COSMOS - CONGESTION MANAGEMENT STRATEGIES AND METHODS IN URBAN SITES

Keith Wood
Transport Research Laboratory, UK
Christiane Bielefeldt
Consultant to The MVA Consultancy UK
Fabrizio Biora
MIZAR Automazione SpA, Italy
Günter Kruse
Siemens AG Germany

1. INTRODUCTION

Urban congestion is one of today's main traffic problems. Congestion affects in particular radial routes to the town centres in the morning and afternoon peak, and many central business districts even outside the peak periods. The main cause for congestion is oversaturation of the networks, but the situation is worsened when incidents occur. The EU project COSMOS is designed to reduce the adverse effects of congestion, both regularly occurring and due to incidents.

The solutions that are potentially the most effective ones are either increasing the road supply or decreasing the traffic demand. The first is a solution of the past, and, today, is generally no longer an option in urban areas because of both physical and environmental constraints. Decreasing traffic demand through demand management is certainly an option for the future, which could have a major impact on congestion reduction, but will not be widely introduced for a long time. Therefore, Urban Traffic Control (UTC) and network signal control as a central part of it, will have to cope with ever increasing traffic problems for years to come, and will have to be able to deal with congestion.

Most of the congested routes and road networks in urban areas are equipped with traffic signals. However, the signal programs are generally not well prepared to deal adequately with congestion and, even more so, with incident problems. All of the current main contenders for on-line signal network control in Europe (SCOOT, UTOPIA, PRODYN and MOTION) have originally been designed to optimise unsaturated traffic. They are doing this in different ways and using different types of optimisation criteria. The more mature of them have been developed to provide tools to improve the response to congestion and incidents. However, none of them, so far, contains general procedures for Congestion and Incident Management (CIM).

The COSMOS project is developing, and will validate and demonstrate new procedures for reducing and, where possible, preventing congestion in densely trafficked urban areas. These procedures comprise:

- special CIM modules and Automatic Congestion and Incident Detection (ACID) which can be included in any on-line network signal control systems, and
- strategies for re-routing traffic to make the best use out of the capacity at junctions and in the links between them.

Developers and users of three systems, SCOOT, UTOPIA and MOTION, are working in COSMOS. These three UTC systems already incorporate, albeit to different degrees, some functions for Automatic Incident and Congestion Detection, and further functions for relieving the situation once problems have been identified. The new CIM strategies are to be incorporated in the existing systems and will be implemented in London, Piraeus and Torino for verification and demonstration. The paper describes the methods that have been developed to modify the control traffic signals to reduce the effects of congestion, the common control strategies that are generally applicable. It then describes the implementation in London in more detail to show how the strategies can be used in a practical system.

2. COMMON CONTROL STRATEGIES

The Common Control Strategies for the reduction of congestion have been designed to be generally applicable, but because different UTC systems operate in different ways, the means of implementing any strategy will be system dependent. Within COSMOS, four levels of operation were defined:

- strategies;
- tactics;
- tools;
- realisation.

The first three reflect the general approach taken for the definition of the CIM strategies and their elements, and they are therefore relevant not only to SCOOT, UTOPIA and MOTION, but they are also transferable to other on-line control systems and, to a certain extent, to the off-line preparation of signal plans. Strategies, tactics and tools are described further below.

The realisation level, however, reflects the fact that all of the three systems SCOOT, UTOPIA and MOTION have very different philosophies, very different methods of optimising signal times, and are using different technologies. This also means that even where they are currently using similar measures, they are usually implemented in different ways. It was decided early in the conception of the COSMOS project that these existing systems should not be overridden and that any future development work should be sympathetic to each system's rationale. Therefore, for all future work in COSMOS, every system should have, where appropriate, the same common CIM strategies, but the realisation of these strategies must be carried out under the normal rules of the individual system.

2.2 The Strategies

The strategies for CIM form the top level of this hierarchy, and have to reflect the strategic requirements of the system operators. They define the rules:

- under which circumstances
- which tactics and
- which tools will be used
- in which sequence and
- in which combination.

In very general terms, the strategies fall into the three categories congestion avoidance, congestion reduction, and congestion shift. **Congestion avoidance** can comprise both strategies based on a traffic prediction of the imminent onset of congestion, and strategies that avoid a spread of congestion from the primary link into the wider network. **Congestion reduction** involves proactive control measures that will change network signal timings to clear out queues from sensitive areas. **Congestion shift** is based on the premise that whereas congestion in one place may spread rapidly out of control, there may be other places where its negative impact can be more easily tolerated and/or where its knock-on effects, particularly on public transport, are minimised. Typically this will involve the use of queue storage in high capacity long links or even outside the controlled area. Measures to implement this strategy would include re-routing using remote signing.

The optimal utilisation of all strategies depends on high quality congestion monitoring, and incident detection and location. Congestion avoidance, furthermore, depends on the availability of elements of congestion prediction in the UTC system.

2.3 The Circumstances

Different causes of congestion require different responses. To define the circumstances under which particular tactics and tools can be deployed, twenty congestion and incident scenarios have been defined. A so-called 'scenario decision tree' provides a guide through a number of questions that define the features of the different scenarios, which fall into three principal groups: five scenarios for links with primary congestion, ten for links with incidents, and five for links that suffer secondary or blocking-back effects from primary congestion or incidents further downstream.

For each of the scenarios, a number of 'responses' are available, with each response consisting of one tactic and anything between one and four tools that the particular tactic can use in these circumstances. It should be noted, however, that the responses do not try to solve the problems attached to a particular scenario in a holistic approach, but, instead, refer to individual specific features of each scenario. Moreover, many features will be common to a number of scenarios. In so far, the tree is more a device to show which traffic situations can be addressed than a blueprint for designing the structure of the algorithms and the software.

2.4 The Tactics

The tactics are the means that can be employed by the strategies to achieve particular goals in particular situations; the changes that can be made to the operation of the traffic signals to reduce the congestion or move it to a more acceptable location. They are mainly applicable to one intersection, or in some cases to a group of intersections which form a subset of the overall network:

- **Entry gating** is designed to reduce the amount of traffic entering a critical part of the network so as to avoid oversaturation within the critical area. Gating can be implemented just at the local intersection, progressively along an arterial, or at the edges of the controlled area to protect a large part of the network.

- **Opening an exit** will allow traffic to leave a congested network more rapidly than with the standard signalisation. Like gating, it can be applied either as a local tactic, or a progressive linear one.

- **Preventing blocking crossing traffic** is meant to start the red to the main road feeding the congested link before the exit to the junction becomes blocked, that is whilst the main road traffic is moving relatively freely. Changing the signals at this time minimises the probability of having a queue of main road traffic blocking back through the junction and preventing the crossing traffic moving during its green time.

- **Giving priority to a particular traffic stream** is designed to provide green time for traffic that tries to join the congested stream from a specific upstream link when they can effectively use this green time, i.e. when the back of the downstream queue is moving.

- **Ensuring full utilisation of exit capacity** is a tactic that applies to short links where congestion is building up because the existing green time cannot be fully used due to an inappropriate offset.

2.5 The Tools

The tools that are used by the tactics relate to the elements of the signal plan and the ways in which they can be modified. The twelve tools that are available are:

- **Double cycling**, which can be used when traffic would flow better in several small platoons rather than fewer large ones, either because of the lack of storage space for long queues or to condense the platoons crossing the stopline.

- **Decreasing the cycle time** for the whole network, or a subnetwork where this can be created with reasonable borders, may be an alternative when double cycling is not feasible for some reason e.g. because it would reduce the capacity too much due to large intergreen times.

- **Increasing the cycle time** is the standard response when traffic volumes increase in a network.

- **Doubling the cycle time** can create additional capacity beyond the normal limits that may be useful on long exit links of congested networks. Its applicability will depend on local circumstances, for instance very long cycle times are not normally acceptable where there are many pedestrians wishing to use a crossing facility.

- The purpose of a **reduced offset** is to avoid congestion through avoiding blocking back together with unused green time at the downstream intersection that leads to inefficient use of the green time upstream and, if demand is high, to congestion building up upstream.

- The **balanced offset** can in some cases be designed to reduce congestion, in others it may only help to shift it to those links where it does less harm, i.e. generally from short to long links or from links with residential use to those with mixed or industrial use.

- Another possibility to use the offset is for **platoon compression** to protect short links, if the green time upstream is larger than downstream

- **Double green** can be used for the same purposes as double cycling as an alternative where three or more separate stages per cycle are needed.

- Furthermore, the phase sequence might be **modified to support the creation of a particular offset**, if this helps to reduce stops and delays.

- **Increasing green time** at the downstream signal, within the given cycle time either in line or overproportionately with increasing the cycle time, is a standard tool to increase capacity at the downstream signal in a congested link

- **Decreasing the green time** at the upstream signals can be useful to avoid oversaturation for the downstream link with the consequence of blocking back, and in those cases for which double cycling, platoon compression or double green have to be considered.

- **Adjustment of the green split according to queuing capacity** may be useful in particular when one or more links at an intersection are very short.

3. IMPLEMENTATION AND TESTING

The Common Control Strategies are being implemented in SCOOT, UTOPIA and MOTION and they will be validated and demonstrated in the three test sites in London, Torino and Piraeus. They will operate in conjunction with re-routing strategies that are supplied by the Technical University of Hamburg-Harburg in the cases of London and Piraeus (Cremer and Reimers, 1998), and are already an inherent part of the 5-T system in Torino.

In London, the SCOOT UTC system is currently operational at over 500 junctions. There are a number of complementary projects taking place in London which have introduced several enhancements to the UTC system for control of congested networks. The ASTRID traffic monitoring system (Bowers et. al. 1996) has also been installed and integrated into the UTC system. It currently operates on 100 junctions but is soon to be expanded to operate up to 300 junctions. The validation site for COSMOS will be in the Royal Borough of Kingston to the South West of the centre of London. The area is well delineated by natural boundaries and for traffic approaching the borough from central London there is a choice of three alternative routes. The area has a fairly tight central core with 25 junctions under SCOOT control. Moreover, the area has a number of additional features such as CCTV surveillance and active car park guidance.

Piraeus is the most important passenger port in Greece. Its traffic signal control system consists of approximately 100 traffic signals. These have so far been operated under fixed time control, but the municipality, jointly with the central government, is at present upgrading the traffic control of the city. A new central control computer has been installed and the traffic controllers are being replaced and connected on-line to the central computer. The site, where the enhanced MOTION system will be tested, is located between the port and the major approach road from the landside and comprises around 25 intersections. It offers several routing alternatives to reach the port and the departure and arrival positions of the big ferries. Because these positions are changing, traffic streams have to be directed accordingly. Therefore, a VMS system has been set up in the framework of the DRIVE II SCOPE project and is now in operation with three VMS signs; another two additional signs are going to be installed in 1996, and to be evaluated by a different ATT project, namely EUROSCOPE.

Torino is the capital of the Italian region of Piemonte, and as most industrial cities where private traffic demand is high, Torino suffers from serious problems of traffic and demand management with resulting air and noise pollution. In the light of the positive results of the first ATT application implemented in Torino in 1984, it was decided to expand the ATT application in the city in order to cover all the traffic services like parking management, public fleet control, traffic management and end user information with the aim of optimising the global (public and private) transport service. The UTC system comprises 140 intersections equipped with the SPOT local unit which are interconnected and are linked with the traffic control centre located at the Municipality's facilities through a telecommunication network. For COSMOS, the enhancement of the SPOT units will be performed initially on a sub-set of 10 to 12 intersections, where problems of incidents and congestion are more severe and as a consequence the effects of improvements are most beneficial. After the phase of verification, the central function will be implemented for the overall 5T network for the demonstration phase, and the SPOT units are likely to be upgraded for all intersections.

4. SCOOT IMPLEMENTATION

This section describes the changes being made to the SCOOT system in London as an example of how the CIM techniques developed in COSMOS will be used. In fact, as SCOOT is a mature system, many of the tools have already been developed and included in commercial SCOOT systems. Therefore, the developments under COSMOS have concentrated on improving the incident detection, incorporating options to allow the responsive to be increased beyond what is normally good practice for incident conditions and monitoring and analysing the causes of recurrent congestion.

4.1 Incident Detection Development

Earlier work had developed an Automatic Incident Detection (AID) algorithm, INGRID (Bowers et. al. 1996), to be used with SCOOT. In fact, INGRID is more generally applicable and does not require a SCOOT system, just equivalent information to that which it obtains from the SCOOT traffic detectors.

In order to facilitate the deployment of incident management strategies within COSMOS a version 1.4 of INGRID has been developed. It provides additional information regarding a detected incident's effect on saturation flow. It also incorporates improvements necessary to meet the demands placed on it when operating with large networks such as in London, where it is to be tested experimentally. It will replace INGRID Version 1.3, on which it was based.

The development of INGRID Version 1.4 had the following objectives:

- incorporating saturation flow data from SCOOT;
- reducing INGRID's memory requirements;
- reducing the data requirements for specifying the SCOOT network.

The second two objectives are important operational objectives to produce an easily manageable, workable system. However, it is the first objective that is most important for COSMOS, the provisions of information on saturation flow conditions on a link with an incident. This information can be used to optimise the cycle time in SCOOT to provide some remote management of the incident conditions.

3.2 SCOOT Development for Incident Management

As well as the enhancements to INGRID, a number of other developments to SCOOT are incorporated into the experimental SCOOT system in London and are to be used in response to incidents. These are:

- Increased optimiser authorities

  In normal mode of operation the split and offset optimiser authorities have fixed authorities of 4 seconds. The option has now been provided to allow different optimiser authorities. The change in optimiser authority is node based. When incidents occur it is likely that traffic will be more variable in the area surrounding the incident due to re-routing. The operator will now be able to extend the SCOOT authorities in the area of an incident, allowing SCOOT to make large changes in signal timings in response.

- Rapid cycle time response

SCOOT can be forced to move to a particular cycle time by an operator imposed minimum or maximum cycle time. Previously, the move to the imposed cycle time was gradual and incremental. The option has now been provided to move immediately to the desired cycle time.

- Saturation flow

  SCOOT has been modified to pass to INGRID information regarding the saturation flow at the downstream junction when an incident is detected.

- Saturation occupancy

  SCOOT has been modified to allow greater changes in saturation occupancy (the internal SCOOT equivalent of saturation flow) than currently allowed in situations when an incident has been detected.

3.3 Monitoring and Analysis of Congestion

The MONACO (Monitoring and Analysis of Congestion) program has been installed in a London SCOOT computer for testing. MONACO is an existing program that had been written as on off-line aid to analysing the causes of congestion. It has been enhanced under COSMOS to operate on-line in a SCOOT system to continuously monitor the traffic, to detect recurrent congestion, identify the critical link(s) and provide an indication of the likely cause of the problem. MONACO uses a quantitative definition of congestion, Wasted Capacity, that is designed to measure how much capacity is lost on links immediately upstream of any congested links. Therefore, MONACO only registers congestion when a queue on one link interferes with the operation of other links.

When it has detected Wasted Capacity, MONACO examines neighbouring links to build up chains of congested links. As congestion normally builds upstream from the original problem, MONACO defines the critical links as the first link downstream of a chain of congested links that is not subject to Wasted Capacity. It is this critical link at the critical junction that must be managed to reduce the congestion on the whole chain of links. Once it has identified the critical link, MONACO requests information from SCOOT to allow it to analyse the likely cause of the problem on the link. The analysis is designed to help the system manager in finding consistent and relevant information about the SCOOT area it has been tested on. MONACO has produced information about congestion problems, their location and severity along with the probable cause. This information, particularly about defective detectors, can enable an urban traffic control operator to prioritise repairs and improvements to the network. Improvements to a network can involve 'fine tuning' a few, otherwise perfectly satisfactory, links so that they can cope with congested conditions. This can be achieved using congestion offsets, more accurate default values for when a link goes faulty or increasing the priority a link has at a junction.

New work has been carried out to examine the detailed behaviour of congested links with particular reference to the correlation between exit blocking episodes and the start of green to the downstream link. A new method has been developed to automatically determine the most effective congestion offset from SCOOT system parameters (although the technique is generally applicable to most UTC systems).

3.4 SCOOT Gating

The existing SCOOT system includes a gating facility to take action at a distance to prevent a specific bottleneck in the road network being overloaded with traffic. Gating has previously been used to prevent the gyratory system in Kingston from "locking-up" and to provide bus priority in Southampton. The bus priority application controls the amount of private traffic allowed to join a major radial route into the city to provide free-flow conditions on the radial. Buses are provided with special unrestrained access facilities. SCOOT gating replaced the existing system that was based on special queue detectors and fixed-time signal plans.

Although the existing gating logic had worked very successfully, it was recognised that it could be enhanced to be more controllable and responsive to conditions in an area rather than just a specific link. Therefore, the logic has been expanded within COSMOS to meet these objectives and provide more flexible control for the traffic engineer. A further enhancement has been made to allow the traffic restraint from gating to be implemented progressively along a predetermined set of links. This will enable progressive restraint along a route rather than concentrating all the delay and resultant pollution at the gating points.

4. CONCLUSIONS

The COSMOS project has analysed the causes of congestion and developed a set of strategies and tools to alleviate the effects of congestion. Guidelines have been developed as to which tools are appropriate in which circumstances. Considerable detail of the cause of congestion may be required before action can be taken. The level of detail stretches the capabilities of current automatic incident detection algorithms. For instance, it is much easier to determine that there is an incident on a link than to determine where it is on the link. However, different action is required in response to an incident at a stopline from that required for one at a considerable distance from the stopline.

The tools developed are generally applicable through UTC systems, but the detail of how they are applied depends on how the particular UTC system controlling the signals operates. COSMOS tools are to be tested in three different systems, SCOOT in London, SPOT / UTOPIA in Torino and MOTION in Piraeus. Different methods of implementing the tools will be used in each system.

A description of the main changes being implemented in the London SCOOT system has been used in the paper as an example of how the COSMOS developments are used in a practical application.

5. REFERENCES

Bowers, D. J., Bretherton, R. D., Bowen, G. T. and Wall, G. T. (1996) *Traffic Congestion Incident Detection, TRL Report 217,* TRL, Crowthorne, UK.

Cremer, M. and Reimers, S. (1998) Development and evaluation of co-ordinated re-routing and signalling, *Proceedings of the European Transport Conference, Seminar J*, PTRC, London.