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Analysis of Adaptive Traffic Control Systems Design of a Decision Support System for Better Choices

Luca Studer[1], **Misagh Ketabdari**[2],* **and Giovanna Marchionni**[1]

[1]*Mobility and Transport Laboratory, Politecnico di Milano, Dep. Design, Via Durando 38/A, 20158 Milano, Italy*
[2]*Transportation Infrastructures Engineering, Department of Civil and Environmental Engineering , Politecnico di Milano, Piazza Leonardo Da Vinci 32, 20133, Milan, Italy*

Abstract

Near half of the world population lives in cities. For many years big cities have faced the difficulties caused by junctions. Junctions and congestion are the cause of many other problems, like air pollution, time waste, delays, increased average trip time, decreased average cruise speed, increased fuel consumption and many others. These important issues cost a lot to governments in terms of both time and money. Cities suffer from the well-known problem of fixed-time planning for traffic signals at intersections. In this paper the authors went through these problems and discussed about the difficulties of fixed-time plan traffic lights and their solutions. Adaptive traffic control systems are one of the solutions which are exactly opposite to fixed-time plans. Four different adaptive traffic control systems will be discussed. Each of them has unique characteristics that make it worthy to compare. The general architecture of these systems is based on a similar concept, but there is a great number of general and detailed differences that makes them interesting to compare. By making a deep comparison between these systems, which is one of the outputs of this research, governments and the authorities in charge can have an appropriate reference to look for their benefits and choose an adaptive traffic control system to apply to their networks.

Keywords: Transportation; Traffic congestion; Adaptive traffic control system; Fixed-time planning

Introduction

Traffic congestion is an ever-increasing problem in towns and cities around the world. People must face losses in terms of time, money and health. Wasting the time of motorists and passengers, being a non-productive activity for most people, congestion reduces regional economic health. Delays, which may result in late arrival at work, meetings, and education, causes lost business, disciplinary actions or other personal losses. The impossibility to forecast the travel time accurately forces drivers to foresee a longer time to travel "just in case", and less time for productive activities. The wasted fuel increases air pollution and carbon dioxide emissions which may contribute to global warming. Wear and tear on vehicles as a result of idling in traffic and frequent acceleration and braking causes more frequent repairs and replacements. The traffic blocked for emergencies may interfere with the passage of emergency vehicles travelling to their destinations, where they are urgently needed. The spillover effect from congested main roads to secondary roads and side streets as alternative routes may affect neighborhood amenity and real estate prices. Local government and authorities must continually work to maximize the efficiency of their highway networks, whilst minimizing any disruptions caused by incidents and events. Many developing countries

Still do not consider the importance of managing traffic congestions adaptively, and do not pay enough attention to this ever-growing dilemma which causes high costs to the government. Extensive attention is therefore given to the methods of managing the traffic used in different parts of the world, and to make a comprehensive comparison chart for countries involved in this problem. In recent years (2012), many surveys were carried out in the United States of America to show the seriousness of the situation regarding the malfunctioning of current traffic control systems and the necessity to apply new methods and improvements, as well as to abandon obsolete models. Some highlights and statistics of these surveys are described below. "As in can be interpreted from national traffic signal report card (2012) overall management of traffic signals in the U.S took a grade of 69 or D+. This result indicates that improvement and investment in traffic signal operations remains critical. The labor-intensive process of collecting sample data to create coordinated timing plans is imprecise and limited in its effectiveness. In many cases, upwards of 5-7 years (or more) of signal coordination is based on one 6-10 hour sample of traffic. Even the best, most up-to-date plans cannot respond to random fluctuations in traffic such as before and after special events. The latest traffic controllers use digital hardware, but at their core they are constrained by analog concepts such as fixed offsets, common cycle lengths and standardized allotment of green time, or splits. By emulating old-fashioned thinking, these controllers are unable to quickly serve the phases or movements that best accommodate actual demand. The technology is simply not sophisticated enough to move traffic as efficiently as possible. In the United State, around 30,000 people die in traffic accidents each year. Intersections are one of the main locations of 40% of crashes and 20% of fatalities. The cost of congestion in the U.S. is $101 billion per year or more than $700 for every auto commuter. This figure takes into account 4.8 billion hours of wasted time and nearly 2 billion extra gallons of fuel. Burning nearly 2 billion gallons of nonrenewable fossil fuels due to traffic congestion means we are filling the air with unnecessary harmful emissions – 80,593,762,135 tons of pollutants. Toxic emissions poison our respiratory systems. 6 out of 10 Americans live in areas with unhealthy levels of air pollution. An estimated 50,000 to 100,000 Americans die every year from air pollution, mainly due to lung and cardiovascular diseases" [1]. This research could provide an appropriate database for government and authorities of the countries which deal with traffic problems, high pollution and emission levels, as well as a high fuel consumption. By referring to the comparisons tables which are presented in the last chapters, authorities can make a reasonable decision to choose and

***Corresponding author:** Misagh Ketabdari, Transportation Infrastructures Engineering, Department of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo Da Vinci 32, 20133, Milan, Italy, Tel: +039 02 2399 9725 (9713); E-mail: misagh.ketabdari@polimi.it

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apply the adaptive traffic control system which best fits the demands of a city in order to improve its intercity networks. Furthermore, this research represents a big step for the researchers in this field and could assist them for further studies and to achieve the desired results. The problem of traffic is directly related to people health and wealth. For this reason, we should never stop improving traffic networks.

Differences between fixed-time planning traffic control system and ATCS

Many traffic control systems manage signals on a fixed-time basis, where a series of signal timing plans is scheduled by day of week and time of day. The time relationship between the signals is pre- calculated based on previously surveyed traffic conditions. These fixed-time systems cannot be expected to cope with traffic conditions that differ from those prevailing at the time when the intersection was surveyed. Furthermore, as traffic patterns change over time, fixed-time plans become outdated. This requires the area to be resurveyed, and new signal timing plans to be calculated every few years. Experience has shown that this procedure is expensive, and that it requires resources which are not always readily available. As a result, the development of new plans is either deferred beyond the useful life of the old plans, or improvised changes are made to plans and timetables; either case results in a sub-optimum performance. The problems of most fixed-time systems make it clear that a more responsive approach to changing traffic conditions is needed. One cost-effective answer is the adaptive traffic control system. This is a great improvement compared to fixed-time systems because it implies improved decision-making capabilities. The implementation of a fully responsive system does not, however, mean avoiding to carefully designing each intersection. The present technology only allows for the real-time variation of signal timings at intersections which have known or anticipated traffic requirements (Figures 1 and 2).

SCATS

SCATS, which is the acronym of "Sydney Coordinated Adaptive Traffic System", is an intelligent transportation system and an innovative computerized traffic management system. This system was developed in Sydney, Australia, by former constituents of the Roads and Maritime Services in the 1970s, and it has been used in Melbourne since 1982 and in Western Australia since 1983. After the first positive results, other countries also showed interest in SCATS and applied it to the cities facing with the problem of traffic control system. Tehran, New Zealand, Shanghai, Amman, Dublin, Oakland County, Minneapolis and Michigan are a few examples. SCATS gathers data on traffic flows in real-time at each intersection. Data is fed via the traffic controller to a central computer. The computer makes incremental adjustments to traffic signal timings based on minute by minute changes in traffic flow at each intersection. This adaptive traffic control system helps to minimize stops (light traffic), delays (heavy traffic) and travel time by selecting the most appropriate cycle length, splits, and links (or offsets) [2]. In a different word the philosophy of SCATS can be described with the following points:

1. It detects the traffic volume by movement
2. It converts data into flow rate
3. It calculates the optimal cycle length
4. It calculates optimal splits by phase
5. It determines phase combinations

Case study results

Table 1 shows the results of the application of the SCATS in Oakland County in terms of reduction in accident severity and travel time. Another case study that ought to be discussed is Mashhad. Mashhad, the second largest city in Iran, like many other big cities is faced with increasing traffic congestion caused by a rapidly increasing population and the annual pilgrimage. In recent years, Mashhad traffic and transportation authorities are challenged with how to manage the increasing congestion with limited budgets for major roadway construction projects. Mashhad recognized the need to improve the existing system capacity to get the most out of their current transportation system infrastructures. After comprehensive studies were carried out to develop the Mashhad traffic control center, the SCATS adaptive traffic control system was introduced as the selected intelligent control system for integrating signalized intersections. The first intersection was equipped with this system in 2005 [3]. In this study, the intersections in Mashhad that were equipped with the intelligent adaptive system were selected as study locations (Figure 3). In order to investigate the impacts of this system more effectively, roads were selected where some intersections were equipped with SCATS system. Finally, the selected roads and intersections were studied in two main sections, as follows:

1. Fixed Time-Pre-Time versus SCATS control;
2. Coordinated versus Local control.

Three main roads consisting of six intersections in this city were taken into consideration. The results are shown in Table 2 and 3 in terms of improvement.

Weak points

The SCATS Philosophy is based on real-time enhancement by using many distributed computers as processors. Although it has libraries of offsets, phase split plans, no comprehensive, reliable plan can be defined. Instead, different plans should be checked and selected for the application to advanced cycles. SCATS is not model-based. It relies on incremental feedbacks. Intersections can be grouped as

Figure 1: This image shows a view of Tehran in a clear sunny day (Source: Image by Mehr news).

Figure 2: This image shows air pollution in Tehran from the same point of view (Source: Image by Mehr news).

Site: Oakland Count			
Applying SCATS Control System Survey in 2001			
Strategy	**Accident Severity Analysis (Average)**		
	Low severity injuries	**Medium Severity Injuries**	**High Severity (Cause to death)**
	%	%	%
Before SCATS	66	25	9
After SCATS	79	17	4
Reduction in Travel time	AM peak	OFF Peak	PM Peak
	-20	-32	-7

Table 1: Oakland County results after applying SCATS.

sub-systems. Several sub-systems are accumulated and converted to a system. In other words, there is no traffic model in SCATS, as the "adaptive" process is completed by the local actual control which limits the use of an optimization methodology. Changes to the phase plans are done manually and not automatically, which implies time and personnel costs. This point can cause problems when the system is meant to satisfy dynamic traffic demands. Another important disadvantage of this system is that the stop line detection philosophy makes it is impossible to provide current feedback information about the performance of the signal progression.

Benefits and advantages

The SCATS system can be selected for the application to different projects and cities for the following key reasons:

1. Small system architecture size;

2. Increasing public health savings by reducing the amount of emissions thanks to decreasing traffic congestion;

3. Improving operation for all users, especially for transit bus routes. Enhanced public transport time and reliability;

4. Great ability in handling unpredictable change of traffic volumes and patterns on special days and times. Ability to provide a dynamic response to traffic demands;

5. Adequate handling of traffic patterns and volumes;

6. Possibility to handle long pedestrian clearance time[1];

7. Responsiveness to day-to-day and time-of-day fluctuations on demand;

8. Good responsiveness to traffic congestion resulting from crashes, quick clearing of backups;

9. In case of low volume traffic demand the traffic signal timing will adjust reduced overall delays;

10. Effective maintenance alarm system that reduces traffic delays due to equipment malfunctioning;

11. No need (and associated costs) for signal retiming, typically performed every three to five years;

12. Reduction in collisions;

13. Reduced air pollution;

14. Reduced fuel consumption;

15. Reduced delays.

To conclude, SCATS can be suggested as an economically feasible choice to be implemented in metropolitan areas that may result in a considerable decrease of "Travel Time", "Delay", "Fuel Consumption" and "Stoppage Time". The qualitative results of reduction and installation cost are shown in Table 4.

SCOOT

The, urban traffic control system SCOOT, which is the acronym of "Split Cycle Offset Optimization Technique", was developed within a collaboration between Transport Research Laboratory (TRL) and UK traffic systems suppliers [4]. Peak traffic Ltd, TRL Ltd and Siemens

Figure 3: Location of the intersections under consideration.

		Morning Peak			Evening Peak			Noon		
		SCATS off	SCATS on	Changes (%)	SCATS off	SCATS on	Changes (%)	SCATS off	SCATS on	Changes (%)
Jomhoori Blvd	Average Delay Per Stopped Vehicle	33.3	31	-6.9	33	30	-9	28.1	25.1	-10.7
	Average Delay Per Approach Vehicle	22.5	19.1	-15.1	22.3	18.8	-15.9	17.2	14.2	-17.4
	Average Travel Time of East to West Path (km/hr)	179.1	170	-5.1	186	176.6	-5.1	154.8	143.5	-7.3
	Average Travel Time of West to East Path (km/hr)	202.1	145	-28.3	190.1	179.6	-5.5	134.1	131.8	-1.7
Ferdowsi Blvd	Average Delay Per Stopped Vehicle	33	31.5	-4.5	34.9	33	-5.4	32.5	30.9	-4.9
	Average Delay Per Approach Vehicle	22.1	20.7	-6.3	22.7	19	-16.3	20.8	19.1	-8.2
	Average Travel Time of East to West Path (km/hr)	138.1	125.8	-8.9	143.3	139.5	-2.7	125.5	123.7	-1.4
	Average Travel Time of West to East Path (km/hr)	143.6	141.5	-1.5	144	119.5	-17	128.1	122.3	-4.5
Sajjad Blvd	Average Delay Per Stopped Vehicle	34.3	31.1	-9.3	33.6	30.4	-9.5	29.9	27.6	-7.7
	Average Delay Per Approach Vehicle	25.6	23.4	-8.6	25.8	23	-10.9	20	16.3	-18.5
	Average Travel Time of East to West Path (km/hr)	192.3	167.8	-12.7	319.6	282.5	-11.6	87.3	87.8	0.6
	Average Travel Time of West to East Path (km/hr)	143.5	137	-4.5	192.1	160.5	-16.4	100.6	70	-30.4
Average Parameters for All Routes	Average Delay Per Stopped Vehicle	33.5	31.2	-7	33.8	31.1	-7.9	30.2	27.9	-7.6
	Average Delay Per Approach Vehicle	23.4	21.1	-10	23.6	20.3	-14.2	19.3	16.5	-14.5
	Average Travel Time of East to West Path (km/hr)	169.8	154.5	-9	216.3	199.5	-7.8	122.5	118.3	-3.4
	Average Travel Time of West to East Path (km/hr)	163.1	141.2	-13.4	175.4	153.2	-12.7	120.9	108	-10.7

Table 2: Comparison table of delay parameters for all intersections times of traffic.

traffic controls Ltd have the Co-ownership of the SCOOT adaptive traffic control system. The first edition of SCOOT was tested in Glasgow, Scotland, in the late 1970s. Coventry, England, experienced the developed version of SCOOT for general utilization and Maidstone, England, was the location where the first commercial system was installed in 1980. Nowadays, more than 190 cities in United Kingdom and overseas are taking advantage of SCOOT [5]. The mechanism of SCOOT can be simplified in few main tasks. It is a complete and fully adaptive traffic control system, therefore it gathers data and information that vehicle detectors record and then processes this information to optimize the traffic signal and reduce stops and delays. Over time, SCOOT has developed by following some basic philosophies. Fast response to changes in congestions and traffic conditions can be cited as part of these philosophies. This change enabled SCOOT to serve variations in traffic demand more dynamically on a cycle-by-cycle basis. In this traffic control system responses are fast, but not enough to make it unstable.

[1]Sydney Adaptive Traffic Control System in Chula Vista, CA

SCOOT can avoid big changes and fluctuations in its control system

Location	Time	Condition	Fuel Consumption	CO Emissions	Hydrocarbons Emissions	Fuel Consumption Decrease	CO Emissions Decrease	HC Emissions Decrease
			(Lit)	(gr)	(gr)	(%)	(%)	(%)
Ferdowsi Blvd	Morning Peak	Before	0.404	55.689	4.953	3.7	6.2	5.9
		After	0.389	52.256	4.661			
	Evening Peak	Before	0.412	56.652	5.026	5.2	11	10.3
		After	0.39	50.445	4.51			
	Noon (Normal)	Before	0.387	48.678	4.344	5.6	4.4	4.5
		After	0.366	46.524	4.146			
Jomhoori Blvd	Morning Peak	Before	0.503	73.059	6.396	9.2	17.2	15.8
		After	0.456	60.519	5.383			
	Evening Peak	Before	0.498	71.971	6.304	4.2	6.1	6
		After	0.477	67.57	5.927			
	Noon (Normal)	Before	0.439	57.741	5.127	6.6	12.8	11.7
		After	0.41	50.328	4.53			
Sajjad Blvd	Morning Peak	Before	0.37	60.917	5.328	5.8	6.5	6.7
		After	0.348	56.938	4.972			
	Evening Peak	Before	0.432	78.794	6.786	15.9	21.9	21.3
		After	0.363	61.539	5.342			
	Noon (Normal)	Before	0.286		3.552	8.8	15.9	14.5
		After	0.261	33.218	3.035			

Table 3: The impacts of SCATS on fuel consumption and air pollution.

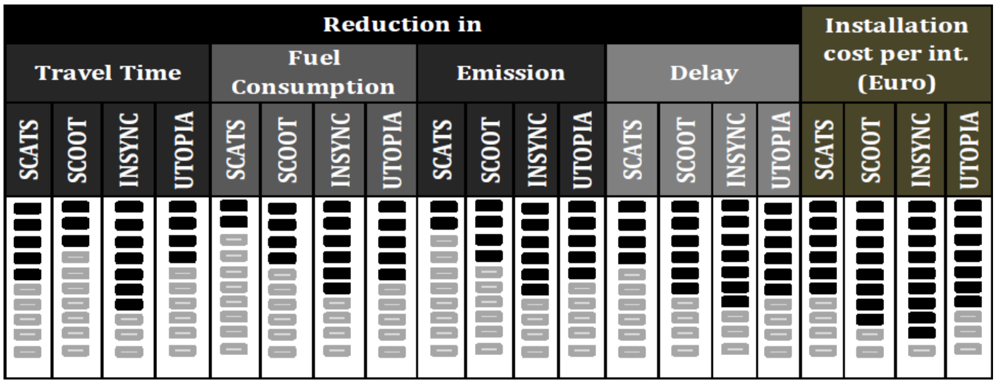

Table 4: Qualitative comparison between the four systems.

that are caused by temporary changes in traffic demand and patterns [6]. Reduction in vehicle delays, congestions and providing many traffic management facilities are just a few options that SCOOT can provide. For instance, an excellent facility was introduced in 1995 to integrate active priority to buses, connected with bus priority, by the SCOOT urban traffic control system. This system was designed to detect buses either by selective vehicle detectors or by an automatic vehicle location (AVL) system [7]. The characteristics of SCOOT can be summarized below:

1. Customized congestion management
2. Maximized network efficiency
3. Flexible communications architecture
4. Public transport priority
5. Traffic management
6. Incident detection
7. Vehicle emissions estimation
8. Comprehensive traffic information

Case studies results

Glasgow, Coventry, Worcester, Southampton, London, Sao Paulo, Toronto, Beijing, and Nijmegen are case studies that have been discussed to illustrate the effectiveness of the application of SCOOT on congested intersections. The results of the improvements are shown in Tables 5 and 6.

Weak points

Maintaining a good offset on a short link can be a problem. Being a short link with little storage capacity, the queue in red will frequently reach the detector. Once a queue has formed over the detector there is no useful information available from the detector for offset optimization. Consequently, left to its own devices, SCOOT may not control the offset both on critical short links and on longer ones [8]. Another weak point of the SCOOT urban traffic control system is that it needs a large installation base. In most cases there would be a problem with a free space for installation.

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INSYNC

The InSync adaptive traffic control system is an intelligent transport system that enables traffic signals to adapt to the actual traffic demand. INSYNC was developed in 2005. In March 2012 traffic agencies in 18 U.S. states selected InSync for use at more than 900 intersections. This system was developed by Rhythm Engineering at first. Rhythm Engineering is a reputable company which works in the field of transportation and mostly in the United States of America. InSync is a plug-and-play system that works with existing traffic control cabinets and controllers. Its two main hardware components are IP video cameras and a processor, sometimes referred to as "the eyes" and "the brain" of the system,

Location	Year of Trial	Previous Control	Reduction in Journey Time			Reduction in Delay		
			%			%		
			AM Peak	OFF Peak	PM Peak	AM Peak	OFF Peak	PM Peak
Glasgow	1975	Fixed-time	-	-	-	-2	14	10
Coventry-Foleshil	1981	Fixed-time	5	4	8	23	33	22
Coventry-Spon End	1981	Fixed-time	3	0	1	8	0	4
Worecester	1986	Fixed-time	5	3	11	11	7	0
		isolated Vehicle Actuated	18	7	13	32	15	23
Southampton	1984-1985	isolated Vehicle Actuated	18	-	26	39	1	48
London	1985	Fixed-time	8% Cars-6% Buses			Average 19%		

Table 5: Case studies results after applying SCOOT.

Location	Year of Trial	Previous control system	Survey Conductor	Delay		Stops	Journey Time	Fuel Consu-mption	Emissions	Annual Benefits
Sao Paulo	1997	TRANSYT	CET (Companhia de Engenharia de Tráfego) - the municipal traffic engineering company responsible for managing the city's traffic	Time of Day	(%)	(%)	(%)	(%)	(%)	
				06:00 - 10:00	41					
				10:00 - 16:00	53					
				16:00 - 20:00	0	26	9	4.1	-	Between 600,000 to 900,000
				20:00 - 23:00	43					
				Average Benefit	38					
Nijmegen	1997	SCOOT over Fixed-time plan	"Witteveen+Bos" Consulting Engineers	25		22	11	3.7	-	500,000 to 800,000
		"SCOOT + incorporated SPLIT weighting" over SCOOT		33		31	14	4.2	-	550,000 to 850,000
Toronto	1993	Fixed-time Plan	Canada Metro-Transportation	17		22	8	5.7	3.7(Hydrocarbons) & 5 (Carbonmonoxide)	-
Beijing	1989	Fixed-time Plan	Beijing Research Institute of Traffic Engineering (BRITE)	07:00 - 08:00 (Bicycle Peak)	41	26	7	4.3	-	500,000 to 900,000
				08:00 - 09:00 (Vehicle Peak)	32	33	16			
				12:30 - 13:30 (off Peak)	15	14	4			
				17:00 - 18:00 (Bicycle/Vehicle)	19	29	2			

Table 6: Case studies results after applying SCOOT.

respectively. Mounted video cameras determine the number of vehicles and how long the vehicles have been waiting (delay). The processor, a state machine, is located in the traffic controller cabinet at the intersection. The system calls up the traffic signal state that best serves actual demand while coordinating its decision with other intersections. Local Optimization InSync uses integrated digital sensors to know the exact number of cars demanding service at an intersection and how long they've been waiting. Approaches are given phasing priority based on this queue and delay data. The dynamic phasing and dynamic green splits of InSync enable the traffic signals to use the green time efficiently [11]. Global Optimization InSync creates progression along an entire corridor by using "green tunnels." Platoons of vehicles gather and are then released through the corridor. By communicating with each other, the signals anticipate the green tunnel's arrival so vehicles pass through without slowing down or stopping. The green tunnels' duration and frequency can vary to best support traffic conditions. Between green tunnels, the local optimization serves the side streets and left turns.

Case studies results

10 case studies are discussed in this chapter and the improvements of applying INSYNC adaptive traffic control system are shown in Tables 7 and 8.

Weak points

1. **Detector dependent:**

One of the major problems of almost all the adaptive traffic control systems is the dependency on the detectors to collect the data and send them to the controllers for processing procedure. A detector failure can paralyze the system.

2. **Oversaturation**

The second weak point of this system is that INSYNC, like most of other ATCS, is unable to adjust an oversaturation.

3. **No Central System**

Another point is that there is no Central system for this adaptive traffic control system. INSYNC cannot manage more than a limited intersection because of this lack. It is applied to each intersection, not to a big system.

Benefits and advantages

Emulating a well-informed traffic engineer at each intersection means InSync must detect demand in real-time, be able to make immediate adjustments in signalization, not be constrained by "mechanical" thinking and be aware of upstream and downstream traffic conditions. In other words, InSync at each signal must know the actual traffic conditions, have the power to make dynamic changes and foresee what conditions will exist in the next few minutes.

This is a substantial difference from other traffic management systems. Nearly all today's traffic control systems use digital hardware but they are limited by analog processing such as cycle lengths, fixed offsets, set sequences, and splits. Instead, the InSync Processor is a modern state machine, i.e. it can dynamically choose which phases to serve and instantly adjust as well as coordinate service and green time. By adapting to actual traffic demand, InSync is superior to predetermined signal timing plans that, at best, estimate the traffic demand based on a small historical sampling and generalize those results across years of traffic signalization. The ability of InSync to constantly see and flexibly serve the actual demand in the best possible way is what enables it to produce such astounding before-and-after results [11]. There is a big difference in Insync compared to SCATS and SCOOT adaptive control traffic systems that is caused by a different way of thinking. In InSync, a state is a phase or concurrent phase pair. The system chooses the state that best serves traffic conditions on a second-by-second basis based on detection data, the operational objectives specific to each intersection and network of intersections and InSync's algorithms. By digitizing the traffic control options available, InSync can dynamically choose and adjust signalization parameters such as the state, sequence and amount of green time to best serve the actual traffic conditions. (Using standard

Cities	INSYNC Intersection	Annual Crash Reduction	Annual Crash-Related Savings
	(Amount)	(%)	(US $)
Columbia County, GA	5	26	1,164,702
City of Topeka, KS	7	24	942,854
Missouri DOT	12	17	1,247,895
City of Lee's Summit, MO	8	15	360,503
City of Springdale, AR	8	30	526,889

Table 7: Case studies results after applying InSync in terms of safety.

Performance measurementIn Terms of Reduction						
City	Stops	Delay	Travel Time	Fuel	Emissions	Annual Savings to Motorists
	(%)	(%)	(%)	(%)	(%)	(US $)
Columbia, MO	73	56	20	12	19	1,984,411
Evan, GA	77	81	34	17	23	2,624,802
Grapevine, TX	47	42	16	8	9	8,067,234
Lee's Summit, MO	84	72	23	10	23	2,452,493
Salinas, CA	64	69	39	N/A	N/A	1,722,152
San Ramon, CA	56	51	27	15	14	2,333,636
Springdale, AR	88	80	36	19	29	5,083,254
Topeka, KS	79	68	43	33	28	2,087,501
Wichita, KS	82	68	31	21	30	975,260
Upper Merion, PA	21	34	26	N/A	N/A	802,204

Table 8: Case studies results after applying InSync in terms of reduction.

sequences, InSync maintains all safety considerations while not being constrained by the ring-and-barrier.)

1. Digitized Way of Thinking
2. System Integration
3. Integrated INSYNC with Centralized Center
4. Saving Agency Time and Resources
5. Mitigation of the Risk regarding the Centralized Center
6. Failure Mitigation (Detection, Communication and Hardware Failure)

To sum up, INSYNC is a plug and play system. Where the current traffic control system is not efficient enough to manage all the actual traffic flow, INSYNC can be suggested as a plug & play adaptive traffic control system that can be installed on the previous system to improve the efficiency of the whole system. The qualitative results of reduction and installation costs are shown in Table 4.

UTOPIA

FIAT Research Centre, ITAL TEL and MIZAR Automation developed and designed UTOPIA (Urban Traffic Optimization by Integrated Automation) - SPOT (System for Priority and Optimization of Traffic) in Turin, Italy. One of the main objectives of this system was to improve private transportation. A major difference between this adaptive traffic control system and the previous one is that the first also improves public transport efficiency. Approximately forty signalized intersections in the central area of Turin have experienced UTOPIA since 1985 as a network. Moreover, this network included a tram-line which after applying UTOPIA-SPOT was also controlled by this system. Italy, Netherlands, Finland, Norway, USA and Denmark are other examples where UTOPIA-SPOT is implemented nowadays. This architecture consists of a higher level (Central system), which is responsible for setting the overall control strategies, and a lower level (controlled junctions) where the traffic light control is implemented by means of the SPOT software.

5T Project

In 1992 a large scale project of mobility telematics named 5T (Telematics Technologies for Transport and Traffic in Turin) was tested. In order to manage the project, a homonymous Consortium was incorporated. 5T designs, develops and manages ITS solutions improving the individual and collective mobility on a regional scale. The aims of the 5T Project were the following:

1. Improving traffic flows and safety.
2. Reducing environmental pollution caused by traffic.
3. Improving the efficiency and quality of public transport.
4. Providing real-time information services to travelers.
5. Development of a strategic supervisory system for all Transport Telematics sub-systems.
6. Extension of the existing Urban Traffic Control and bus priority facilities over a wider area of the urban network.
7. Extension of the functions of the Public Transport Management System to include user information and passenger counting.
8. Development of a system for keeping citizens better informed about mobility services.
9. Functional integration of traffic control systems with the environmental monitoring and forecasting system [12].

Case studies results

Turin, Italy, is one of the most reputable case studies where the UTOPIA adaptive traffic control system was installed. After applying this system to more than half of the intersections of Turin and studying the results, UTOPIA was recommended as a preferred choice. Table 9 shows the results of the improvement achieved.

Weak points

Several problems rose during the 5T experience:

1. Longer waiting times for vehicles because of the priority and preemption given to buses.
2. Some developments were below the expectations,
3. Early termination of some applications.
4. Two systems stopped right after the experimentation.
5. The main cause of delays, misunderstandings, low profile participation by some parts can be found in the incorrect interpretation of users' needs and in the underestimation of the level of agreement necessary to reach the goals [13].

Benefits and advantages

After reviewing the results and consequences of the 5T project and similar mobility telematics systems developed and tried under UE research contracts, the following remarks can be pointed out:

The shift of mobility toward public transport - needed by all European city choked by traffic - can be encouraged by mobility telematics both by improving public transport performances and by enhancing the citizen's perception of this improvement; Telematics management systems, which are able to perform a dynamic traffic-responsive regulation, are powerful tools in reducing congestion and pollution and improving convenience for the travelers. The demand itself must be included when generating and keeping the best balancing solution. Travelers should be therefore given access to the necessary information made available by mobility telematics. In addition, one of the main subjects UTOPIA was designed for is public transport. In this regard, buses and LRT[2] vehicles should have the absolute priority at intersections and junctions, thus requiring some accuracy in forecasting their arrival time. This priority can be again evaluated depending on the importance of the vehicle. In the case of public transportation, importance is measured by the capacity of each vehicle with respect to passengers. For instance, in the city of Turin LRT is given a higher priority than buses because it carries more passengers [14]. In conclusion, UTOPIA could be a good choice as part of a comprehensive traffic plan like the 5T project, also to keep the system integrity. The qualitative results of reduction are shown in Table 4.

[2] LRT: Light Rail Transport

Expected Results and Conclusion

In this paper four different adaptive traffic control systems were analyzed. Each of them has unique characteristics which makes it interesting to compare. By comparing the Tables below, all the aspects and features of these systems were studied. In the Tables below, the functionality of each of these systems is discussed. These four adaptive traffic control systems can be described as follows [15-18]:

1. **SCATS:** It is a traffic control system which can cover one big metropolitan area. The architecture consists of central, regional, and local computers. Its installation costs between "7500" and "12000" euro per intersection. The expected reduction in the travel time is on average between "15%" and "30%".
2. **SCOOT:** It is an optimized version of SCATS, which are some steps ahead. It can cover just a urban area, not freeway interchanges. Its installation costs between "15000" and "19000" euro per intersection. The architecture is the same as SCATS but without central computers. The expected reduction in the travel time is on average between "10%" and "25%".
3. **INSYNC:** It is a plug and play system, which could locally be added to the existing traffic control system to improve the network, or separately as one traffic control system. There is no central monitoring for this system so it can only be applied locally. Its installation costs between "15000" and "22000" euro per intersection. The expected reduction in the travel time is on average between "20%" and "40%".
4. **UTOPIA:** It is a traffic control system which can cover one big metropolitan area. The architecture consists of central and local computers. Its installation costs between "15000" and "18000" euro per intersection. The expected reduction in the travel time is on average between "10%" and "25%".

To conclude, SCATS, SCOOT, and UTOPIA are adaptive traffic control plans which can be used independently and improve the system in terms of reduction in traffic factors, while INSYNC is a plug & play traffic control system which should be installed where there is another traffic control plan to improve the whole system efficiency. SCATS and UTOPIA are suggested for metropolitan areas, SCOOT is acceptable for urban and regional zones, and INSYNC would be efficient just

Performance measurementIn Terms of Reduction & IncreaseTurin (Italy)					
Survey (year)		Travel Time	Fuel	Emissions	Commercial speed
		(%)	(%)	(%)	(%)
2000	Private vehicle	-17			N/A
	Public transport	-14	-8	-10	17
2012	Private vehicle	-17			N/A
	Public transport	-20	-10	-11	N/A

Table 9: Case studies results after applying UTOPIA.

Expected results in terms of reduction									
	Travel Time			Fuel	Emission	Delay			Stop
	AM Peak	OFF Peak	PM Peak			AM Peak	OFF Peak	PM Peak	
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
SCATS	15-25	15-30	7-10	3-8	3-8	5-20	15-20	10-30	10-20
SCOOT	5-20.	4-10	10-25	5-10	5-8	10-35	15-30	10-40	15-30
INSYNC	20-40			10-25	20-30	30-70			40-70
UTOPIA (5T Turin)	10-25			8-10	10-15	15-35			10-30

Table 10: All statistics about the expected results in terms of reduction.

for limited number of intersections (maximum 15 intersections). The summarized results are summed up in Table 10. The qualitative comparisons are shown in Table 4. This research could be used as a valid database by governments and authorities of the countries which have to deal with traffic problems, high pollution and emission levels, as well as high fuel consumption. By comparing the Tables shown in the last chapters, authorities can make a reasonable decision to the adaptive traffic control system which best fits the demands of the city in order to improve its intercity networks. Furthermore, this research represents a big step for the researchers in this field and could assist them for further studies to achieve the desired results. The problem of traffic problem is directly related to people health and wealth. For this reason, we should never stop improving traffic networks.

Further research agenda

New decision support systems can be proposed in order to choose the adaptive traffic control system which best suits the demands and the existing problems. This decision system would be helpful to governments and authorities by providing them with several criteria at different levels as an input to explore the possibilities of the most suitable different adaptive traffic control systems.

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