IMPROVING TRAFFIC LIGHTS EFFECTIVENESS

Project for Technicity Course

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Introduction

A coordination of vehicle flows is usually reached by a cyclical operation of traffic lights, and by synchronizing these cycles. The typical conditions, however, for which traffic lights are normally optimized for, never occur exactly[1]. Large fluctuations in the number of vehicles arriving during one cycle time may lead to an inefficient usage of green times, which are often either too short or too long.

City planners today try to synchronize traffic signals to improve flow. But variables like pedestrians, halting trucks and buses, and accidents can cause traffic jams and increase driver idling time and, thus, add to overall fuel consumption and air pollution.

Traffic-responsive control strategies are essential to overcome these problems and to reduce travel times, fuel consumption, and the emission of pollutants effectively.

The following video (4 min.) from the Discovery channel explains the challenges of city traffic and the way London deals with that issue[2].

[1] Lammer and Helbing
[2] http://www.youtube.com/watch?v=bXQbfrtCYFA

The problem

The situation San Francisco Bay Area commuters face every day — traffic gridlock, probably worst in the United States.	From Popular Science: What Beijing's 62-Mile, Nine-Day Traffic Jam Means For China's Turbulent Future of the Car.
	
illustration URL: http://www.mysqlperformanceblog.com/wp-content/uploads/2013/03/4649108931_f672383ec1_o.jpg	illustration URL: http://www.popsci.com/science/article/2010-08/62-mile-nine-day-traffic-jam-spells-disaster-communter-promise-chinas-auto-industry

Traffic congestion is becoming a more and more pressing issue for society and a major concern fo urban planners. AlphaGallileo organization indicated in 2010 that currently, traffic jams and road congestion do a lot more than annoy millions of people every day. In the United States alone, delays linked to backed-up traffic cost nearly $100 billion each year, and waste more than 10 billion liters of fuel, not to mention countless human hours. And then there's all the extra CO_2 and other pollutants spewed into the atmosphere. As developing nations become more industrialized, these problems will only grow worse. [3]

The existing methods for traffic management, surveillance and control are not adequately efficient in terms of the performance, cost, and the effort needed for maintenance and support[4]. Many techniques have been used including, aboveground sensors like video image processing, microwave radar, laser radar, passive infrared, ultrasonic, and passive acoustic array. However, these systems have a high equipment cost and their accuracy depends on environmental conditions. Another widely-used technique in conventional traffic surveillance systems is based on intrusive and non-intrusive sensors with inductive loop detectors, micro-loop probes, and pneumatic road tubes in addition to video cameras for the efficient management of public roads. However, intrusive sensors may cause disruption of traffic upon installation and repair, and may result in a high installation and maintenance cost. On the other hand, non-intrusive sensors tend to be large size, power hungry, and affected by the road and weather conditions; thus resulting in degraded efficiency in controlling the traffic flow.

Nagel and Rasmussen in *Traffic at the edge of chaos*[5], determine that the Advanced Traffic Management Systems (ATMSs) tend to drive the transportation system to a regime of maximum flow. **This tendency drives the system towards criticality**, which makes the prediction travel time much harder.

[3] http://www.alphagalileo.org/ViewItem.aspx?ItemId=85211&CultureCode=en
[4] Khalil M. Yousef, Jamal N. Al-Karaki1 and Ali M. Shatnawi
[5] http://www.santafe.edu/media/workingpapers/94-06-032.pdf

The problem, Professor Helbing explains, is that **heavy investments in traffic light systems were made in the 1960s and 70s** rendering most systems today, due to use, age and technological advancement, antiquated. Forty to fifty years ago when traffic volume was lighter, the main job of traffic light systems was to manage peak traffic during the day or, for example, sporting events. The lights were centrally controlled, and not programmed to adjust in real time. Rather, they were mostly optimized for pre-established assumed situations, meaning for situations that traffic planners had faced in the past. The disadvantage of this strategy, especially today, is that the more traffic lights there are to coordinate, the more difficult it is to optimize control of the lights. Why? The dilemma is well-known: the larger the number of nodes, or lights, in a system the more computation is necessary until finally computational time "explodes". "Even for normal-sized cities, super computers are just not fast enough to compute all of the different options that exist for controlling traffic lights. So the number of choices actually considered by the optimization program is significantly reduced," says Professor Helbing.

How Traffic Lights are controlled

Classical control concepts assume a cyclic operation of the traffic lights, where the flows of different directions are served periodically. The cycle time and the parameters defining the green time splits determine the intersection throughput, which can be optimized, within certain bounds, by choosing these parameters according to known formulas.

A coordination of neighboring intersections can be achieved by operating them with the same cycle time and by adjusting the offsets between them appropriately. More advanced concepts aim at an adaptation to variations of the average traffic demand. The on-line (or realtime) optimization of signal plans, however, still just varies the paradigm of a mainly cyclic traffic light operation.

Due to stochastic fluctuations, even optimized green times are usually either too short (creating multiple red lights for queued vehicles that could not be served) or too long (creating unnecessary delays to vehicles of other flow directions).

Most traffic lights, therefore, continue to be programmed offline, regardless of the realities of the road. Unfortunately, "the variation in the number of vehicles that queue up at a traffic light at any minute of the day is huge," Professor Helbing says. None of this variation is considered when optimizing for typical Monday or Friday traffic volume curves. "You are optimizing for a situation that basically is true on average but that is never true for any single day or minute: essentially for a situation that never exists. Plus, even adaptive traffic lights in modern control schemes are usually restricted to a variation of cycle-based control."

Latest developments in use

Synchronizing stop lights

An article published by the Daily Mail newspaper[6] states that Los Angeles goes from gridlock capital of America to nation's model for traffic control after synchronizing stop lights. A project that took nearly 30 years to complete synched up all of Los Angeles' 4,400 stop lights. But the result is not convincing: "Synchronization has allowed LA to boast of real improvements on paper, however, the average driver won't always be able to discern the difference."

[6] http://www.dailymail.co.uk/news/article-2331414/Los-Angeles-gridlock-capital-America-nations-model-traffic-control-synchronizing-citys-stop-lights.html

Examples of most recent projects of stop light modernization:

SCOOT[7] is an Urban Traffic Control (UTC) tool. It typically reduces traffic delay and congestion by an average of 20 per cent. The SCOOT (Split Cycle Offset Optimization Technique) adaptive traffic signal management tool was developed over 30 years ago. SCOOT has recently been updated with the latest pollutant (emissions) data and development work to allow optimization based on emissions. SCOOT is used by the London traffic control system.

UTOPIA Urban Traffic Control System offers a wide range of strategies designed to suit any road network. In the fully adaptive mode, it constantly monitors and forecasts the traffic status and optimizes the control strategy according to flow efficiency and/or environmental criteria. This gives high performance even with unpredictable traffic conditions. The system can assign weighted, selective or absolute priority to specific vehicles (e.g. buses/trams running behind schedule) without penalizing other traffic.

Both SCOOT and SPOT/UTOPIA use optimization methods that only look at local areas around a controller. For SCOOT this is done in the control center whereas SPOT/UTOPIA is based on decentralized optimization. In both cases, the optimized coordination structures are somewhat arbitrary[7].

Sitraffic MOTION[7] (Method for the Optimization of Traffic signals In Online controlled Networks), which sends adapted signal plans to controllers every ten to 20 minutes. The network control method uses data that is transmitted every one to two minutes. The effects of Sitraffic MOTION can be seen in the upgraded control system for the Valby district of Copenhagen where the public urban transport system, was to be made 20 per cent faster without slowing the flow of private vehicles. All travel times had shortened. Bus travel times decreased by up to 27 per cent and the speed of private vehicles rose by up to 6 per cent.

The following picture shows the integrated project control system that manages the Boston Central Artery / Tunnel, one of the largest traffic and facility management systems in the world (ITS with intensive human intervention).

illustration URL: **http://www.roadtraffic-technology.com/contractor_images/transdyn/3_CAT_Computers.jpg**

[7] http://www.itsinternational.com/categories/utc/features/germanys-approach-to-adaptive-traffic-control/

Suggested new solutions

In recent years, a variety of traffic responsive control strategies had been proposed.

One of the most widely used approaches is called **rolling-horizon optimization**, where a repetitive re-optimization of the signal switching sequences enables an adaptation to changing traffic conditions. This kind of optimization problem is solved by different methods: OPAC basically enumerates the solution space, PRODYN applies an efficient heuristics, and ALLONS-D searches a complex decision tree using back-tracking.

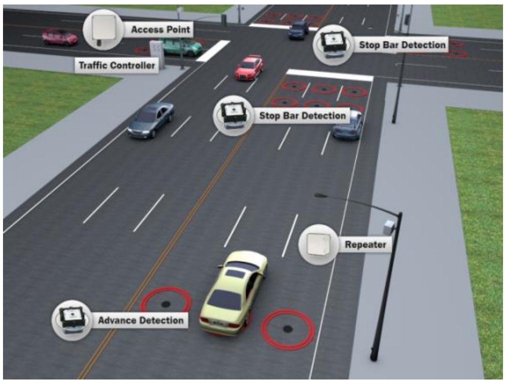
ALLONS-D[8], in some more detail (as an example), is a decentralized real-time traffic control scheme. ALLONS-D is capable of implementing bus priority and supporting progressive signalization on arterial networks. Promising simulation results have been shown to suggest its usefulness as part of a multilevel system for optimal signalization of a network. The novel branch and bound optimization technique that is used to find the optimal delay minimizing signal policy is efficient and could also be utilized to determine optimal signal plans based on other criteria like the number of stops.

Another real-time strategy is **TUC**, which is based on a store-and-forward modeling approach and tries to balance queue lengths by flexible adjustments of green times. TUC, initially developed and field-implemented in Glasgow, Scotland, manipulates the green splits at urban signalized junctions, while the cycle duration and the offsets remain unchanged. The control decisions of TUC are based on real-time measurement data collected from detectors that are located within the controlled area.

Intelligent traffic light control does not only mean that traffic lights are set in order to minimize waiting times of road users, but also that road users receive information about how to drive through a city in order to minimize their waiting times.

The rapid advancements in wireless communication bring a new wave of ideas to traffic management. The ability to wirelessly receive sensed data and transmit commands to stop lights and information boards, will probably transform the way signaling systems are built and controlled, and reduce significantly the involved costs.

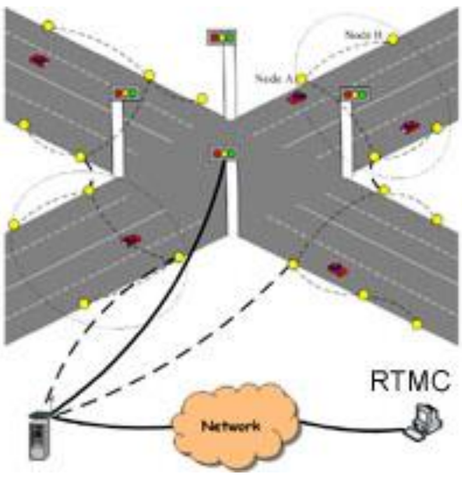
Wireless Sensor Network (WSN) that operates in realtime, uses minimized, self-powered, sensors and communication devices that require much less investment in infrastructure and power supply.



Traffic flow management using wireless sensor networks consists of four elements. They are the Wireless sensor network (WSN), the intersection control agents (ICA), the actuators which are traffic lights and the environment i.e. vehicles. Every sensory node monitors one lane and this data is sent to the ICA. Once the information is received, the intersection agent chooses the best policy for vehicle flow. The intersection agents in different areas coordinate to exchange information and decide which flow model has to be implemented.

illustration URL: http://www.easinet.cn/photo/its_arch.jpg

[8] Isaac Porche and Stephane Lafortune



The WSN-based traffic information collecting system is comprised of wireless traffic information collection nodes (TICoN), wireless data aggregation node (DAN) and remote traffic monitoring center (RTMC). TICoN nodes collect and process real-time information in a distributed and coordinated fashion. They transmit the results to the DAN node wirelessly. Then, the DAN node transfers the information to the RTMC or uses the information to control the traffic light.

illustration URL:
http://wirelessmeshsensornetworks.files.wordpress.com/2014/03/advance_detection1.png?w=640&h=481

Self-organizing traffic lights is a new conceptual system proposed by Lammer and Helbing[1]. Their idea is of intersections that communicate and make decisions in coordination with others to optimize traffic flow. That allows for variable adjustments not only of the duration, but also of the order of green phases. They tested a decentralized approach that lets the traffic lights communicate and calculate how changes at each intersection would affect the entire system. Traffic lights could request green time only when there is a definite demand for them, the researchers write. This acyclic approach could eliminate the particularly annoying problem of sitting at a red light while there's no traffic. They found that delay times could be reduced from 10 to 30 percent with system-wide decentralized control.

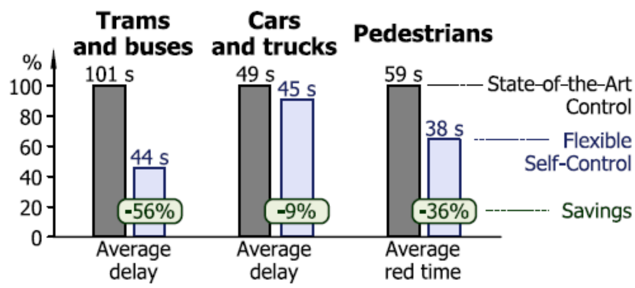


Figure 11 In comparison with the currently used state-of-the-art control (left columns), the flexible self-control (right columns) reduces the average delay for all modes of transport.

They applied their method to the city center of Dresden (Germany), by simulating 13 traffic-light-controlled intersections. The particular challenge is to coordinate heterogeneous traffic streams in an irregular road network topology and to prioritize several public transport lines (tarms and busses) at the same time.

In contrast to a fixed-time controller, the green times are requested only when there is definite demand for them, the cycle time is not fixed, and the service is not necessarily periodic. If the traffic load is heavy in one direction, that road will be served two times, while others will be served only once.

The acyclic operation of the traffic lights is an essential feature of the proposed concept, which compensates for random fluctuations in the traffic flows, and which consequently reduces the mean value as well as the variance of vehicle and pedestrian queues and delay times. Instead of serving each flow exactly once in a cycle time, self-controlled traffic lights tend to give green lights to heavier traffic flows as long as possible and more often.

Simulation tests show that this strategy works well. With non-periodic - not cyclically repeated - traffic lights releasing long traffic queues, travel time even becomes more predictable. Flow is kept stable, fuel consumption and emissions are reduced.

Conclusions

I live in Haifa, Israel. From the city's website I learned the following:

Haifa has at least 147 traffic signal control systems, with some systems controlling multiple nodes, and each node has several stoplights. Large junctions usually have stoplights in all directions, stoplights for pedestrians and several sets of lights in the same direction - one set before the turn and another one in the node. For sections of the road with several nodes it is very important to coordinate the lights. Computer control switches the lights depending on traffic speed to make fewer stops, but even a deviation of a few seconds in one stoplight can cause large queues.

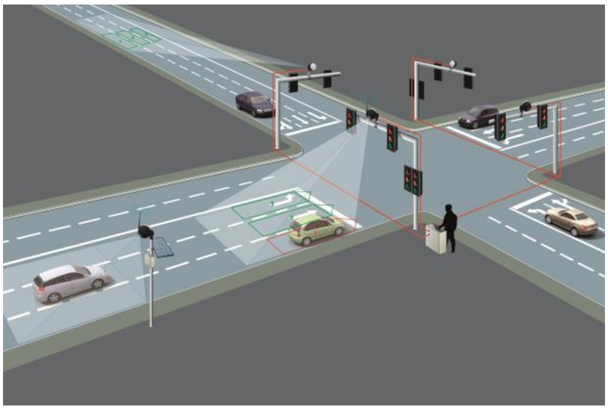
The system uses electronic sensors to sense that vehicles are waiting and to operate the stoplight accordingly. The timing of stoplights is changed with the time of day, and a busy path gets longer crossing time in rush hours, and less time in the rest of the day. Many nodes also include traffic cameras that allow the control staff to change the schedule as needed and handle the loads efficiently.

This description accumulates to a traditional, fixed-time control system with a control center that changes the stoplight programing by human intervention.

So what would be the solution that I will recommend to the mayor of Haifa?

Adaptive systems like those used in London and other big cities proved to be limited in their capacity to adapt to changes in load and minimize traffic jams. They are also very expensive to install and run.

Synchronizing all stoplights of a small or large city (like the 4,400 stoplights in LA) is a vast and very expensive project, which requires purchasing of expensive hardware and causes prolonged disturbances to traffic during installation.



The emergence of small and independent sensing devices of all kinds, wirelessly connected to create networks, seems to be the trend of the future. Add to that the replacement of traditional stoplight lamps with LED lights, will dramatically reduce the cost of sophisticated systems and will require much less maintenance.

(illustration URL: http://tmcporch.com/assets/trafficOpt1.jpg)

Decentralizing the network of traffic lights programming according to the concept suggested by Lammer and Helbing[1], the **Self-organizing traffic lights**, seems to be the most innovative way of thinking. This idea requires less computational power, less human intervention, less top-down control and much more flexibility. It can better respond to the local situation of each node and neighboring areas, and coordination along routes can be achieved with less computation power, as Lammer and Helbing showed in their research.

Other ways that may help alleviate the traffic load and it's environmental consequences, would be to improve and promote public transportation as an alternative to using private cars, to tax drivers in congested urban areas (like the London congestion charge), to promote car sharing, walking, and bicycle riding.

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