APPLICATION OF ADAPTIVE SIGNAL CONTROL IN DEVELOPING COUNTRIES

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Abstract:
This study details a case study along Lodhi Road in Delhi, India where smart network optimisation was implemented using PTV Balance and Epics along a 3 km long route, with six signalised intersections. A simulation was conducted using PTV Vissim, a microsimulation programme, in which the fixed time signal controllers were replaced with adaptive traffic signal controllers and integrated with the Balance and Epics systems. Simulation outputs indicated very good mobility improvement along the test corridor. Average operating speed along the network was shown to increase by 27%, while average travel time and queue length decreased by 26% and 37% respectively. It was therefore recommended to implement systems that integrate traffic signals to provide network wide traffic optimisation. Real world testing of adaptive signal control in India will be implemented shortly.

Keywords:
Adaptive Signal Control, Network Optimization, Traffic Signal, Non-lane-based traffic

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Introduction
Urban populations are increasing across the globe, as well as in developing countries. Population growth increases the demand on the transport network in cities, leading to higher levels of congestion and delay to commuters. Very often, infrastructure cannot be upgraded or expanded to address congestion due to insufficient space in urban areas and usually due to inadequate funding opportunities, especially in the developing country context. The solution to the increasing traffic problem in cities therefore cannot be limited to infrastructure improvement, rather it will require improved management of the transport network.

Advances in technology allow traffic engineers to develop new methods to reduce travel time and traffic congestion on urban road networks. One of these methods, effective traffic signal control optimisation, is detailed in this paper. Traffic signal controllers on a network of intersections can be integrated and optimised to promote seamless travel along a route, thereby reducing delay to traffic and significantly increasing operating speed. These systems can be integrated to regulate traffic control on a network of traffic signals, improving the flow of traffic in urban areas, and therefore decreasing congestion.

This paper considers the application of adaptive signal control in a developing country environment. A case study carried out in Delhi, India is presented that employed traffic control tools developed by PTV; namely PTV Balance and Epics, to investigate possible improvements to traffic flow at signalised intersections. A traffic simulation indicated good improvements to operating speeds and reduction in queues with the application of traffic signal optimisation using the PTV applications. The recent application of these systems in the Indian city of Chandigarh is briefly discussed. It showed very good results that match those of the simulation.

The study also considers the future application of traffic signal optimisation in African cities, considering the infrastructure requirements for such systems. Special emphasis is given in the paper to traffic conditions that are particular to the developing country context, such as proper detection of traffic that may be non-lane based.
Adaptive signal control

Signal coordination

The technology that is available in the 21st century allows us to adapt our environments to streamline our activities. The same can be done with traffic lights. It is possible to use technology and communications to coordinate traffic signals along a network to implement a continuous green wave along a route, allowing vehicles within the wave to travel seamlessly and without delay from origin to destination. The peak direction of travel during, for example, the morning peak hour can be allocated priority along a road network, to ensure that these vehicles stop at as few intersections as possible. Coordination of signals is arranged to ensure that signals change to green as a platoon of vehicles approaches a traffic signal, preventing delay. This can reduce fuel consumption and vehicle emissions, as vehicles can travel at a relatively constant speed, without needing to break and accelerate at intersections.

PTV Balance (Balancing Adaptive Network Control Method) is a software tool for optimising traffic network signal control. A macroscopic traffic model uses real time traffic flow input from traffic detectors placed along the road network (Prabhu, et al., 2016). The traffic volume input is used to identify any changes in transport patterns, allowing the actual traffic situation to be modelled for an entire road network (PTV Group, 2016). PTV Balance then assesses different signal settings and control options for the road network and can interface with traffic signal controllers to implement updated signal phasing plans. The programme considers the network simultaneously, and can therefore integrate traffic signal controllers at individual intersections to coordinate green waves along a network, as well as reduce the overall delay of the network.

Signal optimisation

Another method for traffic signal control improvement considers the optimisation of signal cycle phasing at a single intersection. In this instance, the traffic signal controller is adjusted to consider the actual traffic flows arriving at the intersection. The green time allocated to each approach is adjusted to minimise the total delay of all vehicles using the intersection, thereby optimising the operation of the intersection.

Signal optimisation is usually carried out when the traffic signal phasing plan is prepared for the intersection based on counted traffic volumes. In most instances, a set signal plan is prepared for the main traffic periods of the day, for example the morning and afternoon peak period, the midday period and the off-peak evening period. The signal timing is then implemented and the traffic signal operates according to the set phasing plan until the responsible traffic authority updates the plan. Unfortunately, this signal phasing plan does not take into account dynamic changes in traffic patterns over time, or the influence of an incident, such as an accident or special event on the traffic patterns. If traffic signals are not regularly optimised, they can continue to operate according to an outdated and therefore inadequate signal phasing plan for years. This reduces the operational capacity of the intersection, and therefore the entire road network.
PTV Epics (Entire Priority Intersection Control System) optimises the traffic signal timing of individual intersections to improve operation of traffic on all approaches of the intersection. Epics estimates the traffic condition for 100 seconds into the future, based on real time traffic detector data and measured queue lengths (Prabhu, et al., 2016). It then optimises the signal timing for the intersection, and can also take into account prioritisation for public transport at the intersection. PTV Epics adjusts the signal phasing plan, either lengthening or shortening green phases for approaches, or totally omitting a phase (PTV Group, 2016).

**Combined System for Adaptive Signal Control**

PTV Balance and Epics can be combined. This allows individual intersections to be optimised (through PTV Epics), after which the discrete intersection information is passed to PTV Balance, which integrates the signal patterns of the corridor network, allowing signal coordination. The most appropriate network signal timing plan is implemented, and sent back to Epics, which can adjust and update the individual signal timings according to the network plan if necessary (PTV Group, 2016).

**Case Study: Lodhi Road, Delhi**

A traffic simulation was conducted to determine the impact of operating PTV Balance and Epics along a corridor in Delhi, India. This investigation was detailed in TrafficInfraTech (Prabhu, et al., 2016), and is summarised below. The investigation details the application and improvements that can be expected when implementing traffic signal optimisation and coordination in a developing country context.

**Study Area**

The simulation was carried out in Delhi, along a 2.1 km stretch of Lodhi Road, a major arterial road in Delhi with a road reserve of 45 m and three lanes per direction, separated by a median. The surrounding land uses are predominantly residential and institutional. Six signalised intersections along Lodhi Road, indicated in Figure 1, were included in the study. The intersections are controlled by fixed time traffic signals. Cycle time and green time allocation per phase have particular settings for peak and off peak periods. Delhi has one of the highest rates of car ownership in India. The modal split along the corridor was observed to be 60% private car, and 24% two-wheeler traffic (16% other).
Traffic surveys were conducted for a 16-hour period. Turning movement counts, travel time, speed and delay surveys were conducted and information about signal timings were collected. The Safdarjung Tomb Junction accommodates the most traffic in the network, with 9,056 vehicles counted on all approaches during the afternoon peak hour between 17:30 and 18:30. The average peak hour speed along the corridor was found to be 18.6 km/h and the peak hour journey delay was 269 seconds. The signal cycle lengths at intersections along the corridor varied between 100 seconds and 240 seconds per cycle.

**The Simulation**

The network was modelled in PTV Visum, using Balance and Epics to operate the signal control at the six signalised intersections. The model was then imported to Vissim for traffic simulation and calibration. A network wide cycle time of 120 seconds was selected for all signal controllers along the network to ensure that the intersection signals could be coordinated. The corridor was optimised every 300 seconds. Individual intersections were optimised and then the individual intersections were coordinated to optimise the network.

A snapshot of the Vissim model is indicated in the figure below of the Indian Habitat Centre Junction, the intersection of Lodhi Road (east-west direction) and Max Mueller Marg Road. This snapshot indicates the mix of vehicles that are included in the model as depicted by the relative size and shape of the vehicle symbols. Two wheelers, cars and heavy vehicles are all included in the modal split. It also indicates that the model and traffic sensors are capable of monitoring and modeling non-lane-based traffic. Particularly where two-wheelers are included in the traffic stream, four vehicles can stand adjacent, even though the road is demarcated with three lanes per direction. It is important that the transport model is able to accurately describe the actual traffic condition.
Network Operation Improvement

The results of the travel time analysis along the test route are presented in Figure 4. The travel time per segment that was measured along the route (indicated by “Fixed Time Observed”) is compared to the travel time simulated before optimisation and after optimisation (indicated by “Simulated” and “Balance Results” respectively). The reduction in travel time that was determined by the optimised simulation is clearly indicated on all sections of the route. The weighted travel time results indicate a 26% reduction in travel time along the entire Lodhi Road test corridor when compared to the travel time using fixed time controllers with signal timing as currently operating at intersections along Lodhi Road.

The results of the simulation indicate significant advantages of the optimisation of traffic signals and corridor coordination by PTV Balance and Epics. The percentage change in traffic parameters are presented in the table below.

Table - Result Comparison of fixed traffic signal time vs Balance and Epics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time (seconds)</td>
<td>▼ 26%</td>
</tr>
<tr>
<td>Queue Length (metres)</td>
<td>▼ 37%</td>
</tr>
<tr>
<td>Journey Delay (seconds)</td>
<td>▼ 45%</td>
</tr>
<tr>
<td>Network Speed (km/h)</td>
<td>▲ 27%</td>
</tr>
<tr>
<td>Network Delay (seconds)</td>
<td>▼ 30%</td>
</tr>
</tbody>
</table>

The average queue length at intersection approaches along the corridor decreased on average by 37% at the six intersections included in the analysis.

Emission Impact

One of the major challenges of modern times is environmental pollution. Air pollution in Delhi has been measured at levels comparable to Beijing, the city with the worst air pollution in the world (Prabhu, et al., 2016). It is vital that emissions from traffic be reduced. The transport model investigated emission levels of traffic along the Lodhi Road corridor with current transport management, as well as with the simulated effects of the traffic signal timing coordination and optimisation. Implementing traffic signal optimisation and coordination of intersections along the network is estimated to reduce pollution levels by between 10 and 15 %, including Carbon Dioxide (CO2), Nitrogen Oxides (NOx) and particular matter (PM10), as detailed in Table 2 which considers the change in emissions per kilometre along the Lodhi Road corridor for three different vehicle classes.
Table - Air pollution reduction per kilometre

<table>
<thead>
<tr>
<th>Classes</th>
<th>Vehicles</th>
<th>Co2 (Kg)</th>
<th>Nox (g)</th>
<th>PM10 (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Duty City 2013</td>
<td>Private Vehicles</td>
<td>▼13.6%</td>
<td>▼11.3%</td>
<td>▼14.9%</td>
</tr>
<tr>
<td>HD Medium City 2013</td>
<td>Buses</td>
<td>▼8.3%</td>
<td>▼8.6%</td>
<td>▼7.1%</td>
</tr>
<tr>
<td>HD Heavy City 2013</td>
<td>Commercial Vehicle</td>
<td>▼6.5%</td>
<td>▼2.7%</td>
<td>▼10.7%</td>
</tr>
</tbody>
</table>

The economic impact of implementing the traffic signal optimisation and coordination at all signalised intersections in Delhi was estimated to be $33 million USD per year.

**Implementation of Real-World Testing**

The new systems were implemented in the Indian city of Chandigarh at three intersections, after a simulation study that showed very good results with reductions of 48% in network delay. The present signal controllers and signal heads were kept, but connected to a box of PTV partner ISSD. This box contains PTV Epics and connects to the new video detectors that were installed at existing poles roughly 50 m before the stopline in each approach. Comprehensive surveys with GPS-equipped floating cars were conducted before and after the implementation of the new control. They showed a huge decrease of car delay of 40% at these intersections, and of 20% of travel time (both in evening peak, the measured period), while the overall throughput of cars increased by more than 50% during the peak hour. Furthermore, the boxplots covering all FCD rides (see below) show that all routes show a decrease in delay by 26% -68%; not a single approach had longer delays for any one FCD vehicle, resulting in T-Test values that are much less than 0.01. So the measurements are also highly statistically significant.
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Application in Africa

Application Areas

Developing countries face intense traffic congestion in cities. Coupled with this, planning authorities often have limited resources to update and adjust signal timings, which results in infrequent optimisation of the transport network. Updating traffic signal timings according to traditional traffic engineering methods requires numerous traffic counts as well as highly skilled transport practitioners and operators. Often, budgets do not allow for this process to occur on a regular basis, while more pressing basic services need to be addressed by planning authorities.

Self-optimising and coordination traffic signal systems can provide a solution in developing countries, because it will address the congestion issues in cities without requiring expensive traffic surveys and resources. Additionally, automatic optimisation and coordination of signals can adjust signal timings in real-time to manage traffic control according to changing traffic conditions, either of recurring peak times or resulting from particular traffic incidents.

Traffic Flow Detection

Any tools that are able to optimise traffic signal phasing in real-time according to actual traffic conditions require real-time input of traffic information from the transport network. It is necessary to measure vehicle flows and analyse queue lengths in order to optimise network priorities. In Africa, it is important that a variety of vehicles can be observed and recognised by vehicle detectors, including passenger vehicles, two-wheelers, heavy vehicles and possibly non-motorised modes of transport, according to the requirements of the area of implementation. Additionally, traffic may be non-lane-based because drivers do not necessarily

Figure – Boxplot of before (red) and after (green) travel times on eight main routes
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adhere to demarcated lanes in an attempt to utilise all available space for traffic, especially when there are a number of two-wheeler vehicles in the traffic stream. Non-lane based traffic precludes the use of conductive loops imbedded in the road surface, which are only able to monitor traffic per lane. Solutions to vehicle detection are provided below.

**Camera Based Traffic Flow Detectors**

Non-lane based traffic can be effectively detected by video cameras that monitor each directional movement at all approaches of an intersection, as well as a wide angle, fish eye camera to monitor an entire intersection. Video feed is interpreted by automatic image recognition software that recognise vehicles and the trajectory that vehicles follow to count the number of particular movements at intersections. This will enable turning movements to be counted, which provides significant input for the optimisation of signalised intersections. The success ratio of such a camera system can range between 80 and 90% detection of all vehicles and correct recognition of direction (Prabhu, et al., 2016). A system of cameras is required to be installed at each intersection that is to be included in the traffic optimisation network.

**Alternative Data Sources**

It should also be possible to incorporate other sources of data that observe the operational condition of the transport network. Floating Car Data (FCD) is data collected along the trajectory of a vehicle and includes speed, travel time, and route information. FCD is collected anonymously from probe devices in vehicles, which include cellular phones with GPS applications, personal GPS navigation devices and vehicle tracking systems (Leduc, 2008). Probe devices transmit the speed and positional data of individual vehicles to a service provider that gathers, stores and uses or distributes FCD. Data is usually available to purchase from these service providers and has extensive value for transport planning.

FCD represents a sample of the vehicle population, as not all vehicles are equipped with probe devices. The main limitation of FCD is therefore that it cannot provide actual traffic volume on the roads where it is measured. FCD can however give a good indication of the operation of traffic facilities, through reporting the average operating speed along a road network. Probe devices in vehicles are free to travel anywhere on the road network, hence the term “Floating Car Data” (TomTom, 2011). FCD is available on any road that carries vehicles with probe devices, and so is available on most major roads globally because of the extensive availability of technologies such as smart phones. Additionally, FCD uses existing communication systems (Lovisari, et al., 2016) reducing expenses as there are no installation and maintenance costs directly associated with data collection. FCD does not require infrastructure along the road network like traffic sensors and so could significantly reduce infrastructure and maintenance costs to collect traffic information (Yi, et al., 2004). FCD is considered to be a particularly suitable source of traffic information in developing countries due to its cost efficiency (Rao & Rao, 2012) (Ishizaka, et al., 2005).
FCD can be used to optimise individual traffic signals because it can provide information about the proportion of turning movements from approaches at intersections. Additionally, average speed on intersection approaches can be analysed, indicating if there are queues of very slow moving vehicles forming. FCD can also be useful for the coordination of signals, as they provide an indication of the actual travel time between intersections, which is needed to synchronise adjacent traffic signal to ensure that vehicles can travel along a corridor in a “green wave”.

The availability of FCD in developing countries is an important aspect to consider to ensure that this could be a viable source of data for traffic network optimisation. Cell phones will be a significant market of probes in developing countries. Smart phone penetration in Africa is growing. In 2015, 37% of adults in South Africa owned a smartphone. In Kenya, Nigeria, Ghana and Tanzania, the percentage of adults using a smartphone was respectively: 26%, 28%, 21% and 11%. The lowest penetration of smartphones in Africa is in Ethiopia and Uganda (4% of adults each) (Pew Research Centre, 2016).

It will be necessary to increase the number of probes in developing countries to ensure adequate accuracy of traffic data for use in systems to optimise traffic at intersections. This will require improved internet connectivity and increased probe device coverage. Projects should be implemented to increase probe penetration in Africa to assist with collection of traffic information. Initiatives could include improvement to internet connectivity, as well as incentives to own a smartphone.

**System Management**

Operating PTV Balance and Epics requires specific hardware and management systems. Traffic detection is required at the intersections. Additionally, a central traffic management centre is required to coordinate network operations with connectivity to the traffic controllers on the road network. PTV Epics is installed at the intersection with the signal control box analytics tools. PTV Balance is run from the central traffic management centre.

Since there are often cases with non-lane based traffic in Africa, it proposed that traffic actuated control be implemented with video detection of traffic at intersections. This will require one camera per direction, placed at the height of 6-8m from the ground level and a fish eye camera to monitor the turning movements and the overall performance of the complete junction.

The detection events of the cameras are handed via WiFi over to the intersection signal control box that has PTV Epics embedded. The traffic turning movement volumes detected by the cameras are also sent via a web server to the central traffic control centre, together with further state information of the intersection, including the current signal control state and running program. The connection to the control centre can be done by any means that allows TCP/IP connection, such as GSM, fibre optics, modem or Ethernet connection, thereby providing very cost effective data transmission. The traffic information is transmitted to PTV Balance – running
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on a dedicated computer in the traffic centre. The signal plans for the network are optimised, and then the optimised and coordinated phasing plans are returned to the same server to be transferred to the control boxes and used as reference by PTV Epics to manage each individual intersection’s traffic signal. The system is flexible enough to be run together with existing signal controllers. Additionally, Bluetooth sensors are available in the controller boxes, allowing for a comprehensive traffic state analysis of the road network und thus helping the adaptive network control.

**Conclusion**

Traffic signal optimisation and coordination can greatly enhance the movement of vehicles along a traffic network. As indicated in the case study conducted along Lodhi Road in Delhi, India using PTV Balance and Epics, delay on the network and queue lengths on approaches to intersection can be reduced, while increasing overall network operating speed and improving emissions levels. Real-world installation in the city of Chandigarh show similar reductions in delay and travel time. The continuous optimisation of the intersections along a road network can respond to changing traffic patterns over time, caused by traffic incidents or special events, and thus reduce the need to modify the systems.

It is proposed that similar traffic signal coordination systems can be used in African or other developing countries to reduce congestion in cities without the need for expensive updating of traffic signal timings through scheduled traffic counts and manual traffic signal optimisation. The requirements of the signal optimisation system were considered in this paper, which includes traffic sensors (cameras) at intersections, and a traffic control centre, while the existing control hardware can still be used. It is also proposed that Floating Car Data (FCD) should be considered as an alternative source of traffic information that can be analysed when optimising the traffic network. FCD can be an important source of traffic information in a developing country context because it requires no infrastructure, therefore reducing the cost of collecting data. For FCD to become a mainstream source of traffic information in Africa, the number of probes and internet connectivity should be increased through programmes and initiatives to increase smart phone use.
References


