A Review of Adaptive Intelligent Traffic Control Systems

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Abstract

The aim of this paper is to review the literature associated with adaptive intelligent traffic control systems. Internet search engines and databases like Google Scholar were used for identifying literature related to the topic. Different periods of time were also considered so that sufficient representation is given to early seminal research as well as very recent works. However, it is not claimed that this review is exhaustive. It only highlights the important issues related to traffic congestion management using adaptive intelligent systems and their effectiveness. The search yielded 30 usable research reports. The research works reviewed adequately demonstrate the multiplicity of approaches possible to tackle traffic management problems in specified contexts. Clearly dynamic systems using real time data and predictive models are better than the commonly used static systems which are insensitive to changing traffic conditions. New methods definitely have significant edge over the current ones in reducing wait times and fuel consumption and thus pollution, giving way to emergency vehicles, reducing accidents and ensuring orderly and smooth traffic flow even during peak hours.

Keywords: Adaptive, Traffic Control, Systems, and Intelligent

Introduction

We all have experienced traffic congestions and jams sometime or other. It is an arduous daily experience for commuters who go to schools, offices and other places every day. To ensure reaching their workplace, they need to start much earlier and return home very late. This leaves practically no time to attend to children or other family matters. Daily experience of such types leads to mental strain, frustration and psycho-social problems. Adjustments on food habits, absence of active life with no exercise leads to physical health problems too. Thus, the effects of traffic congestions on people are many and serious.

According to the report of Inrix cited by Korosec (2018), out of the top 10 most traffic congested cities of the world, five are in USA. The most congested city in the world is Los Angeles, second is Moscow tied with San Francisco. Atlanta and Miami are also among the top 10. People of Los Angeles, on an average, spend 102 hours in traffic jams during peak congestion times on the road in a year. This costs $2828 per driver and costs the city $19.2 billion on direct and indirect costs. Other cities in the top 10 may also have similar costs. Congestion rate is similar for all cities. The first three most congested countries in the world are: Thailand, Indonesia and Columbia. US is ranked fifth with Russia here. Drivers in Thailand spend 56 hours negotiating traffic congestion. It is 41 hours for USA, totalling the cost to $305 billion for all drivers or $1445 per driver on an average. However, different ranking organisations use different parameters for traffic congestion ranking and hence, have different cities at different ranking levels. Tom Tom Index (Tom, 2017) places Mexico City, Bangkok and Jakarta as the top three and Los Angeles is only in 12th position.

In their article, Subramaniyam, Sivaraman, Ramachandran, and Veeraraghavan (2017) cited the report of WHO that globally about 1.6 million deaths occur due to traffic accidents and 62% of these are due to technologies not available for efficient traffic management.

Increasing population, increasing number of vehicles and poor traffic management systems are given as the causes of such heavy traffic congestions in these and other cities (Records, 2018). Countries like Denmark, Norway, Japan, Sweden and Finland, which have promoted cycling in a heavy manner, have very less traffic congestion problems (Records, 2018). These reports show that the only way to manage traffic and reduce congestion is to implement intelligent traffic control systems adaptable to current traffic situation, supplemented with policies and strategies to use alternate means of transport and adjusting the working hours of different sectors appropriately. However, no single strategy will be completely effective to reduce traffic congestion. A combination of different strategies are required to address the issue. For this review, the adaptive intelligent traffic control systems, has been selected as the topic.

Before dealing with the topic of adaptive intelligent traffic control systems, it is necessary to define a few terms. A few definitions related to this topic are given below.

Definitions of Some Terms

Traffic congestion on roads has been increasing rapidly over the years. Traffic congestion defined by Definitions.net (2018) as a condition on the road networks that occurs when the vehicle capacity of the road is nearing saturation. When vehicles are crowded on the road, traffic slows down resulting in traffic jams with vehicles stopped for varying periods of time. Now, the road is oversaturated with vehicles. Slower speed increases travel time and leads to vehicular queueing.

Traffic control systems are traffic management methods using automated electronic traffic controls.

Adaptive traffic control system (ATCS) is a traffic management strategy in which traffic signal timing changes, or adapts, based on actual traffic demand. This is accomplished using an adaptive traffic control system consisting of both hardware and software.

Method

Internet search engines and databases like Google Scholar were used for identifying literature related to the topic. Different periods of time were also considered so that sufficient representation is given to early seminal research as well as very recent works. However, it is not claimed that this review is exhaustive. It only highlights the important issues related to traffic congestion management using adaptive intelligent systems and their effectiveness. The search yielded 30 usable research reports. These are discussed in the following sections.

Review

How A Typical Traffic Control System Will Look?

In a survey of current methods, Nellore and Hancke (2016) noted that traffic management systems (TMS) using wireless sensor networks (WSNs) are becoming popular as they help to avoid congestion, ensure priority for emergency vehicles and reduce the average waiting time (AWT) of vehicles at intersections and WSNs, RFIDs, ZigBee, VANETs, Bluetooth devices, cameras and infrared signals are increasingly being researched. A diagrammatic presentation of a typical WSN-based traffic management system by the authors is reproduced in Fig 1 below, as it is very illustrative.

Figure 1: WSN-based urban transport management system (Nellore & Hancke, 2016)

The article by Subramaniyam et al. (2017) highlights many important points related to urban traffic and its management. A good traffic management system should have the outcomes of increased efficiency of the transportation system, increased mobility and safety and reduced fuel consumption and environmental cost. To achieve them, the following things need to be facilitated: adaptability to current traffic conditions; response for a target and adjacent intersections; unrestricted and varied durations of control periods. The system needs to update signal plans frequently and the operations need to be entirely on-line. These outcomes also will increase economic productivity and can be used for a traffic management system using Futuristic Internet of Things. Intelligent transport control systems must be capable of handling traffic jams, ensure the minimum needed wait time and patience among drivers and provide traffic information to the users. The design features should be appropriate to achieve these goals.

Multi-Level Controls

Development of a multilevel advanced traffic signal control for intelligent transportation systems was announced by Gartner, Stamatiadis, and Tarnoff (1995). The design consisted of real time control of an urban transportation signal network, which could be adapted to current traffic status. The system could be built up gradually for different levels of responsiveness. Thus, allowances could be made for characteristics of the network and traffic conditions. The aim of this multilevel design was to enable strategies of selective control for maximum benefits and overall effectiveness. It is not stated whether the system was tested and validated.

A multi-agent decentralised strategy was used by Ferreira, Subrahmanian, and Manstetten (2001) for controlling urban traffic. All agents are involved in managing traffic in intersections. Lane sensors provide local traffic conditions of each intersection. Agents collaborate leading to implementable decisions for traffic control systems of intersections. Simulated modelling for an area in Pittsburgh showed encouraging results. Applicability of such an autonomous intelligent agent for adaptive traffic control was evaluated by Roozemond and Rogier (2000) also. In this work, four types of agents were defined: Special road segment agents (RSA) representing roads; Intersection agents (ITSA), representing controlled intersections; Higher level area agents for specifically defined road areas; Higher level route agents for specific routes that covers many adjoining road segments. Prediction-based control strategies were being discussed ass future work in this direction.

The term intelligent transportation systems (ITSs) denotes automatic road traffic management systems to manage road traffic aimed at improving traffic safety, optimizing the traffic flow speed and minimizing the energy consumption of vehicles. In this system, there is a surveillance system, a communication system, an energy efficiency system and a traffic light control system. Traffic light control system may use fixed time, actuated or adaptive approach. There are a number of variables to consider in each traffic light control system. These include: an intersection type like single-lane or multiple-lane, traffic volume, time of day, the effects on other roads, and the involvement of pedestrian traffic. Applications like fuzzy logic, genetic algorithm, neutral network are used for designing and implementing adaptive traffic control systems. In their research, Zhou, Cao, Zeng, and Wu (2010) proposed an adaptive traffic light control algorithm which uses traffic information and determines the sequence and length of traffic lights to be applied for traffic regulation. It contains mainly three components: vehicle detection, green light sequence determination and light length determination.

A multi-objective traffic control system was proposed by Khamis and Gomaa (2014). The functions of the system were: minimization of trip waiting time, total trip time and intersection waiting time. It was designed as a multi-agent system. Each traffic signal agent cooperates with the agents of this multi-agent system. Agents act automatically without human intervention. The system becomes a reinforcement learning traffic signal control by simulating driver behaviour continuously both in time and space. Bayesian probability was used for integrated system decisions. The system was able to respond to rapidly changing road conditions. The system outperformed conventional system under both congested and free road conditions. The average wait time was reduced by six times and trip time by eight times.

ACCs and CACCs

An early study by Hoedemaeker and Brookhuis (1998) was aimed at assessment of the driver response to Adaptive Cruise Control Systems (ACCs), as a function of driving style. Participants drove in a simulator. The drivers differed with respect to driving speed and focus to resist distractions. Successful adaptation of speed and reduced minimum headway with larger breaker force were noted. There was no effect of driving styles. The drivers perceived the system positively; however, undesirable behavioural adaptations should be discouraged.

Addition of vehicle-vehicle wireless communication to adaptive cruise control system (CACC) was found beneficial (Milanés, et al., 2014) in improving traffic flow through intelligent vehicle cooperation. This additional information was in the form of augmented range sensor data to the wireless communications to make it adaptive intelligent system. One controller to manage the leading vehicle and another to manage a vehicle joining the traffic flow, were included. The system was experimentally validated by incorporating in four vehicles and testing on the highway. In an earlier paper, using simulation studies, Van Arem, Van Driel, and Visser (2006) also found CACC attached to vehicles improving stability and efficiency of traffic flow in traffic merging scenarios. In another simulation study using CACC, reduction in traffic delays of up to 91% and fuel use of up to 75% were reported by Malakorn and Park (2010).

Reinforcement Training

Many intelligent transportation systems decision support tools can exert real-time, adaptive control of transportation processes at its core. A new method, reinforcement learning, has some key advantages in this regard. It works using an artificial intelligence approach. This method provides the control agent with the ability to learn from the relationship between actions and effects. It is certainly a great improvement over specified models of environments. In a case study, Abdulhai, Pringle, and Karakoulas (2003) applied Q-learning, a simple algorithm of reinforced learning, to traffic signal control to obtain positive results.

Car-based reinforcement learning was used for traffic light control system in a study by Wiering, van Veenen, Vreeken, and Koopman (2004). Cars estimated their gain in setting their lights to green and all cars voted to generate the traffic light decision. Co-learning was a added feature of this algorithm. This allowed drivers to select the shortest route to avoid long waiting. The authors used Green Light District traffic simulator to run three experiments. The results showed that reinforcement learning can be gainfully used for efficient traffic management, co-learning vehicles avoided crowded intersections leading to less waiting time, reinforcement learning algorithms outperformed fixed control systems by reducing waiting times over 25%. Simplified versions of reinforcement learning can also be used. But co-learning may not always result in improved performance.

Some Smart Control Systems

A new adaptive intelligent traffic control system, The PIACON (Polyoptimal Integrated traffic Adaptive CONtrol) was proposed by Adamski (2002) for urban transport management. Integrating system mechanisms, control modes, nominal working point, traffic mode, automatic online adaptive control actions, robust features and smooth transfer between different control points, were highlighted as the main features. There is no indication that the model was tested and verified.

Adaptive dynamic programming (ADP) was used by Li, Zhao, and Yi (2008) to design a traffic signal control for urban multiple intersections. ADP was used because it could learn continually from experience and apply it to achieve a near optimal control policy under varying conditions of traffic. The need for cooperation among adjacent intersections was required to achieve near-optimal control for any intersection. To solve this problem, a new method of signal control based on a model-free, action-dependent ADP (ADHDP) was used. A unity parameter was defined to achieve cross-control between intersections. The model was verified through simulation studies.

A smart city network, which transmits information about traffic conditions to vehicle drivers to take suitable decisions, was proposed by Khekare and Sakhare (2013). The system has also a warning system module with intelligent traffic lights to alert the driver about the obtaining traffic conditions.

In their research, Li, Zhang, and Chen (2016) proposed a dynamic traffic light control system. The system changes the traffic light signals in real time according to the speed of vehicles. This system uses V2I (Vehicle to Infrastructure) communication model. The data is transmitted between vehicles and traffic lights. Vehicles send speed messages to the traffic light when passing an intersection. Then the traffic light analyses the information and makes real time adjustment to the signal time. This traffic light control system achieves maximum number of vehicles passing intersection leading to reduced congestion and pollution.

After a review of different intelligent traffic control systems, Biswas, Roy, Patra, Mukherjee, and Dey (2016) proposed a new method. The current systems were classified as two basic types: real time systems and data analysis systems. In real time systems were included: traffic density and path optimisation methods. Data analysis systems include information chaining and green light optimisation methods. The new method proposed by the authors consisted of using infrared proximity sensors on the sides of the road and a centrally placed microcontroller to use vehicular length along the road. The system is claimed to be suitable for developing countries. However, no test for validation of the model was reported.

A novel deep learning-based TL prediction algorithm was proposed by Tang, Fadlullah, Mao, and Kato (2018) to forecast future TL and congestion in network. A deep learning-based partially channel assignment algorithm was used for intelligent allocation of channels to each link in the SDN-IoT network. A deep learning-based prediction and partially overlapping channel assignment was used on the novel intelligent channel assignment algorithm. This was able to intelligently avoid potential congestion and quickly assign suitable channels in SDN-IoT. The simulation results showed this system significantly outperformed the conventional channel assignment algorithms.

Special Applications

Traffic management at Guangzhou in the Asian Games of 2010 was the topic of study by Xiong, et al. (2010). The city was already congested due to inadequacies of transportation infrastructure. The Asian Games was being conducted at 58 existing game facilities and 12 new sports stadiums, which were spread across the city. Hence, an intelligent transport control system to manage the traffic, a parallel traffic management system, was devised for the purpose. In this system, similar but independent transport operation system is used for both actual and artificial transportation systems. The paper discussed only the plans as the Asian Games had not yet started. The concept of parallel control and management of intelligent transportation systems was further explained by Wang (2010).

The fixed protocol of traffic lights causes increased waiting time even when traffic is less. To solve this problem, Kareem and Jantan (2011) proposed a monitoring (sub) system to transform it to intelligent traffic light system. Three street cases- empty street, normal street and crowded street- can be determined by this intelligent system. Implementing the system consists of a training phase and a recognition phase. A stream of street images are used for this purpose. Adaptation to any street condition is very quick as was proved by experiments in one intersection in Penang, Malaysia.

Most of the traffic delays in Mashhad city of Iran occurs at signalised intersections. To solve this problem, the SCATS adaptive traffic control system was integrated with the signalling systems at intersections. A field evaluation (Samadi, Rad, Kazemi, & Jafarian, 2012) comparing between fixed actuated-coordinated signal timings and those dynamically computed by SCATS, showed reduction of fuel use and air pollution due to the use of the latter. This was reported as a case study.

Smart Vehicles

Connecting vehicles among one another and to traffic control systems can provide continuous real time data to obtain a more complete picture of the traffic conditions. Thus, it is better than static infrastructure-based conventional traffic control systems, which can provide only point information. A real-time adaptive signal phase allocation algorithm using connected vehicle data was proposed by Feng, Head, Khoshmagham, and Zamanipour (2015). The algorithm optimises both phase sequence and duration using two optimisation levels for solution. The aims were: minimization of total vehicle delay and minimization of queue length. An algorithm to estimate the states of unconnected vehicles was also included, as very few vehicles were connected. In the experiments, the proposed model reduced total delay time by 16.33% compared to currently used actuated control systems.

If multiple vehicular gap changes with memory is incorporated in the design of cooperative adaptive cruise control systems can make traffic flow more stable and reduce the probability of accidents, according to Yu and Shi (2015).

In their work, Zohdy and Rakha (2016) provided a simulation/optimization tool to optimize the movement of CACC-equipped vehicles to replace traditional intersection control. The system was named iCACC. The assumption is that the intersection controller receives requests from vehicles to travel through an intersection. The controller, then, advises each vehicle regarding the optimum course of action to ensure that no crashes occur, when minimizing delays at the intersections. Comparison of iCACC with a traffic signal, an all-way stop control (AWSC), a roundabout as scenarios showed a reduction in intersection delay by 90% and fuel consumption by 45%. It is shown that three factors, namely: vehicle dynamics, weather conditions and level of market penetration of equipped vehicles determine the future of automated vehicle control systems.

Conclusions

There are several more research works in which various methods of adaptive intelligent traffic control systems have been used. Most of them will be additions to the topics dealt above rather than being newer to the already reported ones. The research works reviewed here adequately demonstrate the multiplicity of approaches possible to tackle traffic management problems in specified contexts. Clearly dynamic systems using real time data and predictive models are better than the commonly used static systems which are insensitive to changing traffic conditions. New methods definitely have significant edge over the current ones in reducing wait times and fuel consumption and thus pollution, giving way to emergency vehicles, reducing accidents and ensuring orderly and smooth traffic flow even during peak hours.

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