# Automatic signalling systems for control of traffic congestion

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## Abstract

An exploratory qualitative review on automatic signalling systems to control traffic congestion, has been attempted in this paper. Google Scholar was searched using the topic itself as the search term, yielding 42 usable papers of both old and recent papers. These papers were discussed under various sections covering different systems, comparison of systems, algorithms, emergency vehicle passage, urban road network and IoT.

The review revealed predominance of papers on the signal control systems for single intersections only. One paper dealt with two intersections. A few papers which considered the whole urban road traffic networks. One specific topic was the easy and rapid passage of emergency vehicles especially ambulances.

Broadly the systems developed can be categorised as tested time-based or density based systems. But these two types were not compared. Only in the latter case, comparisons with fixed time signals were made. In most studies, apart from traffic signal control, associated variables like vehicle arrivals, queuing and inter-vehicular distance were also measured.

In spite of all these researches, no system can be straightaway adopted in any traffic context. The most appropriate few systems need to be tested and compared to select the most suitable one for the given traffic context. When this does not lead to selection of an existing system, need to research arises again. That is where the unlimited scope for future research exists on the topic.

**Keywords:** Signalling, Automatic, Traffic Control, Adaptive System

## Introduction

Increasing population, increasing economic progress giving more expendable money to people, availability of loan schemes to buy vehicles improving affordability of vehicles for middle income groups have all contributed to substantially more vehicles and increasing density of vehicles on the road, irrespective of time of the day. A large number of people move on the road for various activities throughout the day. These conditions create traffic congestions especially at busy times. Such congestions lead to delay in reaching destination, extra fuel consumption while waiting the traffic to clear and the resultant economic losses. Pollution levels also increase. As the congestion effects are more serious in urban roads, control systems are more important in urban areas. However, with limited resources, they find it very difficult to implement an effective automated traffic control system. Hence, an efficient, effective and an affordable control system is required. This paper, through a literature review, examines the scope for automatic signalling systems for this purpose.


Figure 1. Traffic jam in Sau Paulo, Brazil (Wiki)

Traffic congestion on Marginal Pinheiros, near downtown São Paulo is shown in Fig 1. According to Time magazine, São Paulo has the world's worst traffic jams.[6] Drivers are informed through variable message signs that display the prevailing queue length.

Among many choices of adaptive intelligent traffic control systems to control traffic congestion on the road, automatic signalling system is one, which may be cheaper than establishing roadside or on-vehicle monitors or both with a central control system, as has been suggested in many works.

## Methodology of this review

Google Scholar was searched using the topic itself as the search term in different time frames to access both old and most recent papers. The search yielded 42 usable papers. The findings of this review are presented in the sections below.

## Results

### A review

In a review on the subject, Wang, Yang, Liang, and Liu (2018) discussed the merit of using self-adaptive signalling systems in controlling traffic congestions. The advancement of the wireless communication technologies and the development of the vehicle-to-vehicle (V2V) and vehicle to infrastructure (V2I) systems, called Connected Vehicle or V2X, has provided an opportunity for using traffic signal control and driving behaviour control to optimize the operation of urban traffic network. More than 20 self-adaptive traffic control systems have been developed by various transportation research organisations worldwide. Only less than half of these systems have been put into actual use so far. The history of development of traffic control systems given by the authors is reproduced in Fig 2.

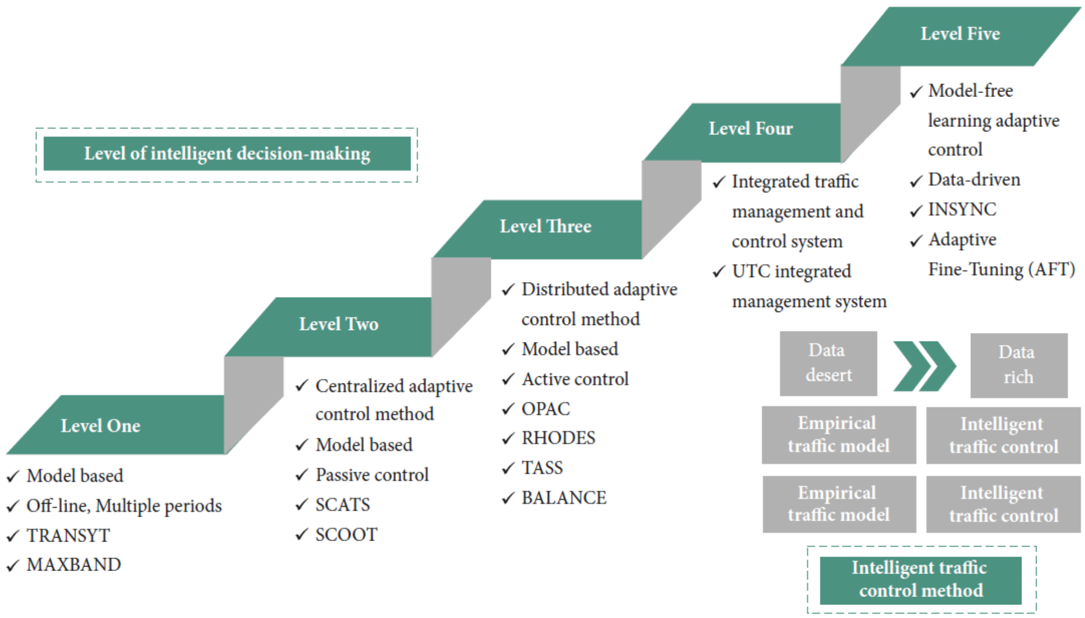


Figure 2. History of adaptive traffic control systems (Wang, Yang, Liang, & Liu, 2018)

Some comparisons of the control systems developed by research have also been done. Usefulness of any control system is highly determined by the context. Adaptive fine tuning (AFT) of level 5 has given promising comparisons with existing systems. Some limitations of the systems in the diagram are: absence of learning ability, inability to achieve desired level of traffic control by even the largest centralised systems due to large expansion of traffic networks, limitations of corridor effect restricting usefulness in large traffic networks, lack of timely response to actual traffic situation making real time control difficult, differences between model assumptions and actual traffic flows and need for highly skilled people due to the need for human interventions. Overall, most of the currently used traffic control systems adopt "prior" feed-forward control or delay-based limited information control methods. The control effect depends on The accuracy of the model describing the actual traffic environment determines the control effect achieved. There is no learning ability to adjust the online control knowledge based on the feedback of the control effect. Traffic signal control based on reinforcement learning is a true sense of closed-loop feedback self-adaptive control, in which the instantaneity, accuracy, and self-learning can be ensured.

**Urban road traffic networks**

To remove the limitations of fixed time signal system, SCOOT ((split, cycle and offset optimisation technique) was developed by a team of research and industry since 1973 and implemented progressively in some cities like Glasgow and Coventry while the system was being updated progressively. Hunt, Robertson, Bretherton, and Royle (1982) described the details of these processes. Evaluations showed that SCOOT reduced travel time significantly, quickly adapted to unusual traffic conditions also, signal times are automatically updated and provides real time information on traffic flows and queues. The aim of Oliveira-Neto, Loureiro, and Han (2009) was to assess the operational performance of passive and active bus priority techniques in fixed and real-time signal systems on a main road in Fortaleza, Brazil. The operational benefits of a SCOOT adaptive signal control system was compared with it using well-adjusted fixed-time plans using TRANSYT for optimisation in the conditions of medium and high traffic volumes. The findings did not support the adoption of passive and active priority schemes. Programming SCOOT's real-time control for a good signal progression of the general traffic (buses and automobiles) was better than passive and active control strategies in the specific traffic context.

Hayashi and Sugimoto (1999) reported about the introduction of a signal control system in Japan. It was named MODERATO (management of origin-destination related adaptation for traffic optimization). MODERATO served as the nucleus of the integrated traffic control systems. It also served as the core of the universal traffic management systems (UTMS). The system was evaluated to benefit by contributing to traffic safety and smoothness significantly through its advanced signal control technology.

Another couple of systems, SITRAFFIC and MOTION, were reported by Busch and Kruse (2001). MOTION is the core online model of SITRAFFIC UTC as it optimizes the control variables related to the traffic lights. MOTION is useful for incident detection and automatic signal plan generation. It has advanced features for public transport prioritization.

Case-based reasoning (CBR), a technique in artificial intelligence (AI), was used by Hossain, Kattan, and Radmanesh (2011) to design a control strategy termed RESSICA (RESponsive SIgnal Control for Arterial). This strategy matches the traffic pattern and assigns a corresponding timing plan from its library. This required minimum recomputing. RESSICA was field tested in a corridor network with four signalized intersections under various levels of non-recurrent congestion scenarios. The performance of RESSICA was significantly better than the current pre-timed/actuated signal controller with respect to reducing travel time, delay, stop delay and intersection delay in the test area.

The network-wide real-time signal control strategy, TUC, was implemented in three traffic networks with varying traffic and control infrastructure characteristics. These were: Chania, Greece (23 junctions); Southampton, UK (53 junctions); and Munich, Germany (25 junctions) with current real-time signal control strategies TASS, SCOOT and BALANCE respectively. TUC was equal or better than these current systems in most cases. TUC is an easy-to-implement, inter-operable, low-cost real-time signal control strategy (Kosmatopoulos, et al., 2006).

Aboudolas, Papageorgiou, Kouvelas, and Kosmatopoulos (2010) modelled the traffic flow process using the store-and-forward modelling paradigm. Network-wide signal control (including all constraints) problem was formulated as a quadratic-programming problem to minimize and balance the link queues for minimum risk of queue spillback. For real time applications, the appropriate optimization algorithm is embedded in a rolling-horizon in a model predictive control scheme. The control strategy's efficiency and real-time feasibility was validated by comparing with the Linear-Quadratic approach of TUC (Traffic-responsive Urban Control) signal control strategy and with optimized fixed-control settings through their simulation-based application to the road network of Chania city centre in Greece from a number of different demand scenarios. More details of the TUC system was provided in an earlier paper by Diakaki, Papageorgiou, and Aboudolas (2002).

### Vehicle occupancy area

Lakshmi and Kalpana (2017) proposed a method of locating the vehicles on a road by measuring the area occupied by them so that all vehicles on the road are counted and this helped in automatically controlling the traffic signalling in a sequential manner based on the amount of traffic on the road. A similar method of determining traffic density by measuring total areas occupied by vehicles in the video frame and image processing techniques, was proposed for controlled signalling in Bangladesh was proposed by Hasan, Saha, Hoque, and Majumder (2014).

### Dynamic signal control

A framework for automatic and dynamic signal control system was proposed by Basavaraju, Doddigarla, Naidu, and Malgatti (2014). In the general conditions, in an intersection, each traffic light is assigned a steady green signal time. Dynamic time-based coordination schemes can be developed for the green signal time of the traffic lights are assigned on the basis of the current traffic conditions. In this study, the authors used data/input/image from object/ subject/vehicle data to the computer for processing and feeding into the microcontroller. The result is displayed on the traffic light signal to control the Closed Loop System.

The traffic signalling is made dynamic based on regressions over data archives, containing a detailed set of traffic quotient and time. This technique incorporates a simple, unique way to calculate traffic quotient based on the physical dimensions of the road and nature of traffic on the road. Pandit, Mundra, and Talreja (2009) developed vehicle tracking systems based on RFID (Radio Frequency ID) technology, called RTSV. In this system, congestion analysis is an important aspect of traffic signalling system. It can be used for suggestion of faster routes and balancing traffic on various routes. To implement RTSV, RFID tags need to be installed on all vehicles and RFID readers need to be installed on the junctions. FASTag is an application of RFID for use in electronic payment of toll fees without waiting at the toll (FASTag, 2020).

A framework for dynamic signal control system with automatic functioning was designed by Wen and Yang (2013). Arena simulation model was used. The physically observed arrival and departure times of vehicles at intersections were used in a simulation experiment. In the simulations by controlling signal light duration and speed limit, traffic congestion was fully controlled. A more detailed explanation of this simulation model and its six sub-models was provided by Wen (2008). How the congestion was removed by reducing red light duration and increasing green light duration was also illustrated. The effect of adjusting durations of red and green lights on traffic on other roads arriving the intersection wee also evaluated and optimised for all roads.

An approach to make the traffic signal adaptive to the dynamic traffic flow using wireless sensor network was proposed by Bhuvaneswari, Raj, Balaji, and Kanagasabai (2012). The system was simulated in LabView software and was compared with the currently used fixed time control scheme. The proposed approach outperformed the existing approaches.

### Imaging systems

Jadhav, Kelkar, Patil, and Thorat (2016) noted that today's traffic management systems are inefficient because they do not consider live traffic scenario. The authors proposed a system smart traffic control system using image processing method. A web camera is placed in a traffic lane to capture images of the road where traffic control needs to be implemented. Efficient processing of these images by MATLAB software informs the current traffic density. Based on this data, the controller sends commands to the traffic LEDs to show particular time on the signal to manage traffic and also to provide alerts to drivers.

Priyanka, Sekhar Rao, Amrutha, and Naidu (2017) implemented an image processing fixed and adaptive algorithms in real time efficient traffic light control. A web camera placed in each phases of traffic light, captures the still images of the road aimed to control the traffic. These captured Images are sequentially matched using image matching with a reference image of an empty road. The traffic is controlled according to percentage of matching. It is possible to use an embedded based module to implement this system.

Rachmadi, et al. (2011) designed an adaptive traffic signal control system using camera as an input sensor to provide real-time traffic data. Principal Component Analysis (PCA) is used for and classification of object on a video frame to detect vehicles. Distributed Constraint Satisfaction Problem (DCSP) method was used to determine the duration of each traffic signal, which was based on counted number of vehicles in each lane. Implementation is through embedded system using BeagleBoard™. The screenshot of a running programme is reproduced from this work in Fig 3.


Figure 3. Screenshot of the running programme in this system (Rachmadi, et al., 2011)

Deng, Liang, Wang, Wang, and Hung (2005) developed a vision based surveillance as the unpredictable and disturbances, which are difficult to measure, may disturb the traffic flow. The vision based methodologies included an object segmentation, classification and tracking methodologies to know the real time measurements in the road. Agent communication was derived based on real time traffic measurement. The adaptive traffic signal control strategy was designed to adapt with the traffic signal time. Experimental comparisons showed this vision-based system to be superior to traditional traffic signal control system in improving the traffic queuing situation.

Rajkumar, Prethi, and Priyadharshini (2017) proposed a signal control framework that uses image analysis to estimate traffic flows. Only low-cost web cameras are required to support a signal control strategy, which uses the current traffic volume. The traffic volumes of the roads near the traffic signals can be estimated from the images obtained at a few observation points and then adjust the signal control. Significant reduction in travel time was noted from experiments comparing with fixed-time signal control system.

**Mixed traffic scenario of manual and automatic vehicles**

Kamal, Hayakawa, and Imura (2020) proposed an innovative adaptive traffic signal control scheme for a mixed manual-automated traffic scenario in an isolated intersection. The optimisation of traffic signals is done using a receding horizon control framework. The aim is to minimize the total crossing time of all vehicles as they are in dynamic states. Manual vehicles are able to cross without problems as the basic characteristics of the traditional signal management system are maintained. The automated vehicles can adjust their speed as the optimal signal changing times are broadcasted one cycle ahead. They are able to cross the intersection with minimum stop-delay. All these are achieved by optimising the green light time of each signal ignoring the current cycle-split concept. In simulations, this type of optimisation usually resulted in the shortest greenlight period each signal without reducing the capacity of vehicles at the intersections irrespective of traffic volumes. As a result, the short signal time enhanced the average speed of vehicles and reduced traffic density and number of idling vehicles. This also helped to improve fuel efficiency and reduce carbon emissions. The proposed system compared well with fixed time signalling system and actuated signal control systems. Some diagrams explaining the system given by the authors are reproduced in Fig 4-6.

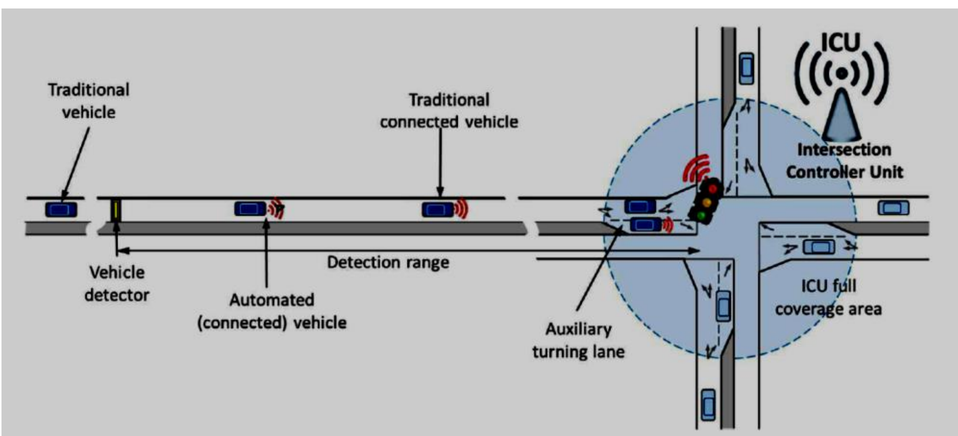


Figure 4. Signal control problem in a typical intersection where both manual and automated vehicles are on the road (Kamal, Hayakawa, & Imura, 2020).

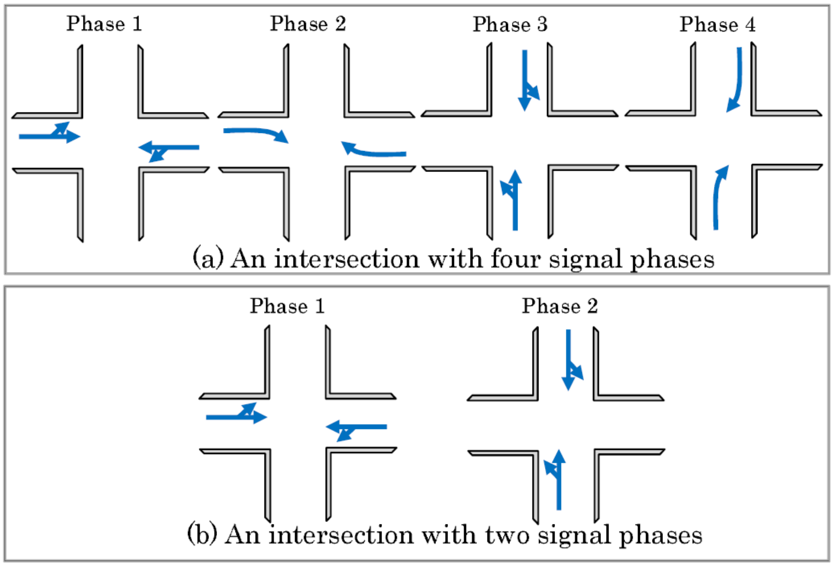


Figure 5. The proposed system explained. Movements of traffic (shown by arrows) at an intersection are grouped, and each group is assigned under a phase to receive the right-of-way cyclically. Examples of signal phasing of the intersection: (a) 4-phase and (b) 2-phase movements. Usually, only one group may have green signal at a time during its assigned phase (Kamal, Hayakawa, & Imura, 2020)

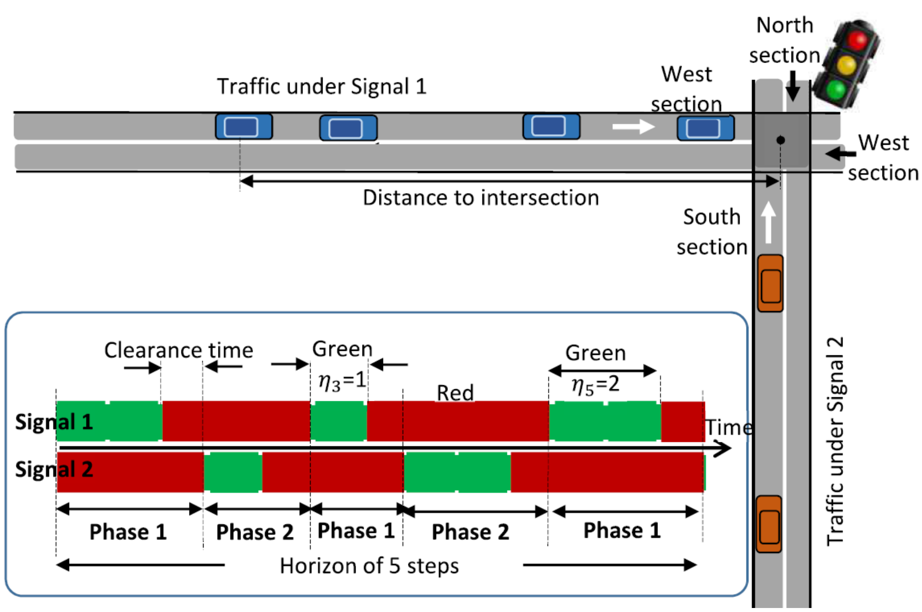


Figure 6. Concepts of time determination for green and red lights considering the number of incoming vehicles and intersection clearance time, which are illustrated using an example of the west and south sections. At the jth step in the horizon, the green duration ($\eta_j h_f$ ) is set in proportion to the number of vehicles $\eta_j$ (Kamal, Hayakawa, & Imura, 2020).

**Rapid passage of emergency vehicles**

Using RFID technology for emergency vehicles and at the intersection to identify it and time prioritisation algorithm, Rayavel, Surenderanath, Rathnavel, and Prakash (2018) developed a signal controlling method for smooth passthrough of emergency vehicles and VIP vehicles at intersections. Two photos of traffic jam in Bilaspur showing ambulance get stuck in traffic jam as people do not bother to give way for it given by the authors are reproduced in Fig 7 and 8.

Figure 7. Ambulance stuck in traffic jam in Bilaspur, India (Rayavel, Surenderanath, Rathnavel, & Prakash, 2018).

Figure 8. Traffic jam and people do not bother to give way to ambulance in Bilaspur, India (Rayavel, Surenderanath, Rathnavel, & Prakash, 2018).

An intelligent traffic control signalling system was devised by Suneetha, Sreekanth, and Sankara (2018) for easy and rapid passage of emergency vehicles. In the system, an RFID tag is placed on the ambulance and a reader is placed at the intersection to detect the ambulance. The microcontroller connected to the reader identifies the ambulance and transmits a signal to the receiver placed on all the traffic light controls on the intersection to turn the green light on for the ambulance to pass the junction. A Pi camera in the ambulance captures the condition of the patient and sends the data to the emergency section of the hospital through Cloud and Python programming to be ready to receive the patient immediately on arrival. An image of an intelligent traffic control system for emergency vehicles, given by the authors, is reproduced in Fig 13. Use of IoT and cloud to connect to the hospital is shown in the diagram. The exact methodology of the authors described in this paper is given in Fig 14.

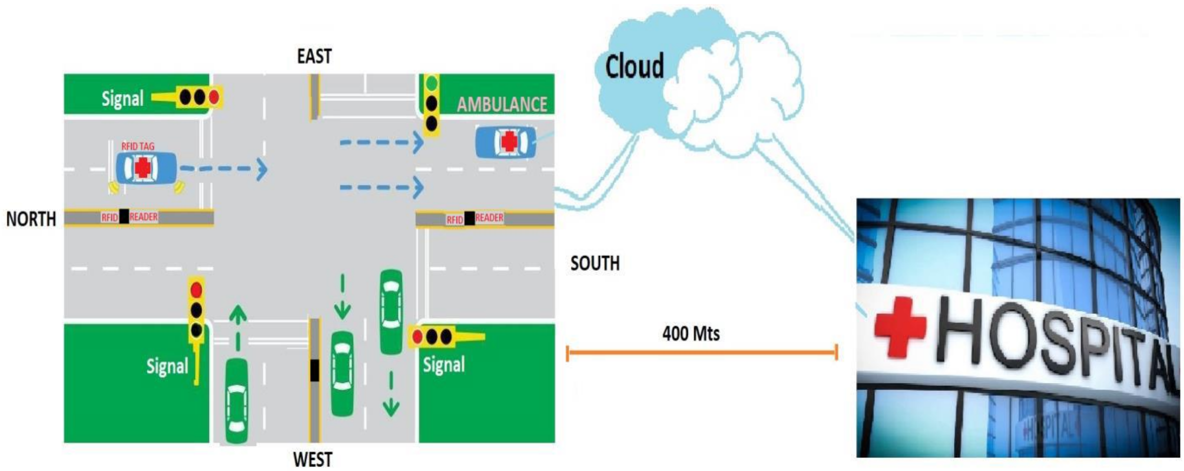


Figure 9. Intelligent traffic control system for ambulances using IoT (Suneetha, Sreekanth, & Sankara, 2018)

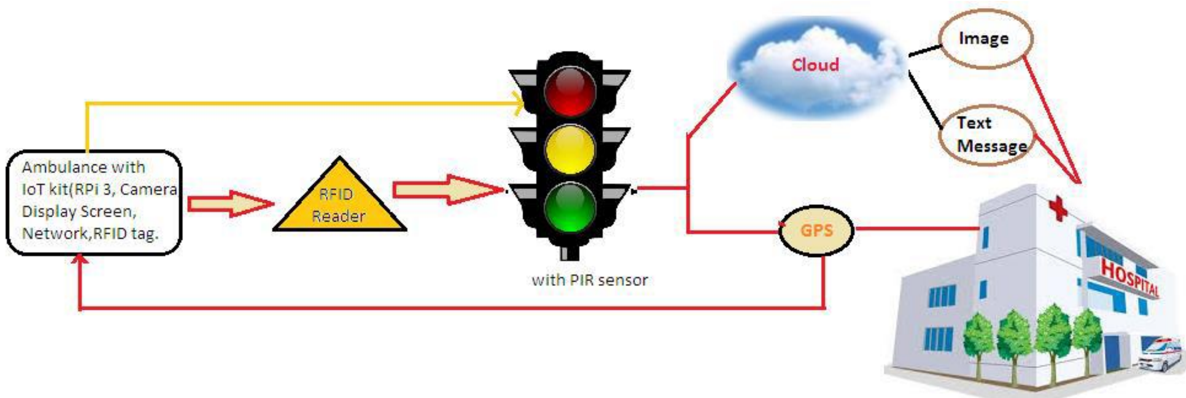


Figure 10. The methodology used in the paper (Suneetha, Sreekanth, & Sankara, 2018)

A system to facilitate easy passage of ambulance by detecting the frequency of the ambulance heading towards the traffic signal was developed by (Iswarya, Bharath, & Reddy, 2018). The system uses sound sensors to monitor the ambulance passing the respective traffic lane using Xbee protocol. This module can be used for all types of high priority vehicles heading towards high density traffic signals.

### Comparison of adaptive control systems

Ta (2016) discussed the most relevant and broadly used adaptive traffic control systems, SCATS, SCOOT and InSync. Vehicular communication technologies and infrastructures developed in future can be incorporated to these system. This will provide efficient automated road congestion alarm systems and facilitate more efficient traffic signal control. Some problems related to the security and vulnerabilities and attacks of the existing systems and possible solutions were also discussed. Authors have provided diagrams explaining the basic concepts and of SCATS, SCOOT and InSync. These are reproduced in Fig 9-12.

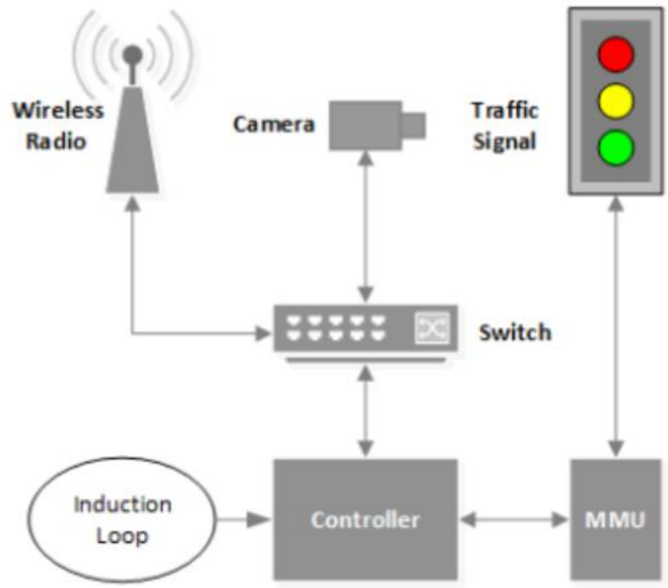


Figure 11. A generic traffic control concept (Ta, 2016).

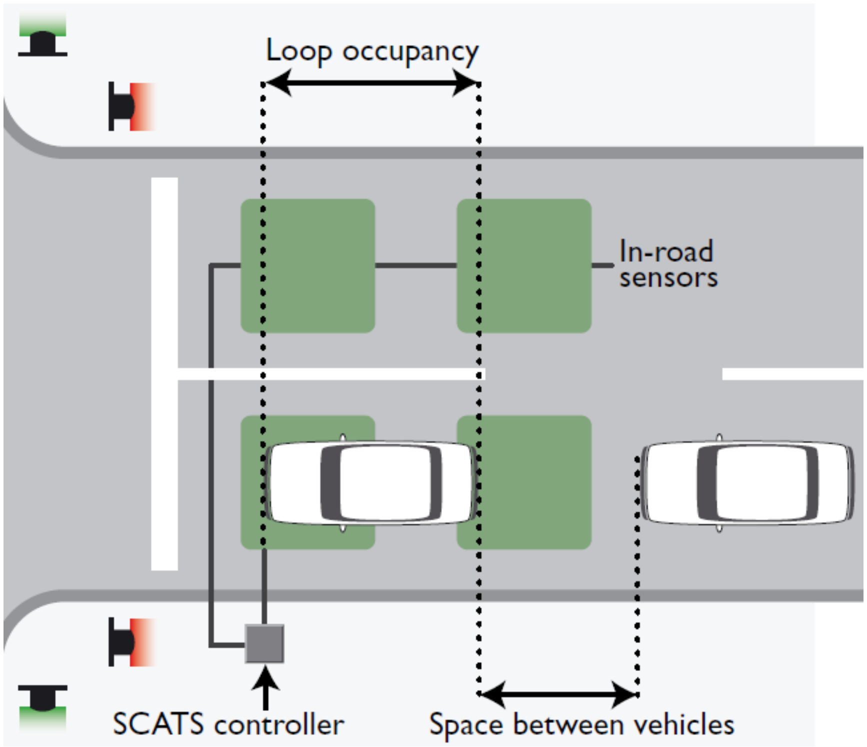


Figure 12. The SCATS (Sydney Co-ordinated Adaptive Traffic System) concept based on loop detectors (Ta, 2016).

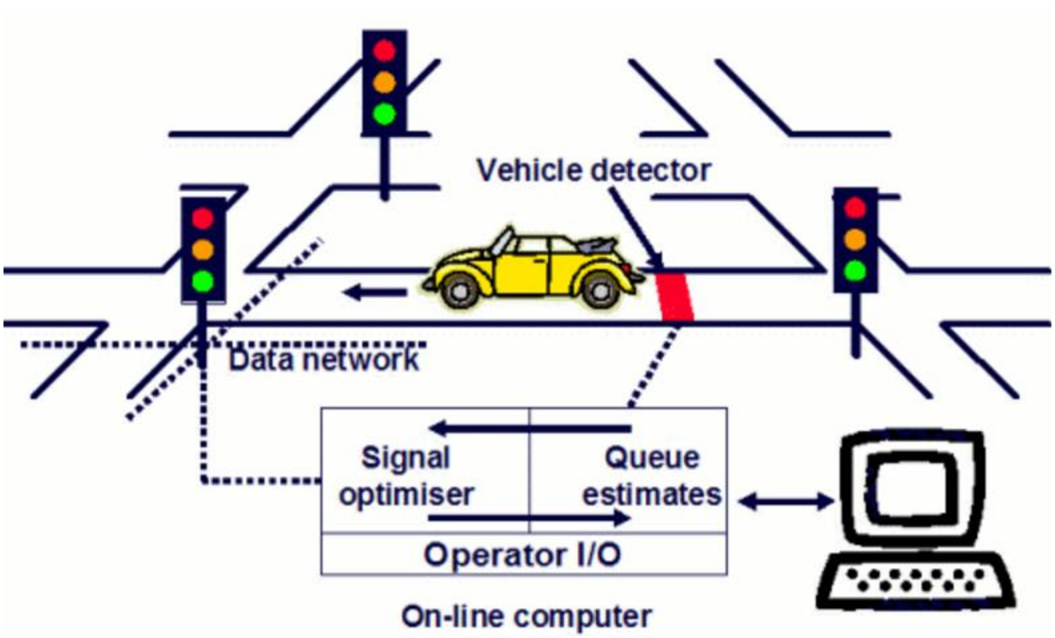


Figure 13. The SCOOT (Split Cycle Offset optimisation Technique) concept based on vehicle detectors (mainly induction loop) (Ta, 2016).

Figure 14. Vehicle counting concept of InSync based on cameras (Ta, 2016).

**IoT for signal control systems**

Frank, Al Aamri, and Zayegh (2019) developed an IoT-based traffic control system, based on the measurement of the actual traffic density on the road. For this purpose, a real time video and image processing techniques were used. The images captured and are stored in the server to compare with the real time image captured via camera to identify the density. The aim is to control the traffic using the traffic density data for controlling the traffic signal through a software application.

The current traffic controlling systems are semi-automatic and based on time only as the parameter, microcontroller-based systems. When IoT has been begun to be used in traffic signalling systems, traffic density has become the parameter. There are security concerns on the sensitive data of great volume is being transmitted wirelessly. Security protocols have been implemented for IoT networks to protect the system against attacks and are purely based on standard cryptosystem. But they cannot handle heterogeneous data type. To prevent the security protocol problems, Sankaranarayanan and Mookherji (2019) implemented SVM machine learning algorithm, which analyse the traffic data pattern and detect anomalies. The SVM algorithm using Python SciKit Libraries, has been implemented for the UK traffic data set between 2011 and 2016 for three cities. It used Raspberry Pi3 processor as an edge router.

**Other algorithms**

Gao, Shen, Liu, Ito, and Shiratori (2017) proposed a deep reinforcement learning algorithm enabling automatic extraction of all useful machine-crafted features from the raw data on real-time traffic and learning the optimal policy for adaptive traffic signal control. Algorithm stability was improved using experience replay and target network mechanisms. In simulation studies, this system substantially reduced waiting time and outperformed two current systems, namely, longest queue first algorithm and fixed time control algorithm.

A solar powered and automated Raspberry Pi based traffic control system using sensors placed on each road of the intersection was developed by Kamate and Patil (2019). The system was aimed to replace the existing time-based system.

The need for an automatic traffic diversion plan for diverting traffic away from congested roads before the vehicles reach, was considered by Sandhya and Karthikeyan (2017). In this plan, the neighbouring traffic signals communicate. The microcontroller in the traffic signal of a jammed road, communicates the position to the previous traffic signal, which enables users take a diversion. Further congestion or accumulation of traffic is prevented till the current jam is cleared. This saves time and fuel and reduce exhaust emissions. In this system, an additional fourth light installed in every traffic light to show the direction of the blocked road. Traffic jam is reported when continuously vehicles are detected every second by the sensor. Traffic jam can be reported as alerts to fire and ambulance services.

A network consisting of a grid system specifically designed to show highly interactive tidal congestion was developed by Hardy and Liu (2017). The available forward road capacity (AFRC) algorithm was used as an extension of existing MOVA control algorithms. The objective of providing maximum junction utilisation under congested conditions is explained along with the proposed solution. AFRC automatically determines the temporal and geographic boundaries of congestion and attempts to resolve the problem across multiple junctions without the need for prior knowledge of traffic flows. The system is therefore self-organising and, as a result, is able to respond to dynamic and unanticipated flow changes without manual reconfiguration.

Gulić, Olivares, and Borrajo (2016) proposed an autonomic system that uses automated planning techniques. These techniques have the properties of easily configurability, modifiability and are capable of reasoning about the impact of changing the default traffic lights behaviour. The implemented system has some autonomic properties. The sequential steps are, monitoring the current traffic state, detection of degradation in system performance, setting up new sets of goals, triggering actions in the planner with control actions and executing the selected sets of actions. Significant reduction in traffic congestion was obtained in simulations and real world studies.

A Markov state transition model for an isolated intersection in urban traffic was proposed by Xu, Xi, Li, and Zhou (2016). It formulates the traffic signal control problem as a Markov Decision Process (MDP). To reduce computational workload, sensitivity-based policy iteration (PI) algorithm is used to solve the MDP. The model is stage-varying according to traffic flow variation around the intersection. The state transition matrices and cost matrices are updated progressively facilitating searching for new optimal policy by the PI algorithm. The proposed model also can be extended to a traffic network using the space-time distribution characteristics of traffic flow and the PI algorithm. Simulation experiments on a small traffic network showed the capability of reducing the number of vehicles substantially compared with the fixed-time control, especially when traffic demand is high and also with high computationally efficiency.

Anisha and Uma (2016) designed a density-based dynamic traffic signal system. The signal timing changes automatically on sensing the traffic density at the junction. In the system, the road on which there is high density of vehicles gets the green signal to move first, with preference for emergency vehicles move first. Accident messages are displayed as and when they occur to affect the traffic. In experiments, the proposed system reduced the traffic congestion compared to the existing system.

Mousavi, Schukat, and Howley (2017) designed two kinds of reinforcement learning algorithms. One was the deep policy-gradient and the other was the value-function based agents. Both were aimed to predict the best possible traffic signal for a traffic intersection. a snapshot of the current state of a graphical traffic simulator was received by these adaptive traffic light control agents at each time step. Control signals were produced by these systems based on these snapshots. The policy-gradient based agent maps its observation directly to the control signal. The value-function based agent first estimates values for all legal control signals and then selects the optimal control action with the highest value. Simulations in the Sumo traffic simulator showed promising results without any instability issues during the training process.

Jiang, Hu, An, Wang, and Park (2017) proposed an eco-driving system for an isolated signalized intersection under partially Connected and Automated Vehicles (CAV) environment. This system prioritizes mobility, which leads to improvement of fuel efficiency and optimisation of the entire traffic flow by optimizing speed profiles of the connected and automated vehicles.

Thamilselvam, Kalyanasundaram, and Rao (2019) used UPPAAL STRATEGO of Eriksen, et al. (2017) for coordination between the controllers at two traffic intersections. This was done by providing a "green wave" in the heavily congested direction. This arrangement resulted in overall waiting time of cars and queue length. Uppaal Stratego is a tool #, in which, machine learning and model checking techniques are combined to synthesize near optimal control strategies.

Labib, Mohiuddin, Al Hasib, Sabuj, and Hira (2019) developed a three-part system to create optimized variable signal timing profiles for a congested intersection in Dhaka. The intersection was being regulated by fixed-time traffic signals. A computer vision tool was used for analysing the video footage of traffic from the intersection to extract traffic flow data. Another data-mining process was done on this data. It resulted in an accuracy of over 90%. A local traffic expert analysed the final data set. Two hybrid scenarios were created one based on the data and the other based on the expert's input. They were simulated at the micro level. The variable timing profiles obtained by simulation for the traffic signals gave a 40% reduction in vehicle queue length, increased the average travel speed, and educed traffic congestion significantly. A conceptual diagram of the proposed system given by the authors is reproduced in Fig 15.

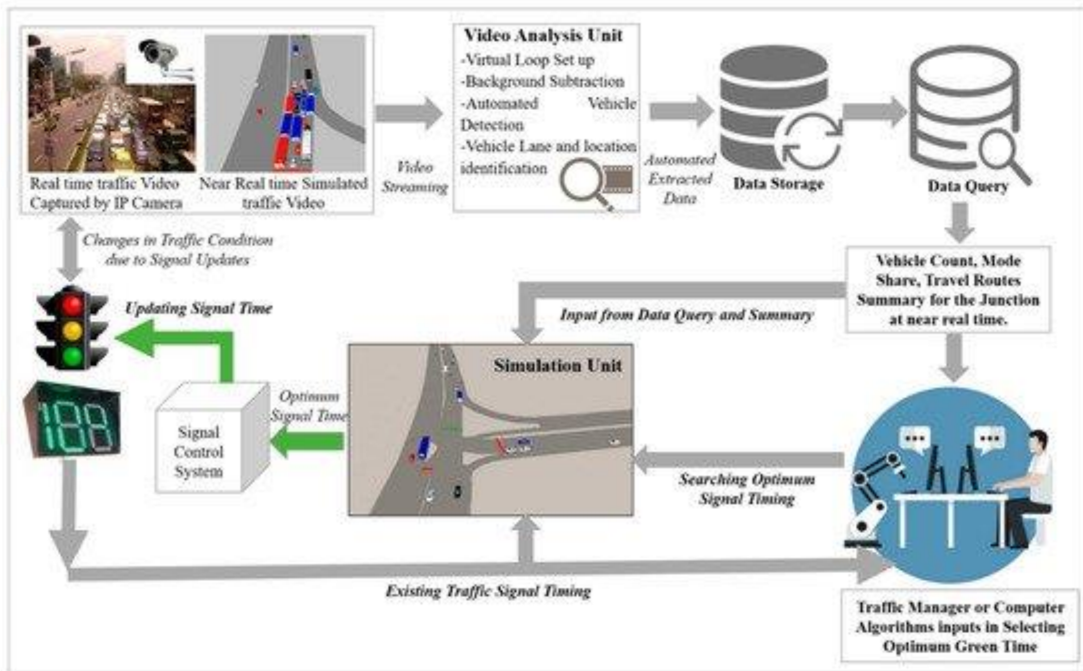


Figure 15. A conceptual diagram of the proposed system (Labib, Mohiuddin, Al Hasib, Sabuj, & Hira, 2019).

**More than one intersection**

It is a difficult to problem to synchronise multiple traffic light systems at adjacent intersections due to many variables involved. Conventional systems are not capable of handling variable flows approaching the different junctions. Mutual interference between adjacent traffic light systems, the disparity of cars flow with time, accidents, passage of emergency vehicles and the pedestrian crossing are not incorporated in the existing traffic system. Therefore traffic jam and congestion are likely to happen in such contexts. Ghazal, ElKhatib, Chahine, and Kherfan (2016) proposed a system based on PIC microcontroller. In the system, the traffic density is evaluated using IR sensors to achieve dynamic timing slots with different levels. A portable controller device solves the problem of smooth passage of emergency vehicles.

## Conclusions

In the above review, most of the signal control systems were intended for single intersections. Rarely, two intersections were considered. There were also a few papers which considered the whole urban road traffic networks. One specific problem researched was the easy and rapid passage of emergency vehicles especially ambulances.

A fair range of papers developed and tested time-based or density based systems. There was no comparison between them. Only in the latter case, comparison with fixed time signals were made. In most studies, it was not just the traffic signal control alone that was researched. Associated variables like vehicle arrivals, queuing and inter-vehicular distance were also considered.

All said and done, when it comes to implementing a traffic signal control system for a particular traffic context, none of these systems can be adapted straightaway. At best the more promising ones can be compared in the given context and selected the best. If this does not provide an answer, fresh research is again called for. That is where the unlimited scope for future research exists on the topic.

## Limitations of this review

This review was originally intended to be a systematic review. But, in systematic reviews, the selected papers (very few only may be qualified if strict criteria of inclusion and exclusions are set) can only be briefly described and tabulated. An ordinary detailed review, on the other hand, permits detailed treatment of the research papers. No particular exclusion or inclusion was set. This made possible inclusion of a large number of papers even within this limited search of only a few Google Scholar pages with time frames set to cover old and new papers.

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