Adaptive intelligent traffic control systems for congestion management

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Abstract

The aim of this paper was to undertake a brief, exploratory, qualitative review of current research trends on adaptive intelligent traffic control systems for congestion management. Selective search of the internet yielded 25 usable papers which were reviewed under different sections. The results of this review are summarised here.

The seriousness of traffic congestion even in the case of a developing country, is evident. The methods of measuring traffic congestion is a less researched area. One of the method to reduce congestion from economic point of view involves any of the different methods of pricing. But this has low acceptability among users.

The methods currently available, researched and used ones can be broadly categorised into control from the vehicle using VANET etc. and control from the road using sensors etc. The former seems to be better and easier to manage with real time data. Replacement of control from the road with control from the vehicle has produced better results in some occasions.

In future, there should be more research on methods of congestion measurement and the possibility of some hybrid technique using both vehicle and road controls.

Keywords: Adaptive, Traffic Control, Systems, Intelligent, Congestion

Background

In a previous paper (Das & Almhana, 2017), it was shown that traffic control systems are used for many purposes and a major objective is to manage traffic congestions. In this paper, we review the various types of intelligent traffic control systems are used for this purpose. When it becomes context-specific, it also becomes adaptive.

Seriousness of traffic congestion

Traffic congestion, traffic jam, occurs when there is too much traffic on the roads. This leads to increased queuing, longer travel times, drivers getting into mental stress and accidents. Traffic congestion occurs when number of vehicles on the road exceeds its capacity, at least temporarily. Short duration traffic congestions may not need any control. But when the congestion lasts over a long time to affect the traffic flow significantly, intervention is needed to manage it effectively. In his article, Morgan (2018) outlines the adverse effects of traffic congestion as delays to work, failure to estimate delays, increased fuel consumption and pollution, road rage leading to accidents, inability of emergency and priority vehicles to reach in time.

As in the case of developed countries, in developing countries also, major traffic congestion problems are common in many cities. In the earlier paper, an Inrix report (Korosec, 2018) was cited according to which the three most congested countries in the world were Thailand, Indonesia and Columbia. Tom Tom Index (Tom, 2017) ranked Mexico City, Bangkok and Jakarta as the three top ranked congested cities. These cities are in developing countries Mexico, Thailand and Indonesia respectively. According to Jain, Sharma, and Subramanian (2012) poorly planned road networks in the developing countries resulted in the presence of small areas as the hot spot of congestion with elongated traffic jams. A simple automated image processing mechanism was proposed, in which, congestion levels in road traffic are detected by processing CCTV camera image feeds. The algorithm is specifically designed for noisy traffic feeds with poor image quality. Local congestion decontrol mechanisms were tested and validated in simulation studies. The authors presented some images of traffic congestion in Rio de Janeiro, Brazil, which are reproduced here in Fig 1. Within five minutes of no congestion observed at 5.15 pm congestion started to build up and lasted till 7.35 pm. When congestion sets in, the reduction in road capacity builds up the congestion further to long delays. A typical toll booth congestion build-up is shown in Fig 2. A smooth traffic input was given here. The congestion built up within 30 minutes despite controlled flow input was provided. Thus, controlled flow input may not be very effective in checking the rapid build-up of congestion.

Figure 1: Traffic at 5.15 pm at a road in Rio de Jeniero Brazil, showing no congestion in the first top picture. Shots of 2-hour long traffic jam in the oncoming lanes starting just five minutes after the first picture was taken. (Jain, Sharma, & Subramanian, 2012)

Figure 2: Typical toll booth congestion build up in 30 minutes duration (Jain, Sharma, & Subramanian, 2012)

Automatic traffic control systems are the only solution

Manual controls by traffic police may not be effective in managing the traffic congestion effectively. They may not be able to clear the traffic in all directions equally. This may result in congestion in one or two directions, while the traffic is smooth in other directions. Automatic signalling systems have helped to manage traffic congestion better. However, even they are inadequate when there is very high density of vehicles on the road over a very long time.

Smarter Cambridge Transport (2016) suggested some interventions, one-hit solutions, low capital investment solutions, medium capital investment solutions and high capital investment solutions in their submission to UK Government's Urban Congestion Enquiry 2017, which was terminated as elections were announced for June 2017 and the parliament was dissolved in May 2017. Although some of these suggestions contained elements of some control systems, the term was not explicitly mentioned.

Now what type of automatic traffic control system is the question which arises. We have seen in the earlier paper that adaptive intelligent traffic control systems have been researched and implemented successfully in many instances. Multi-level, multi-agent control systems were proposed by many researchers as the more effective methods of traffic congestion management.

In this paper, a brief qualitative review of literature specifically on traffic congestion management is attempted.

Method

Google and Google Scholar were searched using appropriate search terms. Different periods of time were considered to obtain a range of periods of research for understanding the research trends in this topic. Being a brief qualitative review, it is more explanatory rather than exhaustive. The search yielded 25 usable papers which are discussed in the sections below.

Results

Methods of measuring traffic congestion

Different methods of measuring congestion were reviewed by Rao and Rao (2012). Mainly speed, travel time/delay and volume and level of service, demand/capacity, costs and other miscellaneous variables are used for measuring traffic congestion. The authors also compared the different methods in a tabulated manner.

A traffic congestion measurement method using speed performance index in road segments was proposed by He, Yan, Liu, and Ma (2016). The method was applied to traffic congestion analysis of Beijing during January to November, 2012 using the speed performance data of Beijing Traffic Management Bureau (BTMB). The usefulness of such congestion analysis for traffic control and management was discussed.

Road/congestion pricing methods

Regulated electronic road pricing scheme was implemented in Singapore to control increase of vehicles on the road in an attempt to reduce traffic congestion. In his paper, Goh (2002) reviewed the public policy on this for extensive congestion management. Unfortunately, the effectiveness of the strategy was not reported in this paper. Road pricing, again, considered for traffic congestion management in the book chapter by Small and Gómez-Ibáñez (1997). The work on this concept has an early history starting from 1955. Sometimes, toll roads and parking taxes have also been included in road pricing in the sense of traffic congestion management. The first example for its actual implementation is Singapore in 1975; but the authors provide other examples of Stockholm, Hong Kong, Cambridge, London etc. employing a variety of road pricing schemes. Hong Kong was the first use fully automated for electronic road pricing (ERP). The manual area licensing scheme of road pricing in Singapore was later automated. Hong Kong scheme was terminated due to public protests. Cambridge scheme was abandoned when a new unsupportive council came to power in 1993. There had been some evaluations on these road pricing schemes. But none of them has adequate data on the quantitative effect of the strategy on reducing congestion. However, in almost all cases, public were negative to the idea. A very complex privatised system of road toll pricing was adopted in the case of California State 91 Expressway. In San Diego, a flat monthly fee was charged for use of toll roads, which effectively became a peak hour permit and thus a congestion pricing. Congestion pricing by fixed block charges were not favoured by the Stockholm public and hence, it was still waiting for implementation around 1997. After several trials and estimations of different types of cordon pricing, London abandoned the idea of congestion pricing as of 1996. In an experiment in Stuttgart, drivers changed to cheaper route, their travel time, public transport or car pool when variable charges on route or time of travel, park and ride, was tested. Combining two or more trips into single trips was also attempted by the road users to minimise their toll charges. Road pricing was one of the methods suggested by Smarter Cambridge Transport (2016) also.

Use of tradable credit schemes for traffic congestion management, on the lines of those suggested for pollution, was proposed by Grant-Muller and Xu (2014).

Control from the vehicle side

An innovative approach, vehicular ad-hoc networks (VANET), was used by Mohandas, Liscano, and Yang (2009) for traffic congestion management. An adaptive proportional integral rate controller, a congestion control algorithm designed for the Internet were incorporated into the system of vehicular networks. The applicability of the model was validated using simulation studies. The feasibility of using Vehicular Adhoc Network (VANET) as a tool for inter-vehicular communications and communication with a fixed infrastructure for congestion management was explored by Jayapal and Roy (2016). VANET was used in a distributed, collaborative traffic congestion detection and dissemination system. A GPS-enabled Traffic App was enabled in the smartphones of drivers for location detection. The information relayed to a remote server helps to detect traffic congestion. Once congestion is confirmed, the b vehicles are advised to divert to other routes. The increasing trend of research on VANET was highlighted by Nellore and Hancke (2016).

Noting that the current intelligent traffic management systems require costly installation of sensors with limited precise traffic information, Bauza, Gozalvez, and Sanchez-Soriano (2010) proposed CoTEC (COperative Traffic congestion detECtion), a cooperative technique using Vehicle-to-Vehicle (V2V) communications and fuzzy logic as a cost-effective means of detecting traffic congestion. Information on traffic congestion intensity and length can also be obtained from this system. The system was validated using simulations of freeway traffic.

An intelligent traffic management system using RFID technology was proposed by Wen (2010) Both practically important traffic data collection and control information were possible. It could even trace criminal or illegal vehicles such as stolen cars or vehicles that evade tickets, tolls or vehicle taxes. The system components were: an RFID reader, a passive tag, a personal computer, two infrared sensors and a high-speed server with a database system. All traffic data are sent to the district system. A flooding algorithm was used. Each server in a district centre exchanged and updated information with all servers in the neighbouring areas and in other district centres. Thus, the servers in various district centres can get all real time congestion messages updated continuously. A dynamic navigation system estimates the shortest path to avoid congestion. Tags or infrared sensors could be used depending upon whether the vehicles are tagged or not.

Replacement of sensors on the road concept with the information on vehicles reporting their location, speed and travel time was found to be very effective for traffic congestion management in the survey results of Leontiadis, et al. (2011). The drivers were allowed to crowd-source traffic information and use this for rerouting to less crowded roads. An implementation prototype for London was also developed.

In their work, Jain, Brar, Malhotra, Rani, and Ahmed (2018) expanded the concept of Internet of things (IoT) to Social IoT (SIoT) and its extension to Internet of Vehicles (IoV) and finally to Social Internet of Vehicles (SIoV). Smart vehicles exchange information on traffic among themselves. Vehicle Social Networks (VSN) proposed by the authors is composed of several sensors for wireless transmission of data. This system based on Vehicle Internet of Things

(VIoT) could optimise global communication. The system performed better than conventional layered solutions. An algorithm using VIoT was proposed for reducing traffic congestion.

When using SloV, the end-to-end delay is large in the case of store-carry-and-forward types of applications. This prevents large scale applicability of SIoV. Mobile-based crowd sensing applications provide real time content dissemination of information on traffic management of the entire city. A system using this principle was tested and validated by Wang, et al. (2018) using real world taxi trajectory analysis and performance. The system architecture of this concept given by the authors is reproduced in Fig 3. The urban environment and its society are divided into three levels of urban, block and node. Many IT infrastructures and networks could be employed. These include wearable and on-board devices, edge servers and cloud. There are four interaction services (sensing, communication, information fusion and decision) at each level. The three levels require different computational and communication capabilities. Hence different types of machine learning need to be implemented.

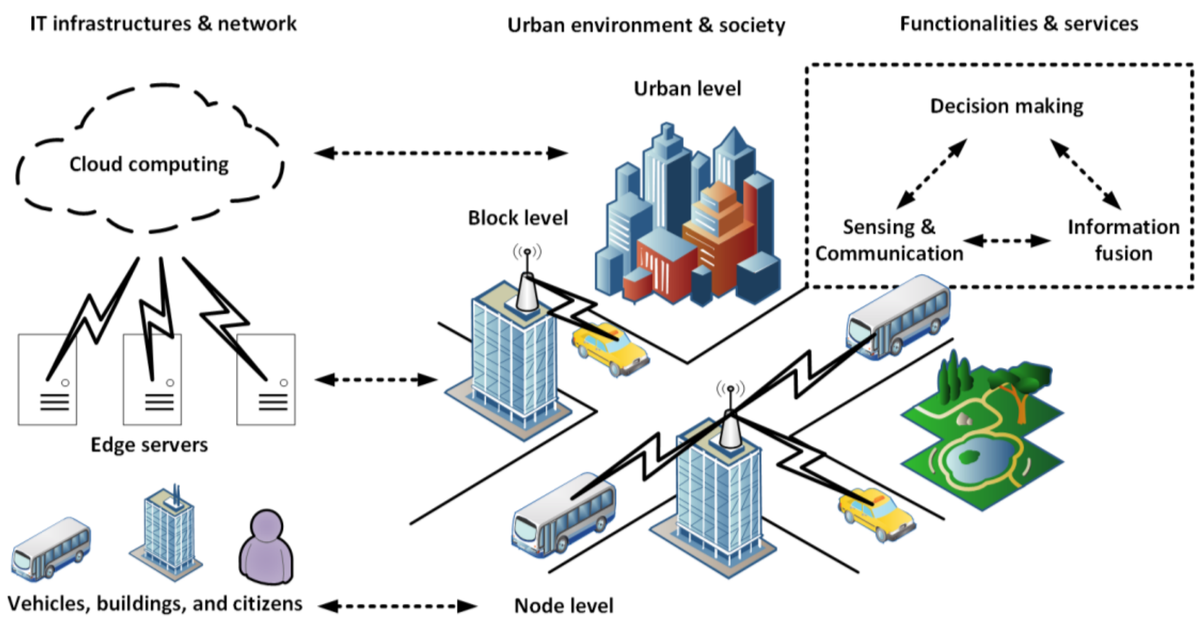

Figure 3: System architecture of a VIoT-based traffic management system (Wang, et al., 2018)

The hesitation of vehicles to participate in vehicular ad-hoc networks through long-term evolution was solved by Das and Almhana (2017) using a game-theoretic based clustering mechanism named as cooperative interest-aware clustering (CIAC). It balances cot of usage and motivate the vehicles to share cost and usage. This protocol outperformed current protocols.

Control from the road

A system to manage and control traffic lights using photoelectric sensors, was proposed by Salama, Saleh, and Eassa (2010) The authors claim a number of advantages for the proposed system. Distributed long range photoelectric sensors prior to and after the lights are employed. The distances for sensors can be chosen by the traffic management department in way that they can monitor cars that are moving towards a specific traffic. These data can be transferred to the intelligent software installed in the traffic control cabinet. The control cabinet controls the traffic lights according to the measurement made by the sensors. An algorithm has been proposed on the basis of the total calculated relative weight of each road for traffic control. This enables the system to open traffic in overcrowded roads and give longer time for the traffic flow than other traffic flows. Emergency traffic by VIPs, ambulance, fire force, police etc. are managed using RFID technology. A complete path is opened for their traffic till their destination. This does not affect the normal traffic flow significantly. The system has the options of both manual and automatic operations.

A software test bed for rapid development of multi-agent traffic control systems, was proposed and evaluated by van Katwijk, van Koningsbruggen, De Schutter, and Hellendoorn (2005) in simulations of two scenarios.

In wireless sensor networks (WSN), self-powered sensing devices are used. They are mutually interconnected through wireless ad-hoc technologies. This technology can be used for traffic monitoring and reduction of congestion. The results reported by Pascale, Nicoli, Deflorio, Dalla Chiara, and Spagnolini (2012) showed more advantages for denser deployment of sensors. Spatial resolution of traffic data improved traffic modelling reliability. Short-term traffic status was predicted more precisely.

User acceptability

A survey was done by Schlag and Schade (2000) on user acceptability of EU transport pricing model, Transprice, which was aimed to demonstrate the potential benefits of several demand management and mode-choice pricing measures by modelling and real-life applications. Eight European cities were tested for eight different traffic pricing systems: cordon pricing, area pricing, parking pricing, HOV line pricing options, public transport integrated fairs and pricing, smart card integrated paying system, access control, park and ride intermodality. From these eight cities, 1459 participants were surveyed. There was a general high level of perception of the traffic problems with only traffic jam and lack of parking space better appreciated. Overall information on demand management was low, with improving public transport and park and ride getting better response. Low level of acceptance of traffic pricing methods may reflect their lack of knowledge. Package approach of charging motorists a fee for driving in the inner city and use this money to provide much better quality and cheaper public transport, and measures to improve the urban living conditions, and better facilities for pedestrians and cyclists was more acceptable than a specific pricing option as an isolated method. Clear earmarking of pricing revenues to improve environment, improve transport infrastructure etc. was acceptable, but not for supporting state or municipal budget. Based on the results of the survey, the authors recommended several steps to improve the acceptability of traffic pricing by the public.

Emissions from slow-moving vehicles during congestion

In a study on the relationship between traffic congestion and CO2 emissions, Barth and Boriboonsomsin (2009) found that if congestion reduces traffic speed to less than 45 kmph resulting in vehicles spending more time on the road will increase CO2 emissions. Moderate congestion to traffic speed of 70 kmph or if step and go pattern is reduced, CO2 emission decreases. The three methods of congestion mitigation, speed management and traffic smoothing were tested using traffic management data of Los Angeles Interstate 110 downtown.

Conclusion

Traffic congestion is a serious problem in many developed and developing countries across the globe. Congestion is caused when several vehicles scramble for the same road space at the same time. This increases travel time, fuel costs, pollution and accidents. These and lost productivity due to delayed arrival of people in their workplace, accidents and pollution have serious impact on national economy also. So, it is imperative that steps are taken to reduce traffic congestion and costs.

Several static and real time dynamic models of traffic congestion prediction and reduction have been proposed through research. Congestion pricing models are economically sound but have low acceptability among users. Either control systems from the road (sensors etc.) or from the vehicles (VANET, VIoT) is possible. Sometimes, replacement of control from the road with control from the vehicle has been advantageous.

More work on methods of congestion measurement and the possibility of developing some hybrid method combining both control from the vehicle and control from the road in future may be useful.

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