

TRAFFIC CONTROL IN RESPONSE TO TRAFFIC INCIDENTS

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SUMMARY

Many problems of modern urban traffic control systems are related to the quality and quantity of traffic data available when incidents happen. If this is the case, traffic control in response to traffic incidents is not likely to have a good performance.

In this paper an efficient incident detection algorithm for a signal controlled road network is developed using fuzzy logic. The algorithm is then integrated into a fuzzy logic based traffic control model, which is also newly developed for solving the problem of incident related traffic congestion.

These will allow the urban traffic signal controller to adapt more adequately to the traffic situations, especially those related to an incident, and will enable it to be automated.

INTRODUCTION

Traffic incidents can cause severe congestion and delay throughout the network as the effect of the incidents spread over. Incident detection and knowledge of the incident location are necessary in order to implement an effective response. Therefore, it is desired to develop a more rapid and reliable detection algorithm for a signal controlled road network.

Demand responsive signal control systems such as SCOOT, UTOPIA, etc. are originally designed to handle traffic under non-saturated conditions even though they have some scope to ease congestion. To maximise the use of existing road network and to adapt traffic control to the unexpected traffic congestion, new control strategies are needed to improve traffic signal control for the recovery of the road capacity in real-time situations.

When fuzzy logic is applied to detect traffic incidents automatically and to control traffic signal in real time, there expected a number of benefits (1) such as: fuzzy logic can handle and combine uncertain, imprecise and linguistic information; fuzzy pattern recognition enables efficient identification of states or transitions between the states; fuzzy traffic control enables the incorporation of expert knowledge and vague ideas

regarding dynamics of the traffic process; fuzzy traffic control can suit several, possibly conflicting, objectives expressed by traffic operators in linguistic terms.

In this paper fuzzy logic is used to develop an incident detection algorithm for a signal controlled road network. The incident detection algorithm is then integrated into a fuzzy logic based traffic control model, which is also developed for solving the problem of incident related traffic congestion.

TRAFFIC INCIDENT DETECTION

An automatic incident detection (AID) system is aimed to provide information to a monitoring unit about the occurrence of incidents and to provide warning to drivers about the unusual traffic behaviour that may lead to other incidents. In the system an incident detection algorithm interprets the information and ascertains the presence or absence of incidents. Therefore, the efficacy and efficiency of the system depend on the incident detection algorithm.

The required qualities of a detection algorithm are generally judged on detection rate, false-alarm rate, and time to detect. Because the main purpose of AID in the urban area is likely to be to obtain improved network efficiency and reduce congestion while that in the extra-urban area is safety, important factors of AID in urban situation are (2): about which incident the operator of the system need to be informed; and what the severity of the congestion caused by incident is.

A number of detection algorithms for the automatic detection of incidents have been developed. The structure of the algorithms varies depending on the degree of sophistication, data requirements, complexity, and the types of surveillance technology used for data collection. They could be classified by: the theories they are based on such as pattern recognition, statistical analysis, catastrophe theory, and artificial intelligence; the methods they use such as comparative and time series(or smoothing); numbers of the detectors they rely on such as one, two or more ; and types of roads they are designed for such as motorways, arterial streets.

Motorway incident detection algorithms have been developed from early 1970's while arterial street ones in urban areas from late 1980's. For this reason, the basic idea for developing traffic incident detection algorithms for a signal controlled road network was gained through knowledge on the research methodology for motorway incident detection. It therefore is worth analysing the incident detection algorithms developed for motorways in order to obtain better knowledge on those for signal controlled roads.

INCIDENT DETECTION ALGORITHMS FOR MOTORWAYS

The California model is an incident detection model developed in the early 1970's and is often used as a standard by which the performance of other algorithms is assessed. Since ten comparative incident detection algorithms were developed and assessed by FHWA(3), the comparative or California-type algorithm has been the most commonly used incident detection algorithm for motorways.

The California model detect incidents using occupancies obtained from each adjacent pair of detector stations at regular intervals. It is assumed that occupancy values upstream of an incident are largely increased while, downstream, those are reduced rather abruptly some time after an incident happened. The algorithm consists of three sequential tests based on occupancy changes at the upstream and downstream stations. The tests are conducted by comparing pre-defined threshold values with: the absolute spatial difference between upstream and downstream occupancy levels; the relative spatial difference between upstream and downstream occupancy levels; and the relative temporal difference between the current downstream occupancy level and the occupancy level recorded downstream 2 time intervals before.

Extended versions of the California algorithm were developed for more accurate incident detection under various traffic conditions. Among them, algorithm 7 which contains a persistence requirement and algorithm 8 which has a compression-wave check with a persistence requirement showed to provide superior performance ((3) and (4)). While specified differences of occupancy values between two adjacent detector stations indicate the presence of an incident in the comparative California-type algorithm, the McMaster algorithm and the HIOCC algorithm identify an incident using a single detector station ((5) and (6)).

On the other hand, if predicted parameter values differ significantly from detected values, an incident is assumed to have occurred in time series (or, prediction) algorithms such as exponential algorithms. To make thresholds in incident detection algorithms more realistic, algorithms using statistical approaches, the fuzzy logic and the artificial neural network have also been developed.

In the case of UK, the occupancy-based algorithm, HIOCC, was developed by TRRL in late 1970's and was extended to the Motorway Incident Detection and Automatic Signalling(MIDAS) system whose first trial on M25 began in August 1995.

INCIDENT DETECTION ALGORITHMS FOR SIGNAL CONTROLLED ROADS

The earliest algorithm for automatic detection of traffic incident on a signal-controlled road network was developed by TORG in 1988 (7). The TORG algorithm is a time series one and is based on the hypothesis that a serious incident might reduce flow at detectors up- and downstream of it, while increasing occupancy at the upstream detector and reducing occupancy at the downstream detector. A time period for data collection in the algorithm is established to one cycle of the traffic signals and the following sequence of tests forms the basis for incident detection:

[$F(t) < F^*(t) - \alpha_1 \sigma^*_{F(t)}$], [$O(t) > O^*(t) + \alpha_2 \sigma^*_{O(t)}$], [$O(t) < O^*(t) - \alpha_3 \sigma^*_{O(t)}$]
 where $F(t)$ and $O(t)$ are observed flow and occupancy values respectively for cycle t , $F^*(t)$ and $O^*(t)$ are their estimated values, $\sigma^*_{F(t)}$ and $\sigma^*_{O(t)}$ are their estimated standard deviations, and α_1 , α_2 and α_3 are pre-specified constants. The expected values are exponentially smoothed.

The TORG algorithm was extended to MONICA (the Monitoring Incidents and Congestion Automatically), which was an EC DRIVE project for developing a traffic monitoring / incident detection system for urban networks (8). INGRID (Integrated Incident Detection) is a system operating in real time for the automatic detection of incidents in urban areas, and is based on earlier work in MONICA (9).

INGRID in SCOOT takes information on occupancy and flow which are collected on a cyclic basis, and initially uses two algorithms to detect incidents. In the first algorithm, only current flow and occupancy are used and INGRID looks for a sudden change in these parameters. In the second algorithm, the current flow and occupancy are compared with historic values for these parameters supplied by the ASTRID (Automatic Traffic Information Database). In each algorithm two detectors are compared and an incident is indicated between the two if the following two conditions apply: - occupancy and flow decrease at a downstream detector; - occupancy increases and flow decreases at an upstream detector. The increase and decrease need to exceed a pre-determined threshold before an incident is indicated ((9) and (10)).

Other detection algorithms for traffic incident in urban areas have also been developed using statistical approaches, the fuzzy logic and the artificial neural network in the similar methods to those on motorways employed. Traffic characteristics and conditions on signal-controlled road networks were considered in those algorithms. As a consequence, they also have thresholds for determining if traffic incidents exist. But the algorithms for city road networks still have some problems in view of the quality.

PROPOSED INCIDENT DETECTION ALGORITHM IN URBAN AREA

As it was discussed above, incident detection algorithms rely heavily on several pre-defined thresholds to distinguish the occurrence of traffic incidents from normal traffic situations. The selection of improper threshold values could result in undesirable detection errors, such as generating high false alarms or failing to detect potential incidents. The fuzzy approach allows users to approximate reasoning by specifying thresholds in decision-making. Chang and Wang (11) investigated the application of fuzzy set theory to improve the California Incident Detection Algorithm 8, and obtained better results than those produced in the original one.

The basic ideas of the proposed incident detection algorithm for urban road networks in this paper are: ① that the algorithm uses data readily available from loop detectors and is not excessively complex in order to be attractive for on-line use under a wide range of circumstances. ② that the algorithm is also based on the hypothesis that traffic flow at detectors up- and downstream of an incident may be reduced below boundaries, if the incident occurs, while the occupancy rate at the upstream detector increased and the occupancy rate at the downstream one reduced. ③ that one cycle time of the traffic signals is considered as a time unit for data analyses in the algorithm. It is because traffic flow changes by a cycle base in urban roads with traffic signals and because a cycle is the basic unit of time in the operation of urban traffic control systems. ④ that it makes use of the fuzzy approach in designing the algorithm for getting the benefits which are: that fuzzy logic can handle and combine uncertain, imprecise and linguistic

that fuzzy pattern recognition enables efficient identification of states or transitions between these states. ⑤ that it should be a time series algorithm which relies on one detector in the consideration of traffic characteristics on a signal-controlled road. However, analysis results at the adjacent detectors are also reviewed in the procedure of identifying an incident.

The input variables of the proposed algorithm are AVEGFLOW, CHANFLOW, AVEGOCCU, and CHANOCCU. These are derived from the equations as follows:

- o $AVEGFLOW(t) = 0.2 FLOW(t-1) + 0.8 AVEGFLOW(t-1)$
- o $CHANFLOW(t) = FLOW(t) - AVEGFLOW(t)$
- o $AVEGOCCU(t) = 0.2 OCCU(t-1) + 0.8 AVEGOCCU(t-1)$
- o $CHANOCCU(t) = OCCU(t) - AVEGOCCU(t)$

where $FLOW(t)$ and $OCCU(t)$ are the average flow and occupancy values respectively for a cycle t ; $AVEGFLOW(t)$ and $AVEGOCCU(t)$ are their values for the last 5 cycles; $CHANFLOW(t)$ and $CHANOCCU(t)$ are their absolute temporal differences when compared with $AVEGFLOW(t)$ and $AVEGOCCU(t)$ respectively.

Figure 1 shows how the variables are combined in the rulebases of the fuzzy process. The fuzzy inference structure was considered for minimising the possibility of identifying normal traffic fluctuations as incidents and for reducing the complexity of making rules when it would be integrated into a traffic control system.

The membership functions of the fuzzy sets could be obtained from traffic data with and without an incident. For instance, if a micro-simulation model is used, a number of data can be derived from various traffic input volumes with and without an incident, and can be plotted in fuzzy input spaces which have two dimensions such as representing ‘AVEGFLOW and CHANFLOW’ or ‘AVEGOCCU and CHANOCCU’, and then the fuzzy input spaces can be divided into several sub-areas along linear regions in which data in normal and incident conditions exist together. Fuzzy membership functions are obtained in these procedures.

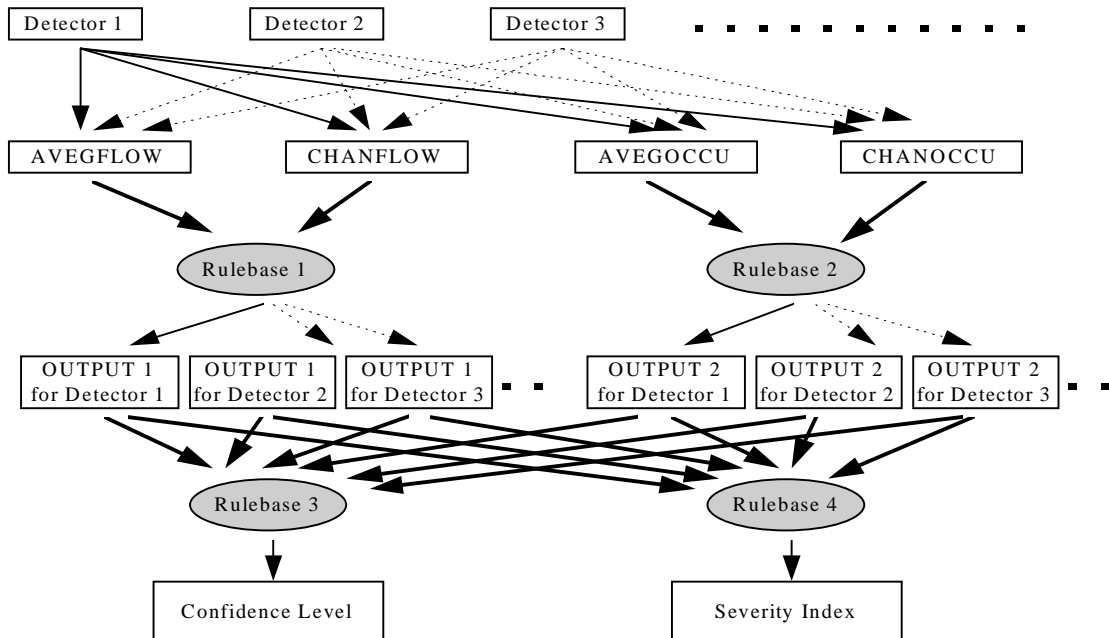


Figure 1. Fuzzy Inference Process for Traffic Incident Detection

The location of an incident can be identified by examining all the links in a network for an upstream or downstream incident, because the fuzzy processes are applied to each link on which a detector is available. The concepts of ‘a confidence level’ and ‘a severity index’ can be introduced by considering the duration of an incident and the number of detectors affected as they were in INGRID. Because the level and the index are likely to be presented as linguistic terms, fuzzy logic is more suitable to deal with these variables and to integrate the results into traffic control systems for managing congestion caused by the incident.

TRAFFIC CONTROL IN RESPONSE TO TRAFFIC INCIDENT

The effect and extent of congestion caused by an incident varies considerably, depending on factors associated with the incident itself and with other conditions (12). The incident factors are: reduction in throughput capacity, duration of an incident, random or some pre-warning, position of an incident along a link, and location of an incident in the network. The other factors which contribute to the formation of congestion are: type of network, background level of congestion, network control parameters, and drivers’ knowledge of the network. Several factors above are likely to be operating at any one time making the spread of congestion even more difficult to predict and control.

CONGESTION AND INCIDENT MANAGEMENT STRATEGIES

Following the definition in COSMOS (Congestion Management Strategies and Methods in Urban Sites) which is an EC ATT project, the direct and indirect impact of incidents are classified as follows (13): *primary incidents* exist when an obstruction in at least one lane in the link reduces the effective capacity of that link causing a queue to build up behind the incident ; *secondary congestion* exists when a queue is building up on a link because the exit capacity cannot be fully utilised due to traffic blocking back from a downstream link during the green time on the affected link. According to these, ten distinct scenarios for congestion are defined.

Four conceptual levels of operation for incident management are also defined in COSMOS, which are general strategies, tactics, tools and realisation. General *strategies* for incident management take account of the traffic situation to mitigate traffic congestion in the network, and are congestion avoidance, congestion reduction and congestion shift. Various *tactics* (entry gating, opening an exit, preventing the blocking of crossing traffic, etc.) and *tools* (cycle time, offset and green time) can be selected in order to achieve these general strategies. Definitions above can be employed in dealing with all types of urban traffic control systems and are applied in this paper.

PROPOSED URBAN TRAFFIC CONTROL IN RESPONSE TO TRAFFIC INCIDENT

The basic ideas of the proposed UTC in response to traffic incident in this paper are: ① that incident detection is not considered in this part. The algorithm concentrates on

analyses of the incident effect and actions for mitigating traffic congestion.② Rerouting, leads to the route guidance, is not involved among the strategies. ③ the proposed algorithm will be a sub-system in an existing UTC system, using fuzzy logic. The input variables of the proposed algorithm are MAIN_SAT, CROS_SAT, and DIFF_SAT. The variable MAIN_SAT and CROS_SAT represent the degrees of saturation on main and minor roads respectively, and the variable DIFF_SAT equals the difference between two other variables.

Figure 2 shows the fuzzy inference structure for managing congestion caused by incidents. Fuzzy rulebases are established for increasing/ decreasing cycle time and changing split respectively, and then they are integrated into existing UTC systems. The underlined concept of this model is that the performance of existing UTC systems needs to be improved in congested situations caused by incidents.

The membership functions of the fuzzy sets can be obtained from the similar methods traffic data with and without an incident.

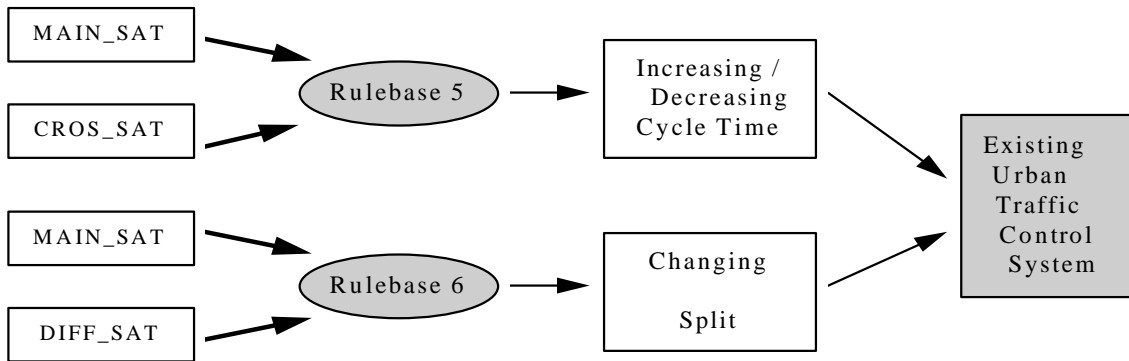


Figure 2. Fuzzy Inference Structure for Incident Management

Table 1 shows basic principles of traffic control in a signal-controlled network. These principles and the severity index defined in this paper also have to be considered in producing the fuzzy rulebases.

Traffic situation / Location	Stable or Increasing Problem	Problem Decreasing
Downstream Intersection (Incident occurs on this link)	Open Exit (OE)	OE - OE - OE - OE
Upstream Intersection	Entry Gating (EG)	EG - OE - OE - OE
2nd Upstream Intersection	Entry Gating (EG)	EG - EG - OE - OE
3rd Upstream Intersection	Entry Gating (EG)	EG - EG - EG - OE

Table 1. Traffic Control Principles on Each Intersection

CONCLUDING REMARK

In this research, a fuzzy logic based traffic incident detection model was developed and then integrated into an urban traffic control model for managing congestion caused by

the traffic incident. An improved performance is expected, because the algorithms are better designed than in existing ones, and because fuzzy logic is better suited to detecting traffic incidents and traffic control on oversaturated networks despite the shortcomings of the fuzzy logic in the calibration of the parameters describing the membership functions. The next stage will be to test the algorithms using a micro-simulation model - SIGSIM.

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