TECHNOLOGICAL INNOVATION IN TRAFFIC CONTROL SYSTEMS

Simon COHEN

Institut National de Recherche sur les Transports et leur Sécurité
2, Avenue du Général Malleret-Joinville
94110 - Arcueil, France

In order to cope with car traffic jams in cities, local authorities have two complementary fields of manoeuvre. The first one consists in promoting different travel behaviour, by means of incitement actions taken with users. The second one concerns a better command of traffic supply, by means of trafic control actions. Today, many metropoles in the industrialized world or in the third world are equipped with area traffic control systems. At the time when average-sized cities and small towns, a long time saved from traffic congestion, take an increasing interest in traffic control as a tool for mastering congestion, some thinking on the real efficiency of the control systems proves to be indispensable. Such an analysis allows us, not only to draw up a balance sheet of the existing equipment, to highlight and guide our choices, but also to stress the possible contributions of some technological innovations in the field of traffic control systems.

This paper goes in this perspective. Some changes made in the main control systems are described here, especially in the "fixed-time real time" evolution. A critical statement of the existing systems suggests some possible research paths. The foreseen improvements, concern measuring techniques as well as methods of surveillance and prevention of traffic congestion. Two concrete cases of innovation are presented, in order to illustrate the way of mastering traffic congestion in cities. The first example concerns the contribution of image processing methods to the operation of an isolated junction. The second example chosen is the one of expert systems for monitoring a controlled urban network.

Without recalling all the ongoing developments, the partial examples given announce the emergence of a future generation of urban traffic control systems.

1. TRAFFIC CONTROL : THE PRESENT TRENDS

Urban traffic control by means of traffic signals consists in determining the changing states of these signals, in order to offer the best possible traffic conditions as a function of the changing traffic data.

Traffic control has multiple ambitions : improvement of safety by solving conflicts between flows of vehicles and pedestrians, improving traffic flow by reducing travel time, greater energy efficiency by reducing stops and travel time, less emissions, improvement of public surface transport vehicles by means of a higher trip reliability.

The historical evolution of traffic control techniques allows us to distinguish two main categories :

- "fixed-time" control consisting in calculating settings on the basis of data collected before installation, any updating having to be made by a human intervention,
- "real-time" control requiring to have available permanently measurements of traffic flow, on the basis of which an algorithm calculates automatically settings applied to the field.

The management of the traffic signals takes places at 3 different levels : at the local level for an isolated junction, at the intermediate level for an axis or an itinerary, at the global level for a whole network.

1.1. The isolated traffic signal

Traffic signal settings at an isolated junction require the determination of various parameters : duration of the cycle, duration of the different movements.

In fixed-time control, the operation of the signal is cyclic : the gren-amber-red light sequency is repeated with a constant duration. The Webster method (1), in spite of its limits, gives a practical way of calculating signal settings.

Adaptive traffic control at an isolated signal modulates green times of each phase according to the state of traffic. Several algorithms can be used : "vehicular intervals", volume-density, Miller's method (2).....

Recent research works, undertaken in France by CERT and INRETS have allowed the elaboration of the PRODYN algorithm (3). Being tested at present in full-size, this method manages only short sequencies (5 seconds) on a given horizon of switching the signals from one state to another, disregarding the cycle concept.

1.2. The axis or itinerary

A widespread method consists in achieving a fixed time "geometric green wave". This co-ordination technique lies in setting off passing onto green of the different signals so that the vehicle flow starting at the first junction meets green-time signals all along the axis. The co-ordination speed, speed at which vehicles are supposed to run in order to profit from the green wave, can be modulated according to traffic volumes.

When the itinerary is a one-way road, graphic elaboration of the green wave is easy to achieve. For a two-way traffic axis, the graphic approach in a time-space diagram is no longer appropriate. Specific calculation programmes can be used. On this last point, it is interesting to underline the development of numerous softwares on micro-computers like TALON (4), for instance.

1.3. The network

Traffic signal plans - cycles, green times and offsets - form the basis of the control system. The drawing up to these settings are based on the operation of traffic data and on an optimization procedure. In general, the optimizing criteria are connected with delays and the numbers of stops of the vehicles running in the network.

The TRANSYT (5) programme, developped several years ago in TRRL, forms a tool for calculating traffic signal plans, successfully tested in numerous cities.

In order to choose between the different plans, several techniques can be used like, for instance, simple manual switching or still time-table programming.

The "vector method" forms a relatively widespread practice of choosing signal plans. To each typical traffic situation corresponding to a signal plan, "a model vector" is associated. Data on flow and occupancy furnished permanently by sensors determine periodically a "measuring vector". The displayed signal plan is the one achieving the smallest deviation between the model vector and the measuring vector.

In practice, fixed time plans must be updated to remain eficient. To this effect, the ongoing research works relative to the development and testing of the CALIFE (6) programme should allow the emergence of an intermediate practice between fixed time and real-time modes. CALIFE calculates periodically new traffic settings (up to 20 per hour), adapted to the present or foreseen traffic conditions, thanks to the use of a certain number of sensors.

Real-time urban traffic control systems date from the beginning of the eighties. After many unfruitful tentatives in the United States, Canada and Great Britain in the seventies, two systems seem today to be relatively efficient : SCOOT (7) developed in Great Britain and SCATS (8) in Australia. In these systems, signal settings parameters are modulated on-line to correspond to the fluctuations detected in demand.

2. REAL EFFICIENCY OF TRAFFIC CONTROL ACTIONS

Various assessments of traffic control systems have been achieved in several cities.

In the whole of a grid network, the implementation of optimized traffic signal plans allows a reduction in travel time - compared with non-co-ordinated operation - by up to 25 %, particularly during off-peak hours (9). Savings in fuel consumption, observed or measured in some networks, are between about 3 and 20 %. In order to remain efficient, fixed time traffic control settings must be regularly updated according to the evolution of the traffic volumes in the network (10). The recent on-line traffic control techniques, like for instance the SCOOT system, implemented in numerous cities in Great Britain (London, Glasgow, Coventry, Southampton, Worcester,...) seem to give slightly more important savings than in the cases of fixed time control networks (11). Improvements observed in travel time very between 5 and 8 % compared to pretimed techniques. During some peak hours or in city-centre networks highly constrained, however, differences between "fixed time" and "real-time" policies are no longer significant. This conclusion is corroborated for instance by the experiments with the SCATS system in Sydney (8), by a campaign of comparative measurements made in Aix-en-Provence (12) or still by the first tests of the PRODYN algorithm at an isolated signal in Toulouse (3).

These results underline clearly that in high congestion periods, classical control algorithms are no longer valid. (For a seaparate junction, the application of Webster's formula for calculating signal setting parameters would lead to an infinite cycle time, for instance).

This statement speaks in favour of a solution of congestion problems using new approaches. Among these, we can mention the possibilities offered by techniques like image processing and artificial intelligence.

3. IMAGE PROCESSING AT AN ISOLATED JUNCTION

The measuring of parameters useful for traffic control is based mainly on electromagnetic loops. These give a presence signal of a vehicle. Thus, by associating several loops, we have access to data on traffic counts, traffic volumes, speeds,... This information is used in controlling processes like control at traffic signals in junctions. There is a manifest interaction between the technical possibilities of the parameters observed and the use of these parameters. In other words, traffic control algorithms described above are based on available information.

Present research works are directed towards the development of new sensors. Among these, it is important to mention the video sensors whose main principle consists in processing automatically the camera images in order to deduce from them traffic parameters. In the field of traffic control, the main advantage of this promising technique is to give the operator direct access to space traffic variables, until now difficult to estimate : concentration, directional movements, queue lengths.

3.1. Vehicle detection at the junction

The traditionally used techniques for segmenting an image are divided into 3 classes :

- thresholding, corresponding to a segmentation into 2 classes,
- contour detection,
- region extraction.

The application of these techniques to video images of urban traffic show that none of them can be applied directly. The levels of grey corresponding to the image of a vehicle do not present, on a coarse image, sufficiently homogeneous characteristics enough different from the road for giving to a procedure of automatic thresholding a good separation between road and vehicle. In a similar way, the variation of grey on contours are often too little marked for just leading to this second class. Finally, for the same reasons, the 3rd class, expensive in calculation times, cannot be chosen.

The road-vehicle segmentation (13) is made by combining several of these methods and above all, by using information issued by movements. In fact, there is a possibility of separating a moving object from the background, by making the difference between a running image and a reference image. This one is built up for containing only the fixed objects of the scene. The reference image is initialized by obtaining the arithmetic average of a great number of successive images. Then this image has the particularly of maintaining faithfully the image of motionless zones and "diluting" the image of moving objects. In order to take into account possible imperfections of the running image or sudden variations of luminosity, the reference image is updated between each new detection. Finally, the image difference presents the following particularities :

- points representing motionless zones have levels of grey close to zero.
- points inherent to moving zones are far from zero. In this stage, the use of image filtering is still necessary. This operation is achieved by means of morphological operators - opening, closing - . The filtered difference image is thresholded in order to obtain 2 classes. These classes represent the support of motionless objects and the complementary support of moving objects respectively. This thresholding is achieved by means of statistical processing of the histogram of grey levels of the image.

3.2. Indicators of congestion

At regular intervals - of about 0.25 s - the detection gives the surface of the vehicles on the scene. So from this, we can deduce information on space occupancy. This is, by definition, the surface occupied by the vehicles in the image at a given time t. It is measured in pixels or units, taking the perspective into account. Related to the surface of a fixed zone, it is the instantaneous space occupancy rate. This rate can be used in different ways : with a window smaller than the size of a vehicle, the time series of the instantaneous rate values can be interpreted as a signal issued by a magnetic loop. After filtering and measuring, we obtain a time occupancy rate or a traffic volume.

If the window has dimensions greater than the size of a vehicle and is placed in a conflict zone, the sensor can give measurements allowing to imagine the implementation of an anti-blocking algorithm. If the zone scrutinized corresponds in its scene to a vehicle queue, the measurements allow a better estimation of demand.

The zone occupied at the time t by vehicles can be decomposed into 2 zones considering the occupied zone as t + 1. The zone occupied at time t and unoccupied at t + 1 corresponds to release. In a complementary way, the zone occupied at t and t + 1 corresponds to congestion. Thus, we can characterize by means of these indicators vehicle progress at an isolated signal.

Therefore video sensors allow us to imagine a new form of control of congested junctions. By giving congestion indices of the junction and its different exit lanes, they should rapidly allow the operator to modulate and adjust the green times given to the different phases of the signal.

4. EXPERT SYSTEM AND MONITORING OF A TRAFFIC CONTROLLED NETWORK

4.1. The operator and the network congestion

Observing saturation conditions in an urban network allows us to state the following phenomena :

- merging of queues vehicles of different origins,
- splitting of vehicle queues when upstream vehicles reach a critical junction, giving artificially free-flow traffic on sections saturated before,
- forming of cycles inside the network.

These phenomena induce a serious lack of balance in data serving to the selection or adaptation of real-time signal plans. Moreover, any action taken on the process requires the follow-up and memorizing of the events. This requirement of time analysis makes us get out a bit from the framework of traditional automation, governing traffic control practices. One of the qualities of the recourse to human operators, resides precisely in their faculty of memorizing. Without being necessarily complex, the reasoning used is based on the identification of saturation causes, like, for instance, a saturated transverse itinerary, an insufficient junction capacity, an incident, illegal parking,... The operator takes advantage from this information for making an appropriate decision. The actions undertaken are of 2 types :

- favouring an itinerary of one or several junctions,
- restraining volume demand on particular links, called "reservoirs".

For any decision favouring a congested axis, the operator makes an appreciation of upstream and downstream congestion of the itinerary to be privileged, as well as on the penalized transverse axes.

4.2. Expert systems for monitoring

In controlled networks, one of the functions of the operating teams is to ensure the surveillance of traffic by means of various equipment : television cameras, synoptic screens, terminals displaying diagrams of the evolution of the indicators,... In case of congestion, the necessary measures to be taken depend more on the competence of a human operator than on an automated system. However, in order to be sure of the reasonableness of his decision, the operator must have followed traffic evolution. Thus the efficiency of a traffic control system depends not only on the comptence but also on the time available to the operating team. Thus, the mode of intervention, scarcely depends on algorithms. Such a knowledge of a human expert is imaginable in a computer, only by means of expert systems.

These considerations form the basis of the elaboration of the SAGE (14) expert system of aids to traffic monitoring. Such a system, based on the techniques of Artificial Intelligence has its own knowledge base, produced in consultations of specialists. Its objective is permanent analysis of the traffic situation, search for the congestion causes and planning possible measures. The supervision function of the expert system forms an important contribution compared to the traditional traffic control methods. The expert system allows to detect the origin of congestion, to make a diagnosis of it, to evaluate its importance and to follow its evolution by means of its information summary. In the example of SAGE, the expert system reasons on occupancy rate measurements given by sensors in the network. These measurements allow the discrimination of the states of traffic flow, congestion or "unknown" states in case of failure or absence of the sensors. Only the new states are conveyed to the expert system, which informs the operator restoring the background of congestion. The expert system sends these messages to the operator in form of alarm signals drawing his attention to the critical junctions, or of proposals of action, like, for instance, start, stop, increment, slow down, go on.

These messages are visualized at the same time as the states of links on a synoptical display of the network. The operator has return access to the texts of the messages by simple designation of the screen. With this developed graph interface, SAGE can be considered as an "Intelligent" synoptical display. SAGE is a definition prototype running with independent data processing material (Apollo DN3000 station). It is at present being tested in real time at the traffic control centre of the City of Paris. This tool, being assessed, lets us hope for significant operating productivity gains, so much the more as the size of the network will increase.

5. TOWARDS A GLOBAL APPROACH

At given demand, present urban traffic control systems prove their efficiency in various fields. As such, they form an indispensable tool for traffic management. In congestion situations, however, the results of the present fixed or on-line systems remain disappointing. The future generation of traffic control systems should integrate progress achieved in multiple fields : communications, processors, sensors, automation, Artificial Intelligence, mapping,... Although it is a perfectible tool in constant technological development, traffic control remains, nevertheless, limited in its possibilities. In order to fight efficiently against traffic congestion, local communities must continue to combine actions of improving supply with measures allowing better to manage travel demand. Such objectives require the participation of all the users, if not traffic restriction measures would rapidly become ineluctable.

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