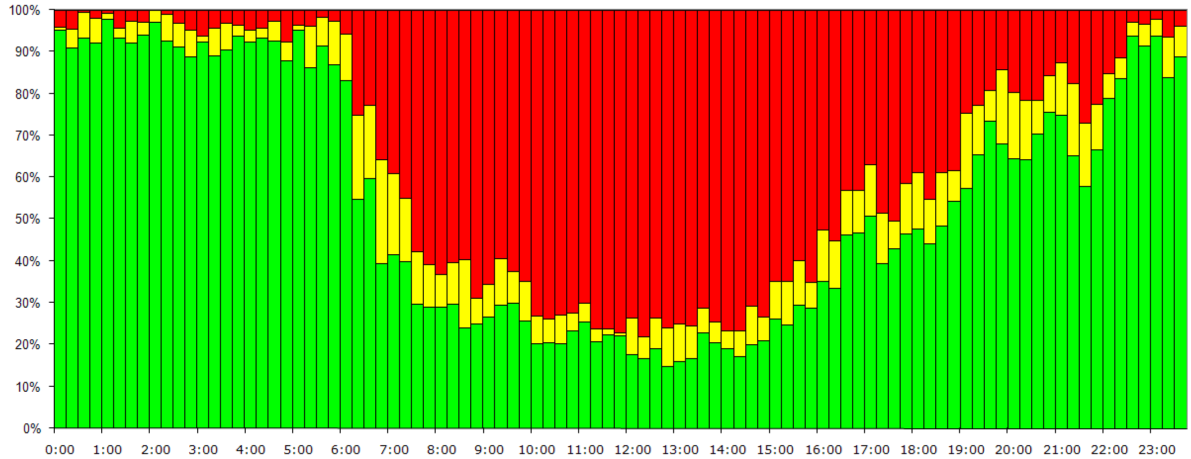

Figure 4 – Traffic conditions of approach 2 (before the implementation of the optimised traffic responsive signal control)

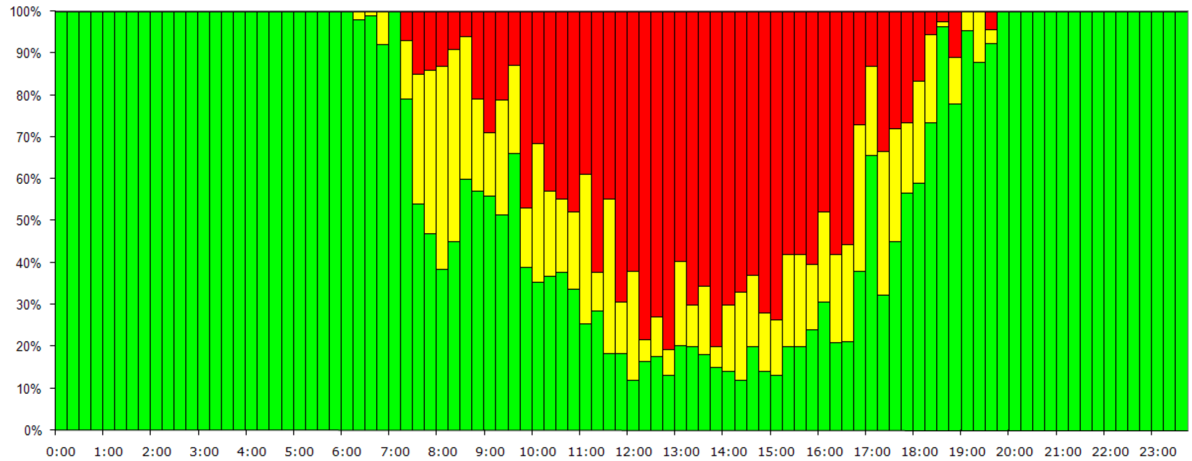

Figure 5 – Traffic conditions of approach 2 (after the implementation of the optimised traffic responsive signal control)

The comparison between the four diagrams shows that in both cases the traffic conditions of the two approaches improved significantly. The heavy traffic conditions time intervals decreased and moreover, the analysis of the traffic data indicated an increase in traffic flow (ranging from 10% to 15%) and an increase in average vehicle speed (ranging from 15% to 20%).

It is important to clarify the reason for the differences between the two diagrams – in the case after the implementation of the optimised traffic responsive signal control method – for the two approaches (Figures 3 and 5). The reason for these differences (in the approach of Figure 5 the heavy traffic conditions time intervals are substantially more then the corresponding ones of Figure 3) involves traffic policy criteria. In this specific intersection heavy congestion on approach 1 results in queues which spill back and have an effect not only on the exit ramp of the highway but also on the main direction of movement on the highway. At the same time heavy congestion on approach 1 does not have an effect on the main direction of movement on the highway, but only on a secondary road and thus, the traffic policy criteria favoured approach 1.

DISCUSSION

As described in the Introduction, VMS are mainly used for providing information to the drivers about the time needed to reach specific destinations. An important parameter for the estimation of travel times according to appropriate algorithms is the input of the green timings for the streams that travel through the road sections comprising the routes.

In the case of off-line interventions in the signal programs using fixed-time signal control strategy, the altered green timings of the specific streams are used as input variables in the algorithms and the estimation of travel times is checked by the use of CCTV control cameras.

In the case of on-line interventions in the signal programs using fixed-time signal control strategy, the altered green timings are initially not used as input variables in the algorithms (since the on-line intervention requires immediate response and the new calibration of algorithms is more time consuming), but if the monitoring of travel times (by the use of CCTV control cameras) indicates that there is a substantial difference between the estimated travel times and the actual ones, then new calibration of the algorithms takes place to cater for the new green timings.

The biggest problem exists in the case of implementation of optimised traffic responsive signal programs. The main characteristic of the traffic responsive signal programs is the change of green timings according to the prevailing traffic conditions. Hence, there are no fixed green timings for the streams comprising the routes. This means that there is a strong influence on the estimated travel times. This influence is not only because of the inaccurate input variables in the algorithms, but also due to the location of the loops.

The ATMC places the loops upstream of the intersection at such a position as to indicate the change from medium to heavy traffic conditions according to the definition of the traffic conditions which was stated in previous paragraph. Hence, the exact location of the upstream loops depends on the number of cycle periods needed for the last vehicle (when traffic lights turn to green) in the queue to clear the intersection (which depends on the green timings of the stream and also on the cycle period). Therefore, a substantial change in the green timings – which might be the case from one cycle period to another in the optimised traffic responsive signal programs – has a significant effect on the way of estimating the travel times.

This has proven to be a significant problem for the estimation of travel times by the ATMC. The implementation of optimised traffic responsive signal control programs resulted in inaccuracies in the estimated travel times for the road section comprising the routes. This problem could not be avoided through the use of the algorithms, since it is not possible to change the input variables on-line.

Hence, the ATMC has decided to adopt the following philosophy: When the upstream loops indicate heavy traffic conditions, instead of a Travel-Time Information message being displayed on the VMS, a message indicating traffic congestion on the specific road section is being displayed. This is done because the heavy traffic conditions on the road section result in the traffic responsive signal program providing different green timings to the approach under consideration and hence, no accurate travel times estimations can be made. In the case of medium and light traffic conditions, the estimation of travel times is made by the use of a fixed value of the green timings and of the cycle period and appropriate information is provided to the drivers by the VMS.

The monitoring of this philosophy has proven to be efficient since it does not lead to frequent travel times estimation inaccuracies and furthermore, in case of heavy traffic conditions it provides an indication to the drivers about what to expect on specific road sections.

REFERENCES

Allsop, R. E. (1971). Delay-minimising settings for fixed-time traffic signals at a single road junction. Journal of Mathematics and its Applications, 8(2), 164-185.

Bang, K. L. (1976). Optimal control of isolated traffic signals. Traffic Engineering and Control, 17(7), 288-292.

Department of Transport, (1984). MCE0141: Microprocessor based traffic signal controller for isolated linked and urban traffic control installations. London: Department of Transport.

Gallivan, S. and Heydecker, B. G. (1988). Optimising the control performance of traffic signals as a single junction. Transportation Research, 22B(5), 3570-370.

Improta, G. and Cantarella, G. E. (1984). Control system design for an individual signalised junction. Transportation Research, 18B(2), 147-167.

Miller, A. J. (1963). A computer control system for traffic networks. Proceedings of the Second International Symposium on Transportation and Traffic Theory (ed. J. Almond), Paris: OECD, 200-220.

Robertson, D. I. and Bretherton, R. D. (1974). Optimum control of an intersection for any known sequence of vehicle arrivals. Proceedings of the 2nd IFAC/IFIP/IFORS Symposium on Traffic Control and Transportation Systems.

Sermpis, D., Babis, C. and Theofilis, I. (2006). Travel time information via VMS in Athens. Proceedings of the 1st International Symposium on Freeway and Tollway Operations, Athens, Greece.

Tully, I. M. S. N. Z. (1976). Synthesis of sequences for traffic signal controllers using techniques of the theory of graphs. OUEL Report, University of Oxford, 1189/77.

Van Zuylen, H. (1976). Acyclic traffic controllers. Note from the Transport Studies Group, University College London (unpublished).

Webster, F. V. (1958). Traffic signal settings. Road Research Technical Paper, London: HMSO, 39.