

Implementation of an optimizing traffic responsive signal control strategy at grade separated intersections of Kifisou highway

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Abstract

The use of an effective traffic management strategy is essential to accomplish the operation of the highways below, near or at capacity level. Long queues in the off-ramps of the Kifisou highway in Athens tend to have an effect on the mainline highway. An optimized traffic responsive signal control strategy has been developed. The strategy that aimed at improving the traffic conditions was deployed in 6 grade separated intersections concerning the off-ramps of the highway to regulate the rate of vehicles exiting the highway. The evaluation of the effect of the signal control strategy on traffic conditions indicated that there was a substantial improvement in both the off-ramps and the secondary roads traffic conditions.

Introduction

Drivers on highways, especially those in the close vicinity of urban networks, are often experiencing increased levels of congestion, resulting in extensive delays, reduced productivity, wasted energy and drivers' frustration. Hence, improved congestion management on highways is essential. Highway management can be achieved by the implementation of several strategies, one of which is ramp control (Parsons, 1993). Ramp control mainly involves ramp closure, ramp metering and interchange connector metering (in case of highway-to-highway connectors).

Ramp metering is used to regulate the traffic flow entering the highways mainline according to the prevailing traffic conditions. It was first implemented in 1963 on the Eisenhower Expressway (Interstate 290) in Chicago and since then has been deployed in mainly urban areas including several cities in the USA, the UK, Germany and the Netherlands. The concept behind ramp metering is to "store" the entering flow in the on-ramps if necessary for the mainline to operate close to the highways' capacity. Another outcome of ramp metering is the break-up of entering platoons to achieve smoother merging in the mainline. Ramp metering uses traffic signals and relies on the traffic data collected from detectors placed on the on-ramp and on the mainline highway.

At the same time, not much attention has been given at traffic conditions of off-ramps, where the exiting vehicles leaving the mainline highway to follow other routes might experience heavy traffic conditions and increased delays if these off-ramps are regulated by traffic signals in their intersection with secondary roads. This might result in long queues in the off-ramps and this can have an effect also on the mainline highway. This phenomenon is evident at the Kifisou highway in Athens where the majority of the off-ramps lead to intersections with other major arterial roads. To avoid the formation of such queues in the off-ramps and hence, to regulate the exiting flow from the mainline highway, an optimizing traffic responsive signal control strategy has been developed and deployed in 6 grade separated intersections involving off-ramps of Kifisou highway.

Traffic Responsive Signal Control Strategies

There are two main methods of signal control, namely; fixed-time signal control and traffic responsive signal control. In fixed-time control, the signal timings are pre-calculated according to the expected flows in the examined approaches. This method applies better to intersections where the mean rate at which the 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. Since the introduction of automatic signals, in 1926, much work has been done on methods for setting traffic signals, the most important of which are Webster (1958), Allsop (1971), Tully (1976), Improta and Cantarella (1984) and Heydecker and Dudgeon (1987).

In traffic responsive signal control, 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
2. Optimizing traffic responsive methods

The basic concept behind the non-optimizing traffic responsive methods is the clearing of the queues in the stream having right of way during the current stage. For the purpose of these methods, vehicle detectors are placed at specific points on the approaches to the examined intersections. These detectors estimate the time when the traffic flow falls below the saturation level (which is characteristic of queue dissipation). One implementation of this method is known as System D (Department of Transport, 1984). In practice this method seeks for gaps, which will indicate that few vehicles are arriving in the examined stream. In that case, the traffic streams having right of way will no longer be shown a green signal if there are vehicles waiting in conflicting streams. Van Zuylen (1976) described a signal controller designed to follow a gap-seeking method (as described previously), but in a group-based analysis. The most important feature in this case is that the sequence of the stages does not need to be specified.

In the optimizing traffic responsive methods, three factors usually need to be known. These 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; namely, the signals which are green, any changes that are underway and the times of expiry of any minimum or maximum durations. Miller (1963) investigated a two-stream intersection with discrete time control. The end of the next green was defined as the planning horizon. The arrivals of the vehicles were given from the detectors for the near future and from exponentially weighted moving average flow rates for the rest of the planning horizon. Robertson and Bretherton (1974) used a dynamic programming procedure to determine the optimum control of traffic signals. Heydecker and Boardman (1999) by extracting relevant information from analysis of video images, developed backward dynamic programming formulations using each of 5s and 0.5s resolutions for decisions. One basic problem of these 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 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 the states remains high and therefore the analysis is computationally expensive.

A number of signal control procedures (with different capabilities and limitations) have been developed over the years which involve traffic responsive signal control strategies. SCOOT (Hunt, Robertson, Bretherton and Winton, 1981) is used for co-ordinated traffic responsive control and it employs a traffic model which predicts the delay and stops caused by particular signal settings. SCATS (Lowrie, 1991) operates in real-time, adjusting signal timings throughout the system in response to variations in traffic demand and system capacity and it

controls traffic on an area basis (co-ordinated control). The principal purpose of the program is to minimize overall stops and delay, and when traffic demand is at or near the capacity of the system, to maximize that capacity and minimize the possibility of traffic jams by controlling the formation of queues. Both SCOOT and SCATS rely on incremental changes of splits, offsets and cycles. Other traffic responsive signal control strategies, such as UTOPIA (Mauro and Di Taranto, 1989), OPAC (Gartner, 1983) and PRODYN (Farges et al, 1983) regard the optimisation procedure as an optimisation problem and therefore, they involve especially designed algorithms to solve it. Hence, these strategies face a considerable limitation when applied to whole network.

Implementation areas

Kifisou highway plays an important role in the Athens road network. Kifisou highway is 20km long with a minimum of 3 lanes per direction and includes several grade separated intersections to allow for entering and exiting traffic flow through on- and off- ramps. During the peak-hour periods, Kifisou highway is unable to serve the traffic demand and this leads to increased queues and severe delays. In some cases the off-ramps lead to intersections with other major arterial roads (which also play an important role in the whole network of the city) which are controlled by traffic signals using fixed-time signal control strategy.

The use of precalculated signal timings resulted - during some peak-hour periods - in the formation of long queues in specific intersection approaches. While these long queues in the approaches of the major arterial roads could have an effect on the neighboring areas the long queues in the off-ramps also had an effect on the traffic conditions of the mainline highway. To avoid the formation of such long queues in the off-ramps (which had an average length of 200m), an optimized traffic responsive signal control strategy was developed and deployed. It should be noted that each intersection has its own particularities – both traffic- and geometry-wise – which have been taken into account.

The 6 isolated grade separated intersections in Kifisou highway (Figure 1), in which this philosophy was implemented are:

1. Kifisou – P. Ralli
2. Kifisou – Iera Odos
3. Kifisou – L. Athinon (west intersection)
4. Kifisou – L. Athinon (east intersection)
5. Kifisou – Lenorman
6. Kifisou - Dyrachiou

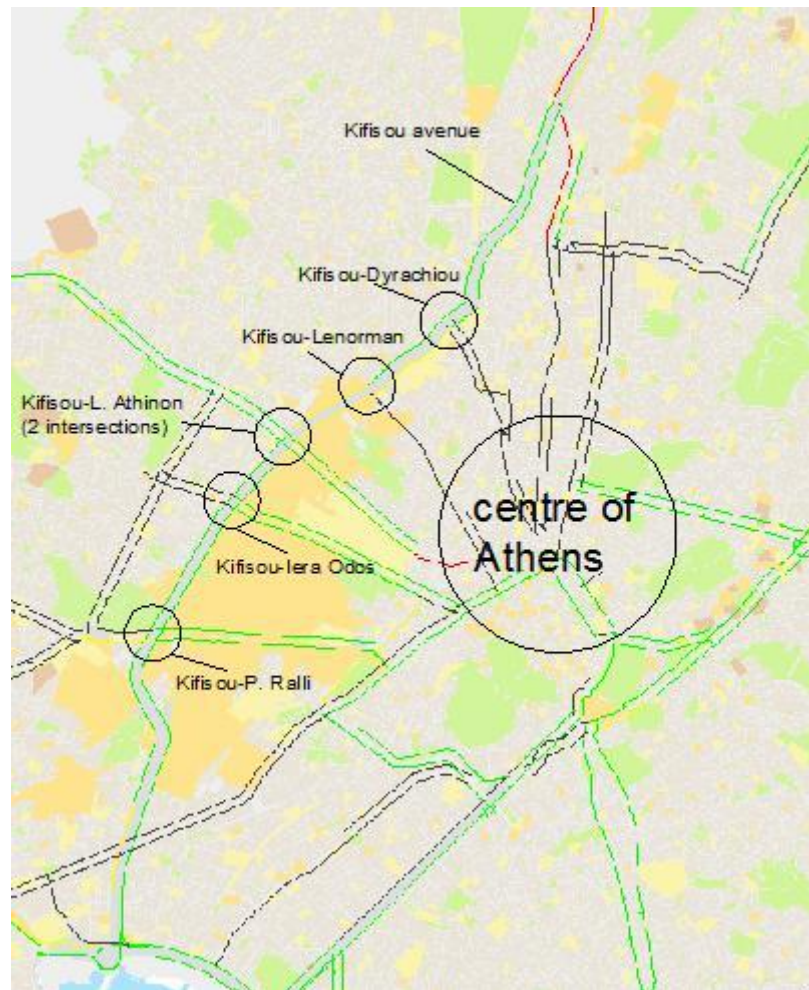


Figure 1: Illustration of the 6 isolated grade separated intersections in Kifisou highway

Philosophy of the optimized traffic responsive signal control strategy

The applied optimized signal control strategy took 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. Considering these particularities proved to be the most important feature of any applied optimized traffic responsive signal control strategy, since there seems to be a significant gap between theory and deployment when it comes to the application of any traffic responsive signal control strategy.

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 marked traffic 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 (detectors) for algorithms of this type (optimization of traffic signals).

The aforementioned technical capabilities of the traffic controller C800 involve 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 be 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 as the main variable of density (in the form of time occupancy) to account for the prevailing 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 (referred as 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 the 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. 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
4. Distribution of the ideal extensions of the green timings to each stage
5. Estimation of the ideal (as it emerged from the sum of the ideal extensions) cycle period
6. 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
7. 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
8. In case of high values of gap (usually greater than 4s), termination of the extension.

Furthermore, it should be noted that the applied strategy has been used with different pre-defined values and sensitivity parameters to account for the special characteristics of each one of the 6 grade separated intersections.

Before applying the designed optimized traffic responsive signal control strategy in the intersections, the microsimulation program VISSIM (PTV, 2008) was used to estimate the effect of the strategy on traffic. VISSIM is a microscopic, time step and behavior simulation model developed to model urban traffic and public transit operations. The program can analyze traffic and transit operations under different constraints such as lane configuration, traffic composition, traffic signals, transit stops, etc. Hence, it can be used as a useful tool for the evaluation of various alternative scenarios including different signal control strategies. It must be noted that VISSIM uses the psycho-physical driver behavior model developed by Wiedemann (Wiedemann, 1974).

VISSIM can use various types of signal control logic. The program can use add-ons that can be simulated through an external signal state generator. This signal state generator polls detector information from the traffic simulator on a discrete time step basis (down to 1/10 of a second) and it then determines the signal status for the following time step according to the applied signal control strategy and returns this information to the traffic simulator. A characteristic example of the simulation with VISSIM is illustrated in Figure 2.

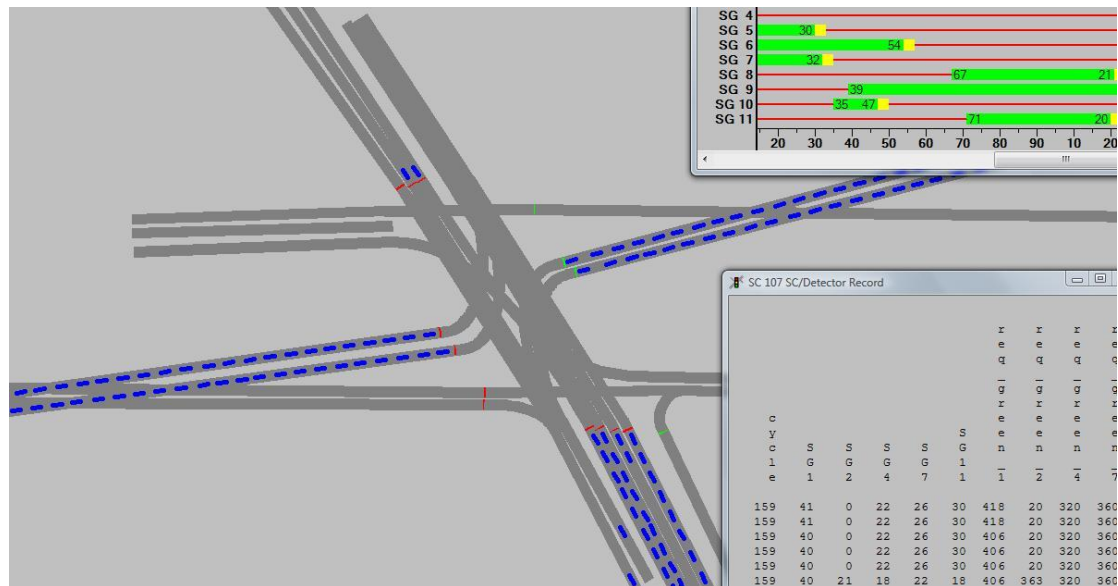


Figure 2: Evaluation of the optimized signal control strategy by the use of VISSIM

After evaluating the effect of the optimized traffic responsive signal control strategy on traffic through a number of measures of operational performance (delays, queues, number of stops, etc) in VISSIM (and when needed, recalibrating the strategy), the finalized version of the signal control strategy was applied in the intersection. Initially, an on-field evaluation was made to ensure the correct application and the smooth functioning of the strategy. The final evaluation was made by monitoring the traffic data and by the use of the CCTV cameras of the Athens Traffic Management Centre in the intersection.

Results

The impact of the applied traffic responsive signal control strategy on the 6 isolated grade separated intersections was analyzed by two means. The first one involved the raw traffic data collected from the "strategic" loops (traffic flow, average vehicle speed and time occupancy) and the second one involved the processed traffic data from the same loops (traffic conditions). More specifically, the Athens Traffic Management Centre 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, graphs were produced which indicate the evolution of the traffic conditions during the day (in time intervals of 15 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 the traffic conditions for the whole period are aggregated and then the corresponding percentages of light, medium and heavy traffic conditions are calculated for the specific time interval.

As far as the raw traffic data were concerned, the analysis indicated a significant increase in traffic flow and average vehicle speed and also a decrease in time occupancy. The increase in traffic flow varied across the streams and the intersections and ranged between 10% and 15%. Furthermore, the increase in average vehicle speed varied across the streams and the intersections within a range of 15% to 20%. Finally, these changes had an obvious effect on

the average travel time of a vehicle traveling through the intersections (the decrease ranged from 15% to 20%) and also on the prevailing traffic conditions, which were estimated by the Athens Traffic Management Centre. As far as the resulted traffic conditions are concerned, a before and after analysis was made to analyze the effect that the strategy had on traffic. Characteristic examples of such diagrams (for 2 different approaches) are illustrated in the next four figures.

Figure 3: MS 962 - before the implementation of the optimised traffic responsive signal control strategy

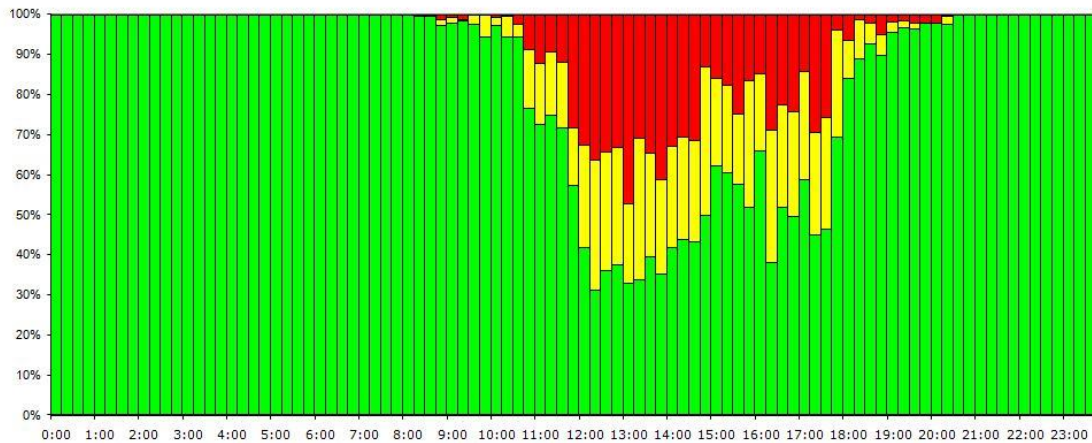


Figure 4: MS 962 - after the implementation of the optimised traffic responsive signal control strategy

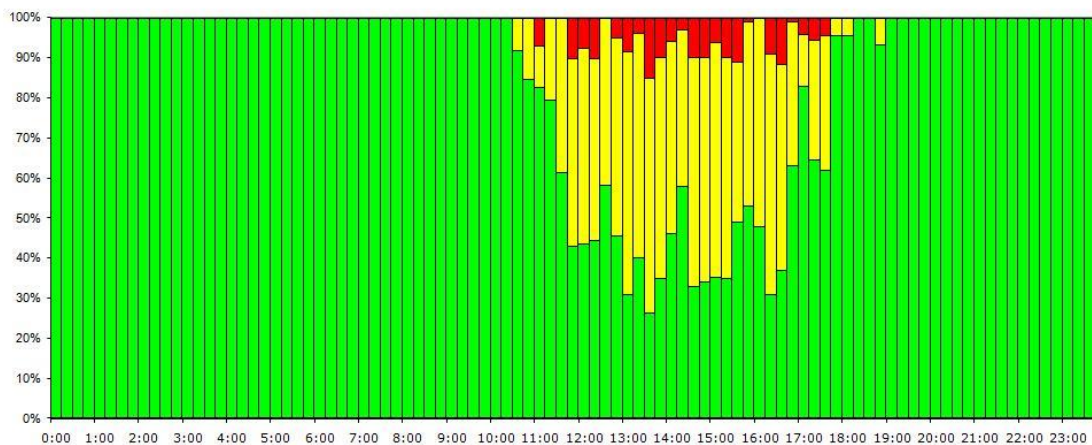


Figure 5: MS 963 - before the implementation of the optimised traffic responsive signal control strategy

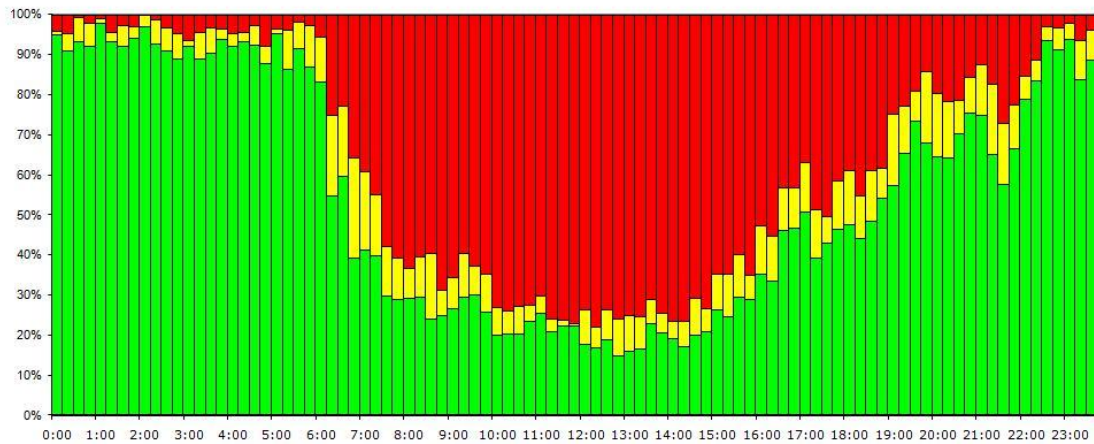
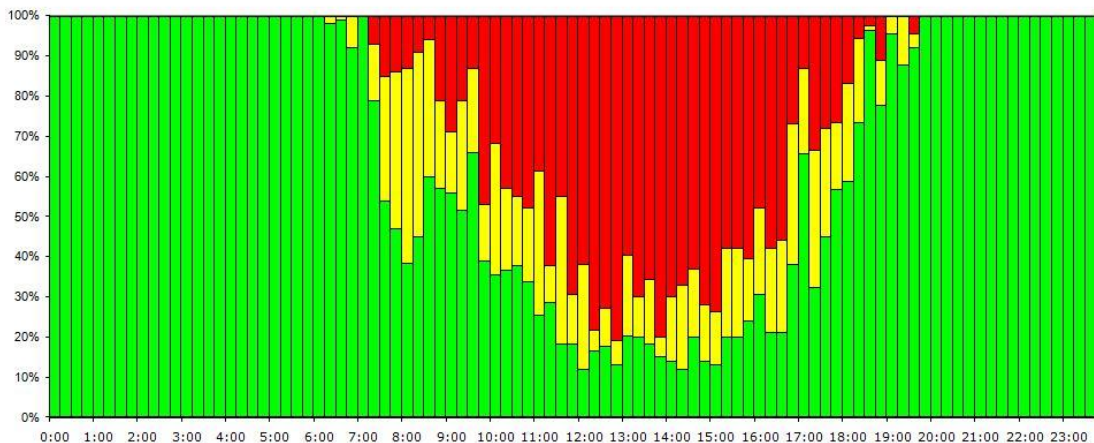


Figure 6: MS 963 - after the implementation of the optimised traffic responsive signal control strategy



The positive effect of the applied optimized traffic responsive signal control strategy on traffic was also evident in the main stream of the Kifisou highway, which was no longer affected by the queues in the off-ramps (as it was the case before the implementation of the strategy). Hence, the main stream of the highway was able to function at a level determined by other traffic and geometric variables and not by the traffic conditions of the off-ramps.

Discussion

The mainline Kifisou highway suffers substantially from the queues spillback at the off-ramps due to the regulation of traffic by the use of traffic signals in the intersections of the off-ramps with other major arterial roads. To avoid the formation of long queues in the off-ramps and simultaneously to optimize the rate of vehicles departing at the approaches of these intersections, an optimized traffic responsive signal control strategy was developed and deployed. A basic feature of the developed signal control strategy was that it uses an optimisation algorithm to split the cycle period in the signal groups serving the corresponding approaches (and streams) but at the same time it uses the traffic data collected from the front detectors to confirm every update interval (which is equal to 1 second) the necessity of the given extension. This corresponds to an optimizing traffic responsive signal control strategy which also takes into account the criterion of gap of the non-optimizing traffic responsive signal control.

The goal of this signal control strategy may vary depending on the particularities of the intersection. The different goals might be to favor the off-ramps (to avoid long queues in the off-ramps which might influence the vehicle movement in the mainline highway), to favor the secondary major arterial roads (to avoid long queues in these roads which might have an effect on the neighboring areas) or to have a balance between the different approaches. Hence, the results (in terms of collected or processed data) must be considered in conjunction with the initial goal.

In all 6 grade separated intersections in which this signal control strategy was deployed, the traffic conditions in the approaches were optimized and the initial goal was achieved. In some cases this was also achieved after the first implementation of the strategy after which the strategy was recalibrated to better achieve the initial goal (after taking into account the resulting traffic conditions). Hence, there was a positive effect not only in the mainline highway but also in the intersection approaches.

It should also be noted that the particularities of Kifisou highway as far as its geometrical characteristics are concerned make the implementation of ramp metering substantially difficult. The variability of several geometrical characteristics such as number of lanes and width of the lanes of the mainline highway and at the same time the variability of the geometrical characteristics of the on-ramps make it extremely tricky to adopt a common control strategy and regulate the rate of the entering vehicles to the mainline highway.

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