Politecnico di Milano
Facoltà di Ingegneria Civile, Ambientale e Territoriale
Master of Science in Civil Engineering for Risk Mitigation

Analysis of Adaptive Traffic Control Systems

and design of a Decision Support System for better choice

Supervisor
Prof. Luca Studer

Controrelatore
Prof. Giovanna Marchionni

Author
Misagh Ketabdari
764597

Academic Year 2012/2013

Politecnico di Milano

Facoltà di Ingegneria
Civile, Ambientale e Territoriale

Master of Science in Civil Engineering for Risk Mitigation

ANALYSIS OF ADAPTIVE TRAFFIC CONTROL SYSTEMS

and design of a Decision Support System for better choice

Supervisor
Prof. Luca Studer

Controrelatore
Prof. Giovanna Marchionni

Author
Misagh Ketabdari
764597

Academic Year
2012/2013

"… Functioning transportation networks are a key element for cities and towns across the Globe and are a precondition for economic activity and social participation. At the same time, economic and social benefits of urban mobility are frequently accompanied by negative side effects such as congestion, social exclusion, accidents, air pollution and energy consumption. In the face of a rising global population, continuing urbanization and the emergence of megacities, there is heightened urgency to apply solutions in the urban transport sector that contribute to sustainable urban development approaches and comprehensive responses to the impacts and causes of global warming while enabling mobility for the population. Sustainable Transportation policies have to consider the multiple social, economic and environmental dimensions of urban transport and formulate effective policies and investment strategies to reconcile competing interests between different modes of transport and societal groups" (UN-Habitat, 2010).

Acknowledgment

This thesis is the result of my Masters Graduation project in the Civil Engineering for Risk Mitigation in Politecnico di Milano University. In this short note, I would like to express my gratitude to all those who gave me the possibility for making this possible and turning my dreams to reality.

First, I would like to thank city of Lecco. Thanks for its amazing life and moments in the past three years, thanks to the beautiful city and its nice people.

My sincere gratitude to my supervisor Professor Luca Studer for the trust and support he gave me in course of this project. I really appreciate the freedom I have been given, and the fact that I had the best supervisor. Thanks for giving me the opportunity to explore and learn from adaptive traffic control theories. Thanks for being patient with me, listening to me and supporting me in all steps of the project. Furthermore my gratitude goes to Professor Giovanna Marchionni who was so patient in this period and gave me her trust and helped me a lot for both my thesis and the related research article that we have done together.

Here I would like to thank my classmates and best friends who made my years of study in Politecnico di Milano full of unforgettable memories. I would like to add their names here to keep their names and memories always alive for me: Syamak Kashfolayat, Soroosh Baghban, Elnaz Ghelichi, Shadi Zendehdel, Afshin Mokaram, Yasaman Ghanizadeh, Adel Khosroshahi, Sadaf Mokaram, Arezo Akbari, Soheil Raheli, Amir Radaei, Roozbeh Hassanzadeh, Ali Vaezi, Fardad Haghpanah, Vahid Davari, Reza Hosseini, Masoud Mohebi, Mahyar Djahangard, Behbood Vosoghtehrani, Sahar Khakzad, Golaleh, Ilnaz Ashayeri, and Mehdi Ramin moayed. Thanks for understanding, supporting and standing beside me.

The last but not the least, thanks to my parents, Mansoureh Tavana and Mohammadreza Ketabdari, and my dear sister Niloufar Ketabdari, whom without their unconditional supports this was not possible. Thanks for supporting me start a new life thousands kilometers away from my home and the loveliest family.

Summary

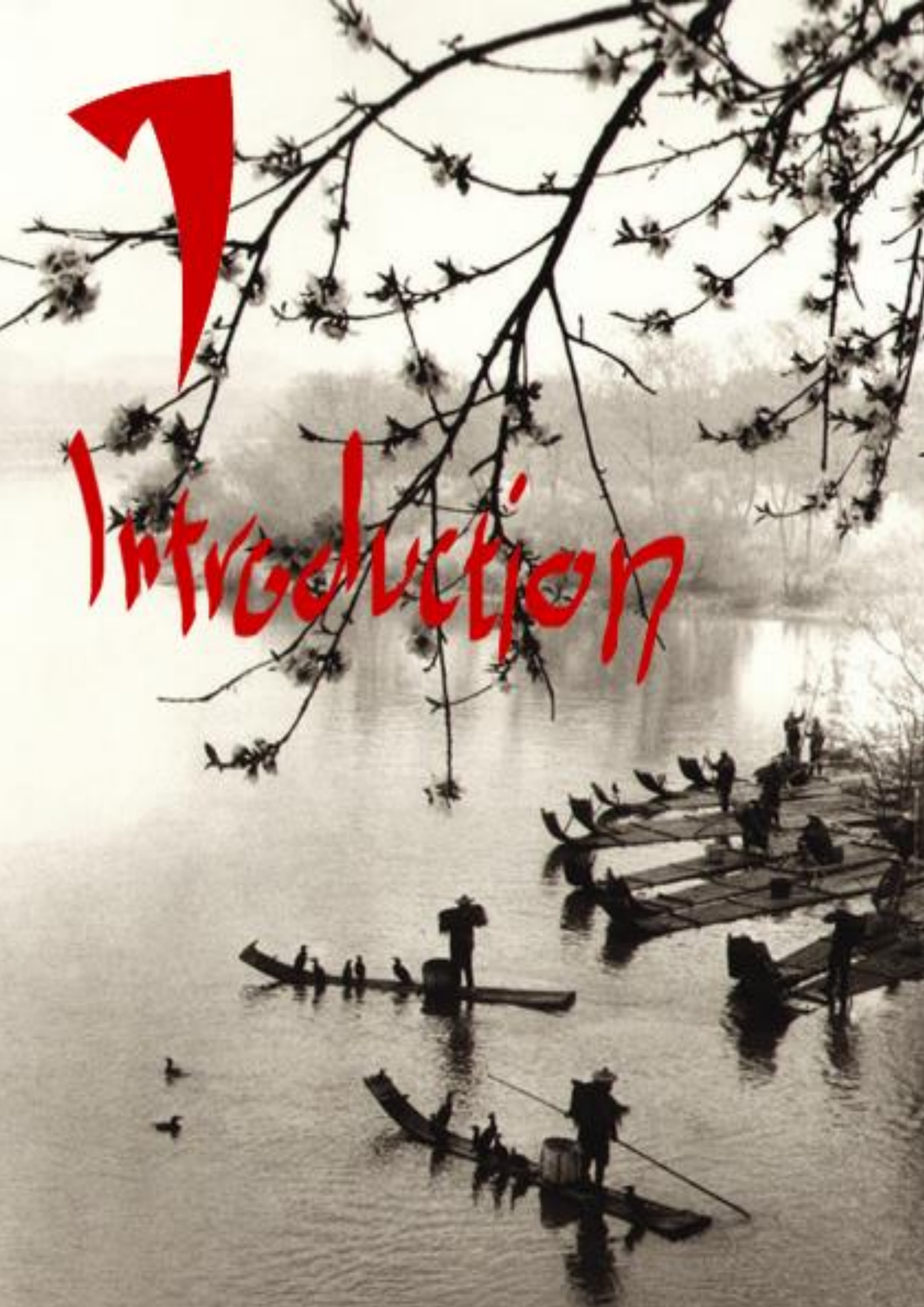
Near half of the population of the world are living in the cities. From many years ago the authorities and governments of big cities have faced with the difficulties that caused by the junctions. Junctions and congestions are the cause of many other problems like air pollution, time wasting, delay, increasing the average trip time, decreasing the average cruise speed, increasing fuel consumption and lots of other problems. These milestones cost a lot to the governments both in time and money. Cities have had the vintage problem of fixed-timed planning for the traffic signals at the intersections.

In this thesis the author went through these problems and discussed about the difficulties of fixed-time plan traffic lights and what are the solutions for them. Adaptive traffic control systems are one of the solutions which stand exactly in the opposite side compare to fixed-time plans. Four different adaptive traffic control systems would be discussed. Each of them has unique characteristics which make them worthy to compare. The general architecture of these systems are based on one similar concept but lots of general and detailed differences make them outstanding to compare. For each of these systems some case studies have been put under studies. By making a big comparison of these systems, which is one of the outputs of this thesis, governments and the authorities who are in charge would have an appropriate reference to look for their benefits and choose one adaptive traffic control system to apply to their networks and wait for the results.

At the end one decision support system regards to adaptive traffic control system is also simulated and proposed to make the decision making for the principles easier. This would be one big assistant to choose one specific adaptive traffic control system for one special case study and reach to the benefits that is requested. Furthermore, one integrated adaptive traffic control system is proposed for city of Milan (Italy), to reduce the amount of the congestions in the city and achieve side benefits.

Table of Contents

1 Introduction



1. Introduction

1.1. Motivation

As a civil engineer who has dedicated lots of his studies to the field of traffic and transport, I have been always fascinated by the intercity traffic management and traffic control systems. Traffic congestion is an ever-increasing problem in towns and cities around the world. People would face with losses in the shape of time, money, and health.

Wasting time of motorists and passengers, as a non-productive activity for most people, congestion reduces regional economic health. Delays, which may result in late arrival for employment, meetings, and education, resulting in lost business, disciplinary action or other personal losses. Inability to forecast travel time accurately, leading to drivers allocating more time to travel "just in case", and less time on productive activities. Wasted fuel increases air pollution and carbon dioxide emissions which may contribute to global. Increased fuel use may also in theory cause a rise in fuel costs. Wear and tear on vehicles as a result of idling in traffic and frequent acceleration and braking, leading to more frequent repairs and replacements. Stressed and frustrated motorists, encouraging road rage and reduced health of motorists. Emergencies-blocked traffic may interfere with the passage of emergency vehicles traveling to their destinations where they are urgently needed. Spillover effect from congested main arteries to secondary roads and side streets as alternative routes are attempted which 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 adaptively the traffic congestions and do not pay enough attention toward this ever-growing dilemma which causes lots of costs to the government. Iran is an example of such countries. In this regard extensive attention goes toward the methods of managing the traffic in different parts of the world and to make a comprehensive comparison chart for countries involving in the problem.

Figure 1: Tehran Toohid Tunnel

1.2. Problem Statement

In the recent years (2012) many surveys were taking place in the United State of America to express the seriousness of the situation in regard to malfunctioning of current traffic control systems and the necessity to apply new methods and improvements and abandoning the vintage models. In the following some highlights and statistics of these surveys are gathered.

- The Inadequacy of Current Approaches

When the culprit for wasted time and fuel is poor signal timing, more can be done to keep traffic moving. Yet both the methodology and the technology currently employed for signal coordination are inadequate.

- Traffic Signal Coordination Gets a "D+"

The 2012 National Traffic Signal Report Card gives a grade of 69 or D+ to the overall management of traffic signals in the U.S. This result indicates that improvement and investment in traffic signal operations remains critical.

- Timing Plans Are Inherently Inflexible

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.

- New Shiny Exterior, Old Thinking Inside

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.

- 30,000 Traffic Fatalities Each Year

In the U.S., more than 30,000 people die in traffic accidents each year. Intersections are the site of 40% of crashes and 20% of fatalities.

- $101 Billion: The Cost of Congestion

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.

- $4/Gallon and Rising

The days of less than $2/gallon gas in the U.S. are long gone, and upwards of $4 is the new normal. As fuel costs continue to rise, families and businesses feel the pressure.

- 80 Billion Tons of Toxic Emissions

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.

- 6 out of 10 Americans Breathe Unsafe Air

Toxic emissions poison our respiratory systems. Now, 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 outdoor air pollution, largely due to lung and cardiovascular diseases.

- Cutting-Edge Research Not Accessible

Many universities are pursuing an academic approach to improved signal timing and coordination. While these projects may have potential, current research coming out is either years away from deployment or unaffordable for the average community. These research projects are often geared toward major metropolitan areas that can spend $10 million on a traffic project.

In this regard, for fighting back to these problems authorities should applied new methods to their traffic control systems.

1.3. Aim

In this research the author goes toward four different adaptive traffic control systems; SCATS, SCOOT, INSYNC, and UTOPIA (5T Turin). Each of these systems has unique characteristic which make them worthy to compare.

This research would be an appropriate database for government and authorities of countries which deal with traffic problems, high pollution and emission level, and high fuel consumption. By the comparisons tables which presented in the last chapters, authorities can make a reasonable decision to choose an appropriate adaptive traffic control system which fit best with the demands of the city and apply, to improve their intercity networks. Furthermore this research is a big step for the researcher in this field and would assist them for further studies and achieving to the desired results. Traffic problem is related directly to people health and fortune. Consequently we should never stop improving traffic networks.

Figure 2: This image shows a view of Tehran in clear sunny day (Source: Image by Reza Shirazi Mofrad)

Figure 3: This image shows the air pollution in the Tehran from the same view (Source: Image by Mehr news).

1.4. Definitions

1.4.1. Intelligent Transport System (ITS)

Currently, big cities are the places where half of the world's population lives, people that needs to move daily to their workplaces. To ensure that all this people arrive in time and safely to their workplaces, smart transportations systems play a vital role in dense urban environments.

Intelligent Transport Systems apply information and communication technologies to make transport of people and goods easy and flowing. (ITS) are advanced applications which aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks (The European parliament and the council of the European union, 2010).

According to a study by "*Pike Research*", global investment in smart transportation systems will raise to the amount $13.1 billion between 2011 and 2017. Most of this investment will be placed on intelligent traffic management systems, since it can be applied to most of the cities. These are crucial in urban environments with heavy road traffic. The objectives of the ITS, are mentioned in the following:

Reducing congestion and bottlenecks and improving economic Efficiency

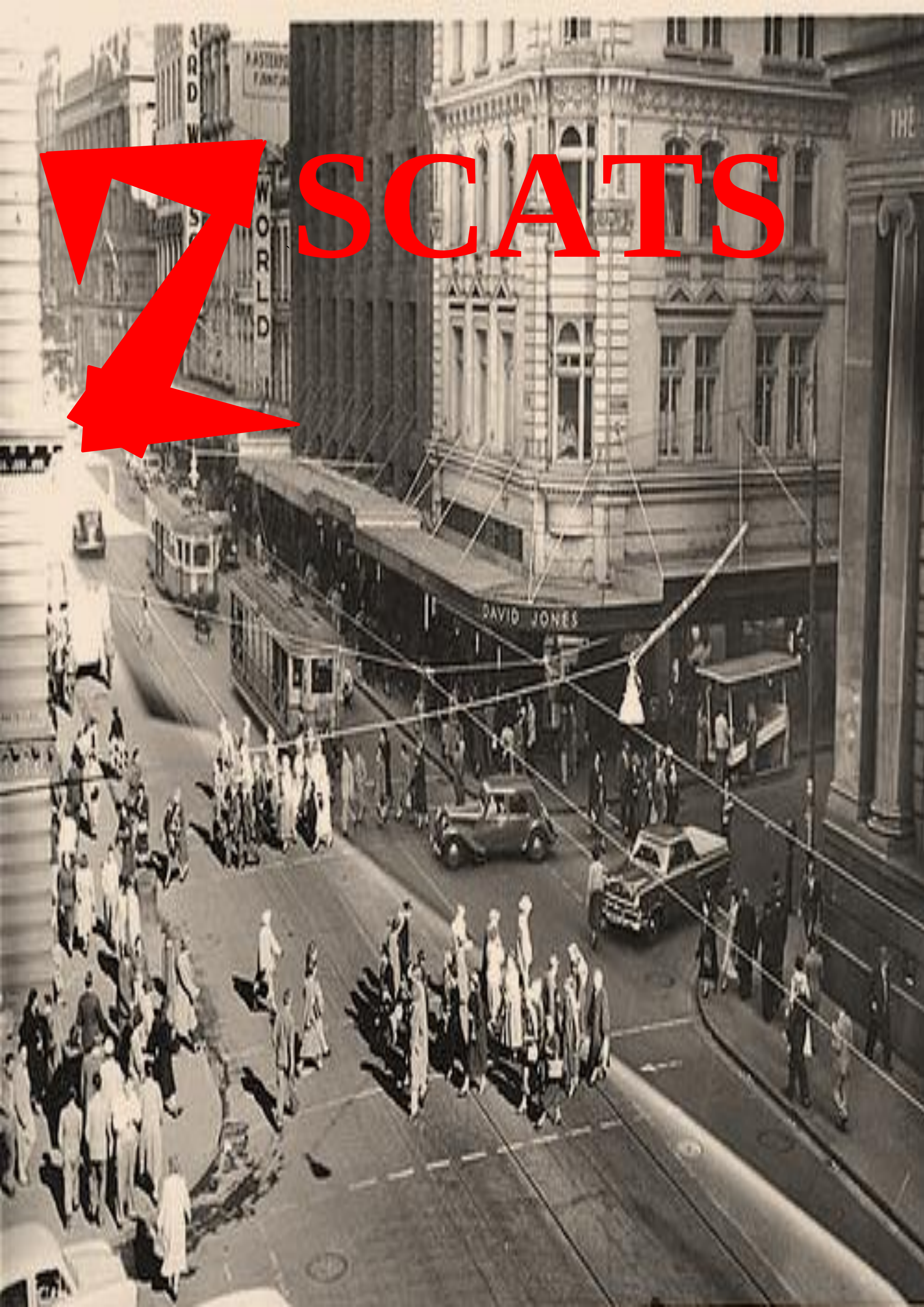
Reducing effects on health and environment

Exploiting the existing facilities

Saving human lives

1.4.2. Adaptive Traffic Control System (ATCS)

Adaptive traffic control system is a traffic management strategy in which traffic signals timing changes, or adapts, based on actual traffic demand. These systems work completely opposite to fixed-time planning, where a series of signal timing plans are scheduled by day of week and time of day. In fixed-time the time relationship between signals is pre-calculated; based on previously surveyed traffic conditions.


SCATS
WORLD
DAVID JONES

2. SCATS

2.1. Introduction

In this chapter one of the pioneer traffic adaptive control system would be put under study. The history, chronological trend, system architecture, and the way of communication are a few parts of this chapter.

The Sydney Coordinated Adaptive Traffic System, abbreviated SCATS, is an intelligent transportation system and innovative computerized traffic management system which primary developed in Sydney, Australia by former constituents of the Roads and Maritime Services in the 1970s. It has been used in Melbourne since 1982 and Western Australia since 1983 (Acott, Kent, 2011).

After releasing initial proper outcomes of the system other countries also got interested in SCATS and applied it to the cities with the problem of traffic control system. Tehran, New Zealand, Shanghai, Amman, Dublin, Rzeszów, Gdynia, Oakland County, Minneapolis, and Michigan are just a few examples of it. Moreover in Hong Kong, SCATS is currently adopted in the area traffic control systems at Hong Kong Island, Kowloon, Tsuen Wan and Shatin. In addition some areas of the US; Oakland County, Minneapolis and Michigan also have been installed this system for managing the intersections congestion.

Depends on where this system would be installed the acronym can alter but except Sydney. Canberra "CATSS" (Canberra Automated Traffic Signal System), Melbourne "SCRAM", and Singapore "GLIDE" are some local alternative names that have been or are in use.

As of June 2012, the Sydney Coordinated Adaptive Traffic System has been distributed to 263 cities in 27 countries worldwide controlling more than 35,531 intersections. In Australia, the majority of signalized intersections are SCATS operated (around 11,000 intersections).

The system uses sensors at each traffic signal to detect vehicle presence in each lane and pedestrians waiting to cross at the local site. The vehicle sensors are generally inductive loops[1] installed within the road pavement. The pedestrian sensors are usually push buttons. Various other types of sensors can be used for vehicle presence detection, provided that a similar and consistent output is achieved. Information collected from the vehicle sensors allows SCATS to calculate and adapt the timing of traffic signals in the network.

---

[1] An induction loop is an electromagnetic communication or detection system which uses a moving magnet to induce an electrical current in a nearby wire. Induction loops are used for transmission and reception of communication signals, or for detection of metal objects in metal detectors or vehicle presence indicators

2.1.1. Instant Fault Detection and Quick Repair

The ATC[2] system is equipped with the function of fault detection and by communicating with the central computer about the fault which is detected in order to facilitate repair and maintenance. Should there be a telecommunication breakdown, the ATC junction controller concerned will switch to standalone and independent mode and continue to function.

2.1.2. History of SCATS Development

Faced with the need to implement a large area traffic control system in Sydney and mindful of the problems of "fixed-time" systems, the NSW (New South Wales) Department of Main Roads (now it becomes Roads and Maritime Services) started the development of a traffic responsive system in the early 1970s. The early move into microprocessor local controllers in Australia in 1975 provided additional impetus to the development because of the increased "intelligence" and flexibility available.

SCATS development was undertaken by the Department of Main Roads (DMR) for the purpose of controlling traffic signals in NSW, but SCATS has since been implemented in many other cities in Australia, New Zealand and overseas. Licensed users of SCATS in Australia and New Zealand belong to a user group which meets annually to collectively discuss features, improvements, and local usage of SCATS.

Many years of research, testing and software coding have been invested in the development of SCATS. Development to further improve SCATS continues to ensure that control of traffic is as efficient as possible and that the needs of road users continue to be met. Many beneficial improvements to SCATS have been inspired by feedback from our ever-growing user community.

2.1.3. SCATS Chronology

- October 1933 - the first traffic lights were switched on in NSW.
- NSW decided that traffic signals were a State Government responsibility not a Local Government responsibility. This gave rise by the 1960's to an organization of dedicated specialists with electrical, electronic, construction and traffic engineering skills in the arts of designing, installing and maintaining traffic signals called the DMR (Department of Main Roads).
- 1963 - The first traffic control system installed in Sydney for 8 intersections.
- 1964 - A new version was installed capable of controlling 96 intersections.
- 1965 - 25 intersections were connected to the new traffic control system.

---
[2] Adaptive Traffic Control

- 1965-1966 DMT built their own intersection vehicle controller and had a 6 phase controller on the streets.
- 1967 - It became obvious that valves and relays should be replaced with semiconductors but still considered too expensive at that time. Eventually all 96 intersections were used up and to make more space two intersections were combined to make one thereby allowing more intersections to be connected.
- 1967/68 - a new system was installed partly solid state to control six intersections in Broadway.
- 1967 - The forerunner to Flexi-link was developed called MASCOT. These MASCOT systems were installed to buy time for the development of SCATS. AWA[3] and Philips Australia manufacture signal controllers with the MASCOT feature built in to the hardware and it is now called Flexi-link.
- 1969/70 - a new rack mount system was commissioned.
- 1970's - a decision to use the PDP 11 computers for traffic control was made and Arthur Sims joined the DMT and software development stated for SCATS
- 1976 - The new system developed on the PDP computers became known as SCATS.
- 1970's - the move to a modern new control center at No. 1 Oxford Street, Sydney which was to be the center of SCATS development for over twenty years.
- 1978 - The first Central Monitoring System (CMS) was installed addressing the need to centrally monitor geographically remote SCATS regions. Its functionality was expanded over subsequent years to provide some data file back up and management facilities.
- 1981 - The first VAX computer, a VAX 11/780 was purchased, progressively taking over many of the development functions and providing a platform for SCATS management and support functions.
- 1982 - The acquisition of a RAMTEK graphics display system provided the first graphical display of SCATS related data. Applications to create and display graphical data at the regional, subsystem and intersection levels were developed in-house.
- 1980's - the first use of personal computers (PC) for the operator interface. Software, known as SCATTERM, was developed to enable these PCs, running Windows®.
- 1989 – PC graphics capability was developed to replace the RAMTEK display system.
- 1990 – version 5 of SCATS in use

[3] **AWA: Amalgamated Wireless (Australasia)** Ltd (later AWA Ltd). Throughout most of the 20th century AWA was Australia's largest and most prominent electronics organization, undertaking development, manufacture and distribution of radio, telecommunications, television and audio equipment as well as broadcasting services.

- Early 1990's – largely arising from the specified requirements for a SCATS 5, system to be supplied to Hong Kong further features were developed
- 1996 – in response to a contract to install SCATS as part of a freeway/arterial integrated corridor project in Minneapolis, development of a traffic adaptive ramp metering function in SCATS which was shown to reduce delay and ramp queuing when compared to the existing MNDoT[4] system.
- 1998 – The first SCATS 6 was trialed after realizing the operating platform for SCATS had to migrate from PDP 11 to PC based computers.

SCATS is now so successful, it is sold internationally through distributors. Roads and Maritime Services continue to develop and support SCATS and ancillary software products.

[4] **MNDoT: Minnesota Department of Transportation**

2.2. How Does SCATS Work

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 help to Minimize Stops(light traffic), delay (heavy traffic) and travel time By selecting the most appropriate; Cycle Length, Splits (that is the phase, or green, splits), and Links (or Offsets).

Traffic network subdivided into regions. Each region has homogenous flow characteristics and subdivided into links and nodes. For each region, calculates degree of saturation for all nodes and calculate ratio of detected flow to saturation flow. It allocates future green time on the basis green time used. It calibrates saturation flow automatically for each lane daily. Also the most critical nodes for each region should be identified. Therefore the highest degree of saturation which is not always the same node should be calculated. Regional boundaries "marriages" and "divorces" can be changed depends on the condition.

2.2.1. SCATS Functions and Highlights of Its Philosophy

The SCATS Philosophy is based on optimizes in real time by using many distributed computers as processors. The point is although it has libraries of offsets, phase split plans, but there is no comprehensive plan which is determinable which trustable completely. But different plans should check and be voted to be used for advanced cycles. SCATS is not model based. It relies on incremental feedbacks (Dutta et al., 2008). Intersections can be grouped as sub-systems and by accumulation of more sub-systems it converts to a system. In a different word the philosophy of this adaptive traffic control system can be cited by the following points:

- Detects traffic volume by movement
- Converts data to flow rate
- Calculates optimal cycle length
- Calculates optimal splits by phase
- Determines phase combinations
- Checks timing alteration thresholds
- Sets up implementation

2.3. SCATS Equipment Requirements

2.3.1. SCATS Data Requirements

SCATS need data to work. Therefor these data should be collected with some devices like sensors and detectors. Afterward these data would send to processing computers and decision making center. Furthermore there are some mathematical terms which are very important for interpreting these data which are collected and to make the results comparable. Degree of Saturation (DS) and Car Equivalent Flow (VK) for each approach lane, are two important factors in SCATS that the computation initiates with them (Gross, 2000).

Degree of saturation is used to vote for Cycle Length and Split Plan, which in continues these terms would be explained more in detail. Car equivalent flow is used to vote for Offset Plan. Controller collects number of spaces and total space time during green of each phase, each cycle for use by SCATS adaptive algorithm. Detectors used for calling and extension. Actual movement data collected by stop line detectors allows accurate split determination. For example loop detectors or equivalent (video detection in Oakland County MI) in each lane at the stop line would be the data collectors which allow accurate split determination (Wilson et al., 1984). In below there are other data aspects which are necessary for this adaptive traffic control system:

- An upstream approach can vote at downstream intersection (Engineer selectable)
- Tactical operation of controller can be enhanced by special detector logic in the controller personality.
- Special functions include:
  - Queue length detectors
  - Detector combinations
  - Turn/through discrimination for shared lanes, etc.
- No modeling required.
- User defines:
  - Subsystems
  - Target cycle lengths and relationship to DS,
  - Split plan strategy
  - Linkages and offsets

2.3.2. SCATS Architecture

The architecture of SCATS is consists of three parts, which in below they are going to be defined separately in detailed. Each of these parts has its own duties and task. They should be connected and communicates to each other depend on the state of the traffic and its magnitude. But these three parts also can work somehow separately. In the figure below these three parts are shown in a graphical way.

- Central Computer – Communications and Database Functions
- Regional Computer – Strategic Control
- Local Traffic Controllers – Tactical Control

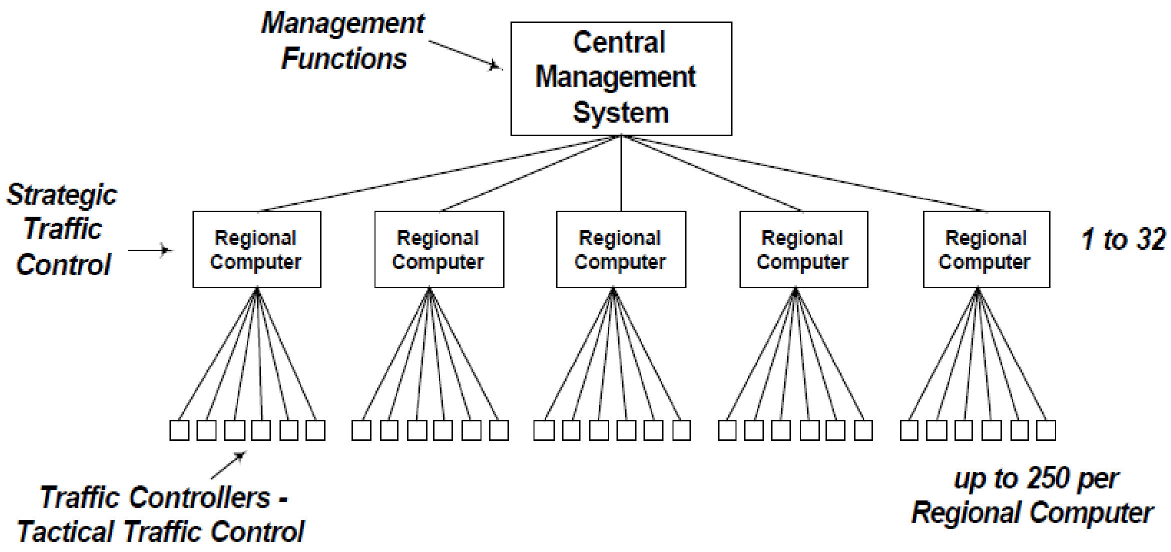


Figure 4: SCATS Architecture

- **Central Computer**

This part of the SCATS architecture has the duty of centralized monitoring of system performance and equipment status. Central monitor computer (CMS) has 2 main major tasks:

(a) Data collection, input and monitoring

(b) Connected with Management Computer

(c) To diagnose faults quickly

Management computer is consisting of printer terminal, visual display, PC work Station. Thanks to the central management, all the events of the system would be recorded as a database in the central computer and would be very useful for further implementations (Daniel, 1992).

- **Regional Computer**

In this scale of the architecture the regional computer maintains autonomous traffic control of a set of controllers. The system is expandable by simply adding regional computers. One of the important duties of these computers is to perform the strategy control algorithm. The second important tasks is to use the time-of-day and traffic information to select green split plan, interval offset plan and cycle time. The local controllers within region are grouped into systems and subsystems:

(a) System:

They are divided by typically geographically unrelated. They do not interact with each other. Consequently they would act separately.

(b) Sub-System:

Sub-Systems are the basic elements of control at the strategic level. Each sub-system may comprise one to ten intersections.

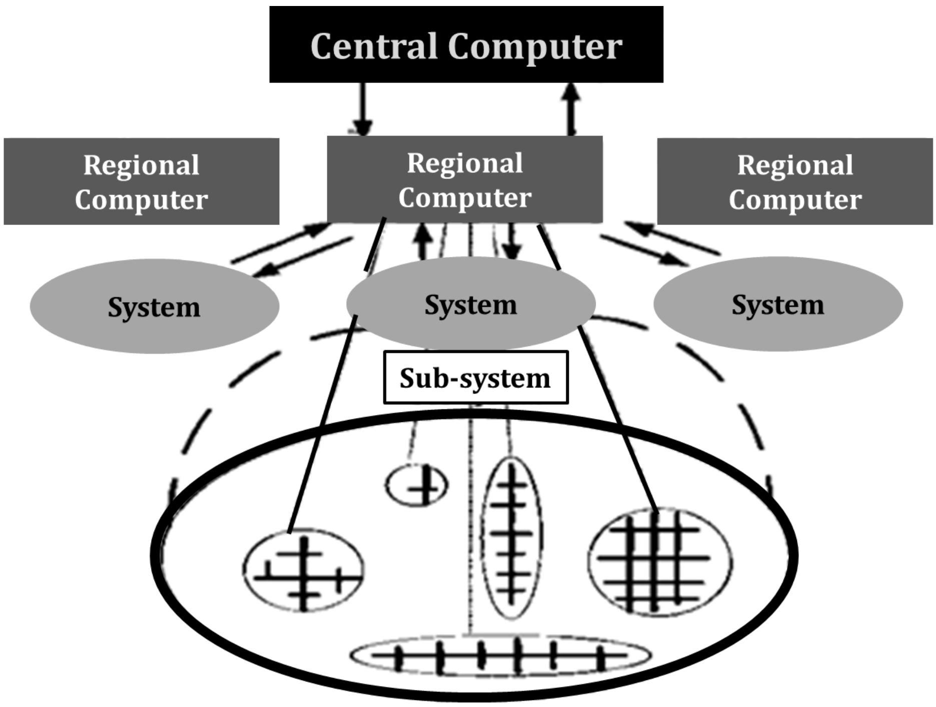


Figure 5: System and Sub-System division

- **Local Controller**

One of the usages of local controller is in the case of strategic operations; it would pass information to regional computer and accepted information to adaptive traffic condition. But the duty of local controller is not confined just to this point; it also has a big role in tactical operations which is consisting of following remarks:

(a) Operate under the strategic umbrella.

(b) Keep local flexibility to meet cyclic variation in demand at each intersection

(c) Base on detector information.

2.3.3. SCATS Configuration

The configuration of SCATS and how different parts of this adaptive traffic control system are connected to each other and which kind on connectors and controllers are used in this regards, are provided in the following figures.

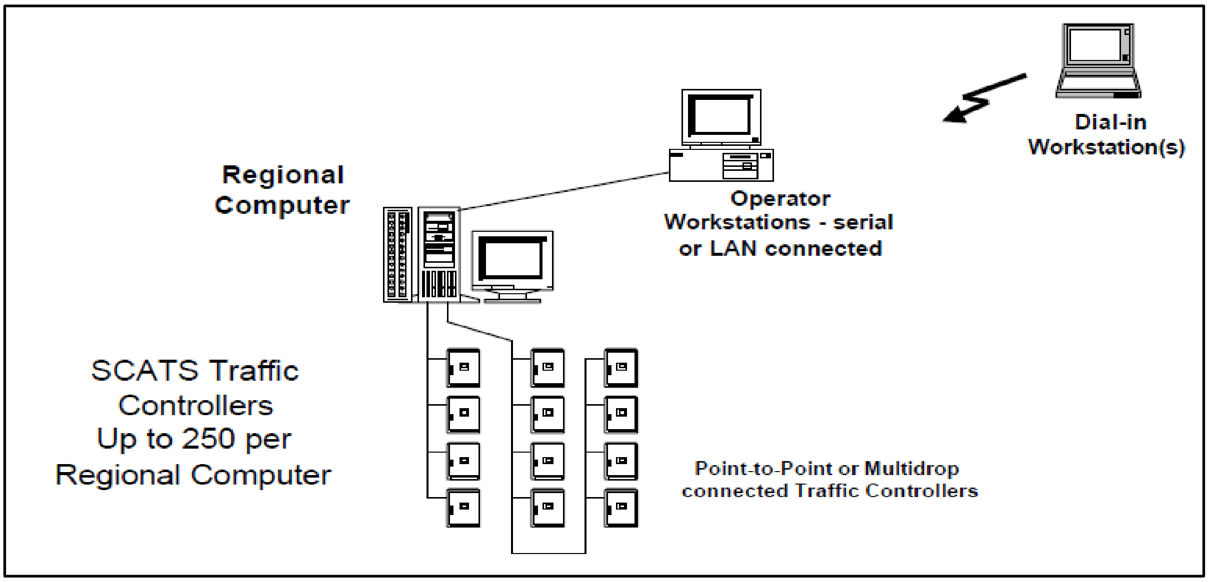


Figure 6: Minimal system – Single region

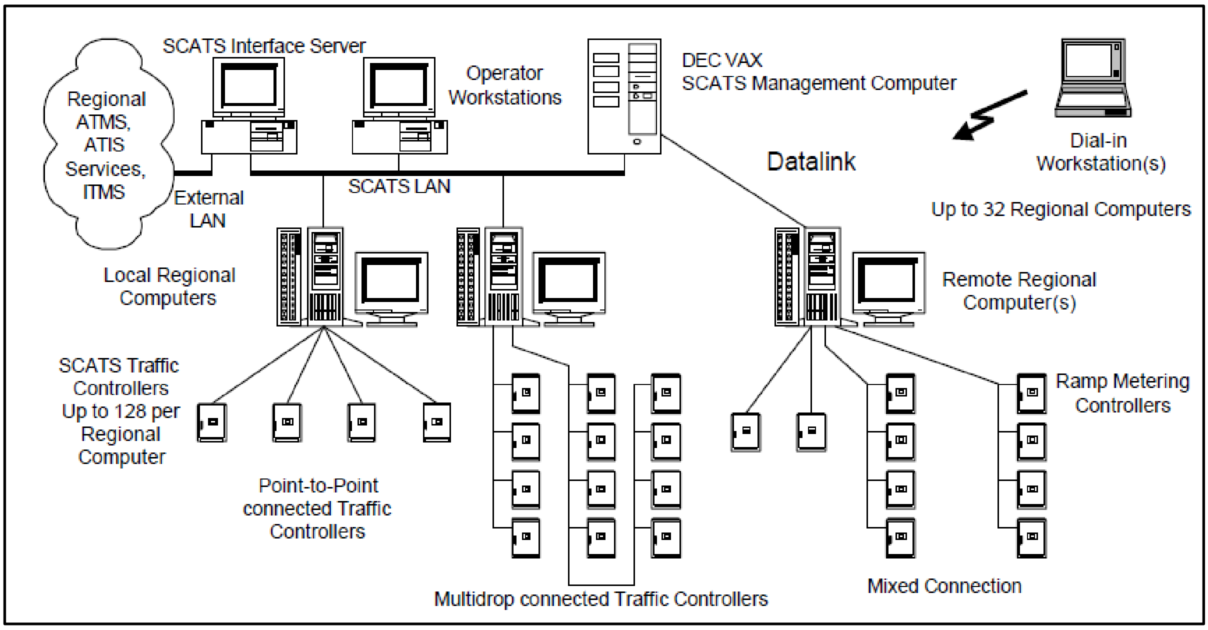


Figure 7: SCATS1 (1st configuration philosophy) – with Integration Server

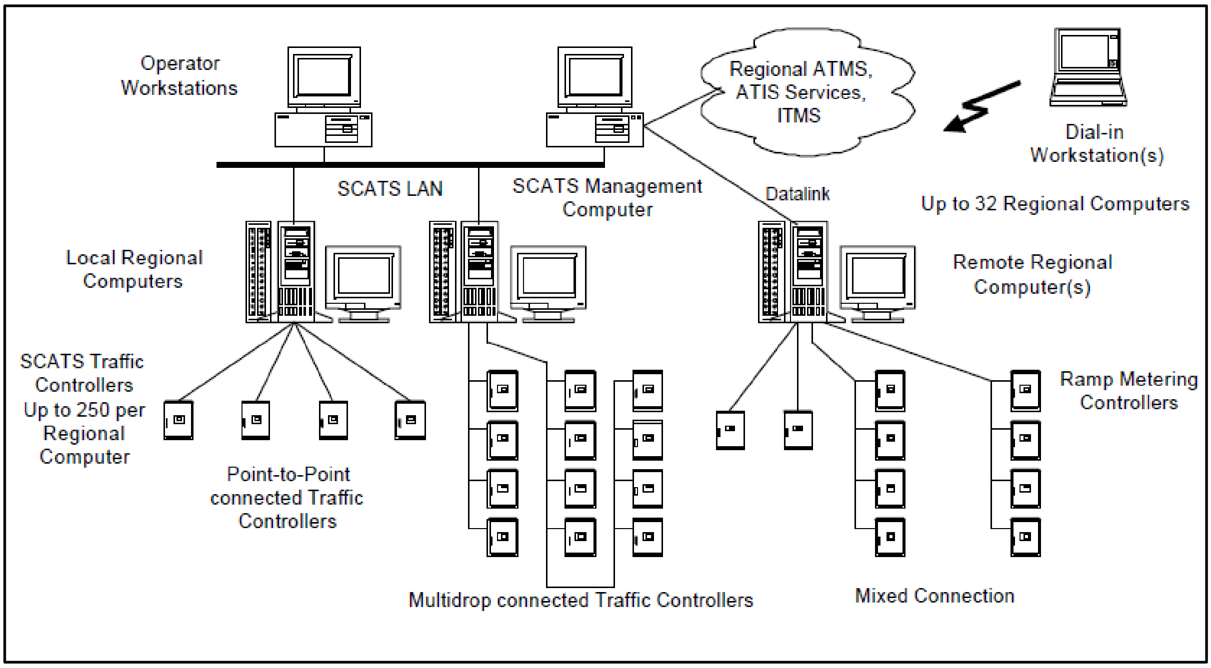


Figure 8: SCATS2 (2nd configuration philosophy)

2.3.4. SCATS Sensors

Controller collects number of spaces and total space time during green of each cycle. Actual movement data collected by stop line detectors allows accurate split determination. SCATS operated by looking at "Space" between vehicles (Gross, N.R, 2000). Degree of Saturation measures the effectiveness of green time. There is a relationship between traffic density and Space time. In the following graph this relation is depicted:

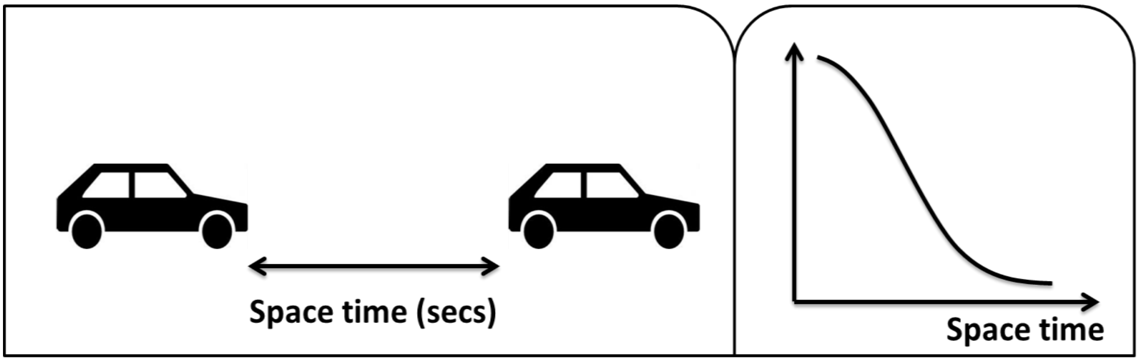


Figure 9: Density – Space time graph

In the following graph an example of where the sensors and detectors are placed, is illustrated. Loop detectors or Video detectors (as used in Oakland County, MI) in most lanes at the stop line. Some lanes can be left without detectors.

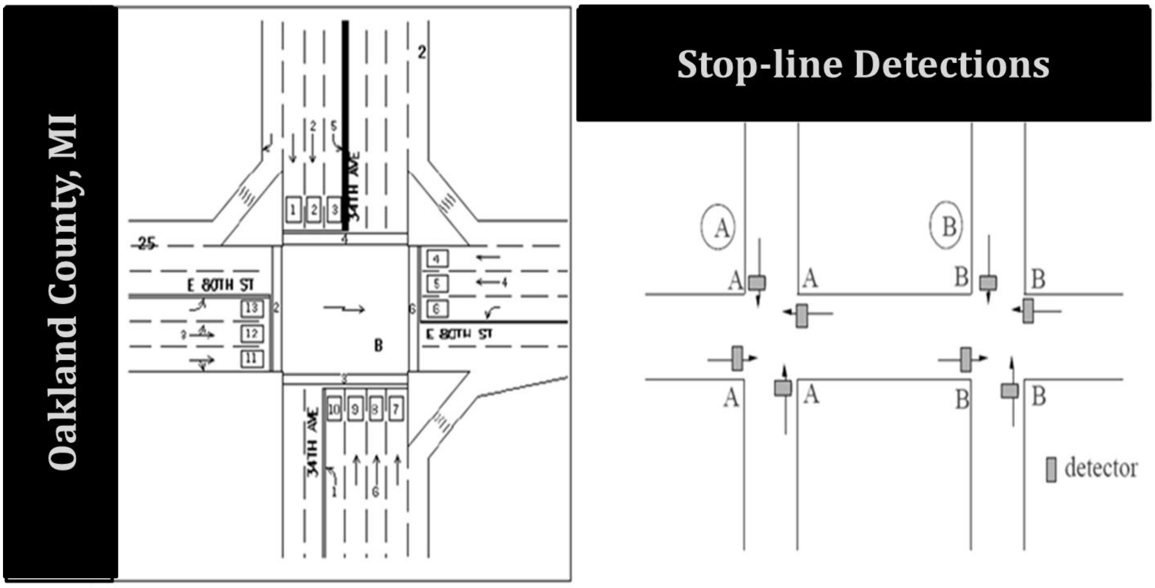


Figure 10: Loop detectors or video detectors at the stop lines

2.3.5. SCATS Traffic Controllers

SCATS provides many facilities for the traffic engineer to achieve "custom" control in special circumstances while still maintaining adaptive operation. Variation routines at intersections allow special operation based on detection of a parameter value (Cycle Length, volumes, stage or phase active, next stage to run).

In the following the traffic controller items which are mostly used in SCATS are mentioned:

- 170 E Controllers Thru Interface Card
- 2070s Thru Controller Software
- Adaptive Traffic Control Controllers

2.3.6. SCATS Communication

The communication of SCATS and how different parts of this adaptive traffic control system are connected to each other and which kind of connectors are used in this regards, are provided in the following figures.

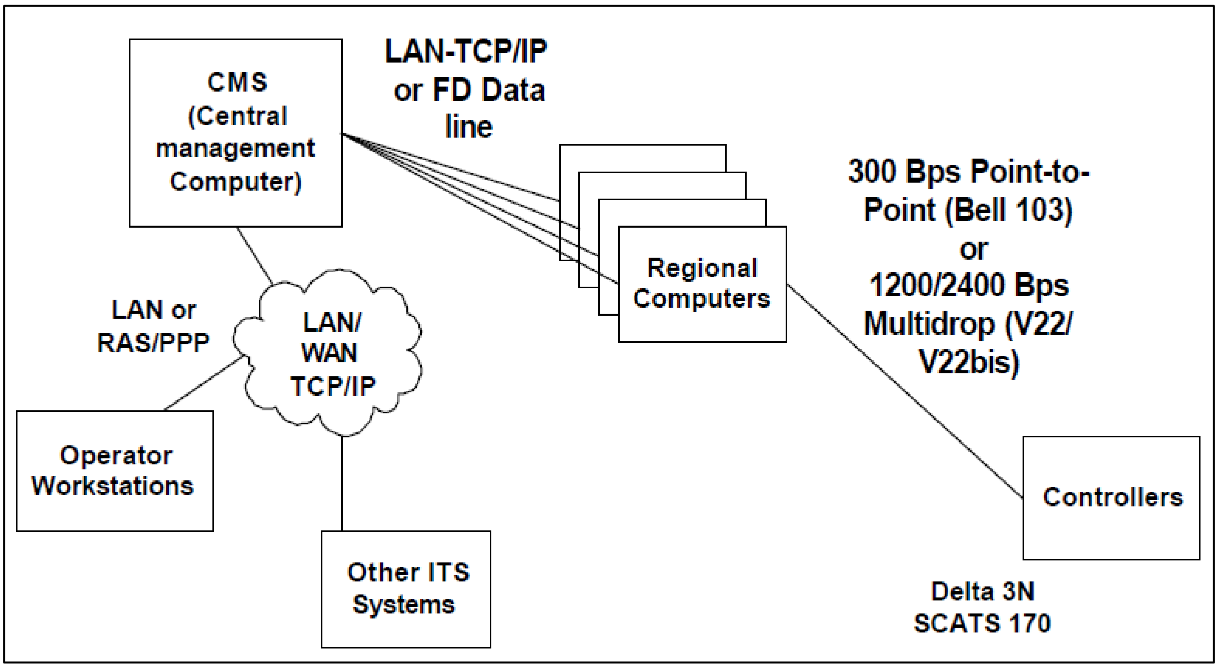


Figure 11: SCATS Communication – 1st philosophy

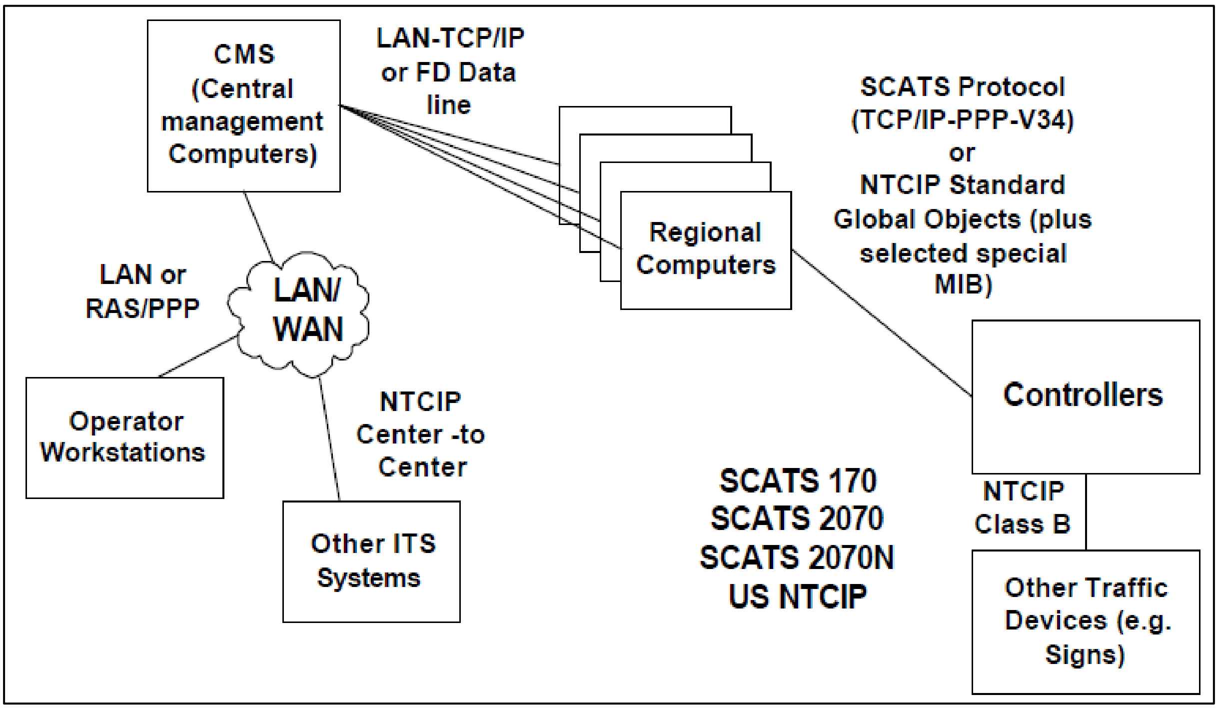


Figure 12: SCATS Communication – 2nd philosophy

2.3.6.1. SCATS Communication Requirements

The requirements for communicating for SCATS such as the type of cables which are used and the size of massages which send to the regional computers are shown in the bellow.

- Point-to-Point or Multi-drop.
- Once per second communication with each intersection.
- Messages are normally 1 to 5 bytes, average 3 bytes.

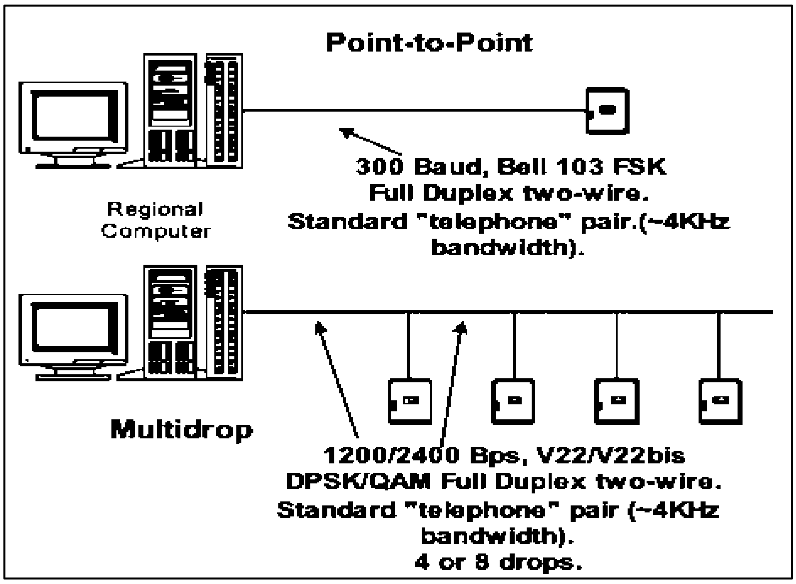


Figure 13: SCATS Communication Requirements

- Optional digital communications port (RS232) for direct network connection.
- Requires 300 Baud Full duplex channel with addressing/routing by network.

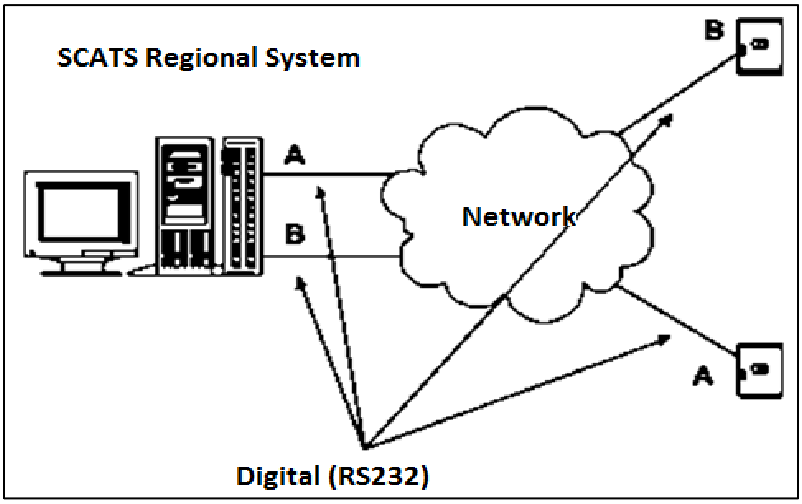


Figure 14: SCATS Communication Requirements

SCATS is able to operate over PAPL, ADSL, PSTN and 3G IP network connections to each intersection. It can also operate on a network of private cables not requiring third party telecommunications support and large parts of inner Sydney have always operated this way.

2.4. Adaptive Control Method

Many traffic control systems manage the signals on a fixed-time basis, where a series of signal timing plans are scheduled by day of week and time of day. The time relationship between signals is pre-calculated; based on previously surveyed traffic conditions. Such fixed-time systems cannot be expected to cope with traffic conditions that differ from those prevailing when the intersection was surveyed.

Furthermore, as traffic patterns change with the passage of time, fixed time plans become outdated. This requires the area to be resurveyed, and new signal timing plans calculated every few years. Experience has shown this procedure to be expensive, and to require 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 the plans and timetables; either case results in 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 SCATS 6 Fixed Time Plan system. This is a great improvement on other fixed time systems because it has the benefit of improved decision making capabilities built-in.

The full answer, of course, is the Adaptive SCATS 6. Unlike most fixed-time or semi-responsive systems, it requires no costly pre-calculation of signal timing plans. Additionally, SCATS is self-calibrating, automatically adjusting to changing traffic patterns over time. The SCATS 6 controllers and traffic control computer analyze real-time traffic data from vehicle detectors, and produce signal timings which are suitable for the traffic conditions as they really are. It offers a variable sequence of signal phases, and the option to omit phases or movements from the sequence on a cycle-by-cycle basis when there is no demand.

The implementation of a fully responsive system does not, however, mean that the careful design of each intersection can be avoided. The present state of technology only allows for the real-time variation of signal timings at intersections which have known or anticipated traffic requirements.

The above descriptions are about traffic control in general. But traffic control specifically in SCATS would discuss in continues. In the Master-link mode of operation, SCATS control of traffic is affected at two levels which together determine the three principle signal timing parameters of traffic signal coordination; cycle time, phase split, and offset. These two levels are referred to as strategic and tactical. Strategic control is basically concerned with the determination of suitable signal timings for the areas and sub-areas based on average prevailing traffic conditions while tactical control refers to control at the individual intersection level within the constraints imposed by the regional computer's strategic control.

Traffic information for both strategic and tactical functions is measured using inductive loop vehicle detectors. All detectors are capable of performing the tactical function. All detectors are capable of being defined as strategic detectors and information from these is pre-processed in the local controller and sent to the regional computer for the strategic calculations.

The cycle time is the time taken to complete one sequence of all phases and must vary to meet the overall level of traffic demand because, in general, increased cycle time increases system capacity. All signals which are coordinated must share a common cycle time. The system dynamically adjusts cycle time to maintain the highest degree of saturation in a coordinated group of signals within acceptable user defined limits.

Phase split refers to the division of the cycle into a sequence of green signals for the competing movements at each intersection and must reflect the relative demands for green time on each approach. SCATS determination of phase splits is essentially one of maintaining equal degrees of saturation on competing (representative) approaches. However, control may be biased to favor principal traffic movements when demand approaches saturation.

Offset refers to the time relationship between the phase introduction points of adjacent signals. The pattern of offsets in a series of coordinated signals must be varied with traffic demand to minimize the stops and delay associated with travel through a network of signals. SCATS selects offsets, based on free flow travel time and degree of saturation, which provide minimum stops for the predominant traffic flows

As it mentioned in previous part, the architecture of SCATS adaptive traffic control system is divided into three parts, which the level of adaptive control is different in each of them. Therefor in continue two main levels of control of SCATS would be expressed more in detail.

- **Strategy control**
  This level of adaptive control is undertaken by the regional computers
- **Tactical Control**
  This level of adaptive control is undertaken by the local controller

2.4.1. Strategy Control

2.4.1.1. General concept

Basically, strategy control is concerned with the selection of suitable signal timings for the target area and sub-areas based on average prevailing traffic conditions. The detection information are preprocessed in the controller and sent to a regional computer to calculate the degree of saturation. The algorithm is applied at a cycle-by-cycle basis. The phase split plan, internal offset plan, external offset plan and cycle length are applied to the sub-system for the next cycle. SCATS strategic control refers to the top level of control which is impressed on a network of coordinated signals by the regional computer. Using flow and occupancy data collected from loop detectors in the road by the local controllers, the strategic algorithms determine, on an area basis, the optimum cycle time, phase splits and offsets to suit the prevailing average traffic conditions. This is carried out for adjacent groups of signals (usually one to ten in size) which are known as sub-systems. Provision is made for groups of sub-systems to link together to form larger systems. Up to 64 sub-systems may be controlled by each regional computer and these may group together to form one big system or several completely independent systems.

Each sub-system consists of one or more intersections and contains only one critical intersection which requires accurate and variable phase splits. The intersections in a sub-system form a discrete group which are always coordinated together and share a common cycle time and interrelated split and offset selection. The sub-system in SCATS is the basic unit of strategic control. Phase splits and cycle time are calculated for the critical intersection and offsets are determined by the amount of traffic flowing in each direction through the sub-system. Phase splits for minor intersections in the sub-system are, by definition, non-critical and are therefore either non variable or selected by a matching process which selects splits which are compatible with the splits in operation at the critical intersection.

To give coordination over larger groups of signals, sub-systems can link together to form larger systems, operating on a common cycle time. These links, which determine the offsets between the sub-systems, may be permanent or may link and un-link according to varying traffic conditions. This ensures that where traffic flow between sub-systems is sufficient to warrant coordination the link is enforced but when one or more sub-systems can operate more efficiently at a lower cycle time, the link is broken.

The basic traffic measurement used by SCATS for strategic control is the degree of saturation on each approach or, more accurately, a measure analogous to degree of saturation. Inductive loop vehicle detectors placed in all important approach lanes at the stop line of the critical intersections (and some detectors at other intersections) are defined in the regional computer data base as strategic detectors. The local controller collects flow and occupancy data from these detectors during the green of the approach. After pre-processing, the data is sent to the regional computer and used (together with automatically self-calibrated saturation flow data for each detector) to calculate the SCATS degree of saturation (DS).

DS is defined as the ratio of the effectively used green time to the total available green time on the approach. The effectively used green time is the length of green which would be just sufficient to pass the same platoon of vehicles had they been travelling at optimum headways as in saturation flow conditions. The difference between the effectively used green and the available green can be thought of as wasted green and this is easily measured by summing the periods of non-occupancy of the detector during the green period and from this subtracting the spaces which must necessarily accompany each vehicle under saturation flow conditions. The value of saturation flow space to subtract is automatically calibrated by SCATS for each lane of strategic detection.

The measure DS is essentially independent of vehicle length and therefore independent of vehicle mix (eg cars, trucks, buses). The algorithm is capable of producing values of DS greater than unity in congested conditions, enabling SCATS to deal effectively with oversaturated traffic. The SCATS DS algorithm will produce reliable and useful values for bicycles when a suitable detector, one meter in length, is installed in a bicycle lane. The calculation of DS relies on the detector being of sufficient length in the direction of traffic flow to ensure that large values of space are not measured under conditions of slow moving closely spaced traffic (which would appear to be the same as light traffic widely spaced). The detector must not, be too long as it would not measure any spaces when traffic moves freely. Research has shown the optimum length of the detection zone to be 4.5 meters.

From the DS measured for each lane of strategic detection, a normalized flow rate is calculated which is analogous to PCU (passenger car unit) flow. This is simply obtained by multiplying the value of DS by the automatically calibrated saturation flow rate.

Cycle time is increased or decreased to maintain the degree of saturation around 0.9 (user definable) on the lane with the greatest degree of saturation. Other lanes or approaches may have lower degrees of saturation. A lower limit for cycle time (usually 30 to 40 seconds) and an upper limit (usually 100 to 150 seconds) are specified by the user. Cycle time can normally vary by up to 6 seconds each cycle but this limit increases to 9 seconds when a trend is recognized.

Phase splits are varied by up to four percent of cycle time each cycle so as to maintain equal degrees of saturation on the competing approaches, thus minimizing delay. The minimum split which can be allocated to a phase is either a user definable minimum or, more usually, a value determined from the local controller's minimum phase length which may vary according to whether pedestrians are using the walk signals associated with the phase. The maximum split which can be allocated to a phase is limited by the current cycle time and the minimum requirements of the other phases.

Offsets are selected for each sub-system (i.e., the offsets between intersections within the sub-system) and between sub-systems which are linked together on the basis of the PCU[5] traffic flow obtained from DS. In this way the best offsets are selected for the high flow movements. Other links carrying lower flows may not receive optimum coordination when the cycle time is inappropriate. However, when traffic conditions permit, the system maintains a cycle time which can provide good offsets on a majority of links even though a smaller cycle time could provide sufficient capacity. Good offsets on the heavy flow links minimize the total number of stops in the system, reducing fuel consumption and increasing the capacity of the system

2.4.1.2. Algorithm

(1) Degree of Saturation (DS)

(2) Car Equivalent Flow

(3) Data Smoothing and Damping

(4) Cycle Length

(5) Green split Plan

(6) Offset Plans

(7) Linking of Sub-systems

(8) SCATS and Oversaturation

[5] Passenger Car Unit

2.4.1.2.1. Degree of saturation (DS)

In traffic engineering, the degree of saturation of an intersection (typically under traffic signal control) or road is a measure of how much demand it is experiencing compared to its total capacity.

The degree of saturation (%) is a ratio of demand to capacity on each approach to the junction, with a value of 100% meaning that demand and capacity are equal and no further traffic is able to progress through the junction. Values over 85% are typically regarded as suffering from traffic congestion (Gross, N.R, 2000).

$$\text{DS} = \frac{g'}{g} \qquad\qquad g' = g - (T - th)$$

DS= [green-(unused green)] / available green

Where,

DS – Degree of saturation;

g – The available green time;

T – The total space time (no vehicle pass the sensor);

t – The unit space time between vehicles while discharging (caused by the distance between vehicles);

h – The number of spaces;

Degree of Saturation is the ratio of efficiently used phase time to available phase time. Unused green is a measure of efficiency. The status of this factor can be categorized in three states; It would be (0) at saturation flow, (+) for under saturation, (-) at oversaturation. Standard space time at the maximum flow is self-calibrated daily. DS can be higher than 100%. For example during the oversaturation condition, the used green can be negative (–), vehicles are closer than standard space time at the maximum flow.

In the following the algorithm of optimizing the plans for managing the congestions by considering the Degree of Saturation is depicted:

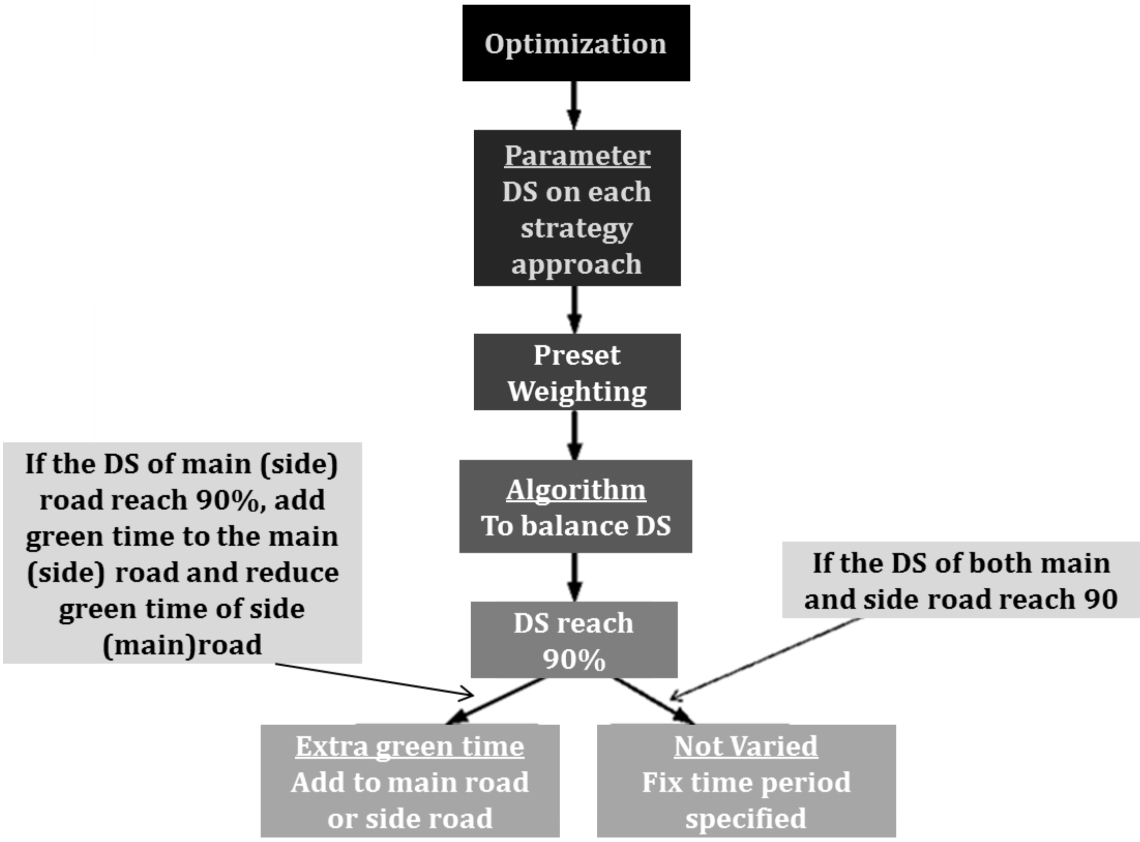


Figure 15: Degree of Saturation interpretation algorithm

2.4.1.2.2. Car Equivalent Flow (VK)

Car equivalent flow is derived from degree of saturation and the lane saturation flow for each lane. VK is Independent of vehicle types in traffic stream. The Car Equivalent Flow is calculated from the "measured DS", and Maximum flow rate for each strategic detector.

$$VK = \frac{DS.g.S}{3600}$$

- VK = DS * Green Time * vehicles per second at maximum flow;

2.4.1.2.3. Data Smoothing and Damping

- Degree of saturation and car equivalent flow are used as weighted averages usually over three cycles.
- SCATS uses smoothing, damping (i.e. reducing the gain of feedback control loops) and hysteresis extensively.
- It is the calibration of these techniques over years of experience that is the key to effective performance.

2.4.1.2.4. Cycle Length (CL)

Cycle length is composed of the total signal time to serve all of the signal phases including the green time plus any change interval. Longer cycles will accommodate more vehicles per hour but that will also produce higher average delays.

The best way is to use the shortest practical cycle length that will serve the traffic demand. Vehicles at a signal installation do not instantaneously enter the intersection. Early studies by "*Greenshields*" found that the first vehicle had a starting delay of 3.7 seconds to enter the intersection with subsequent vehicles requiring an average of 2.1 seconds each. Generally, vehicles will pass over an approach detector with headway[6] of 2 to 2.5 seconds. For general calculation purposes, an average time of 2.5 seconds per vehicle to enter the intersection is a conservative value. This value can be used to estimate signal timing for planning purposes (Gross, N.R, 2000). The cycle length includes the green time plus the vehicle signal change interval for each phase totaled to include all signal phases. Therefore finding the Optimum cycle length is the most important factor for planning purposes.

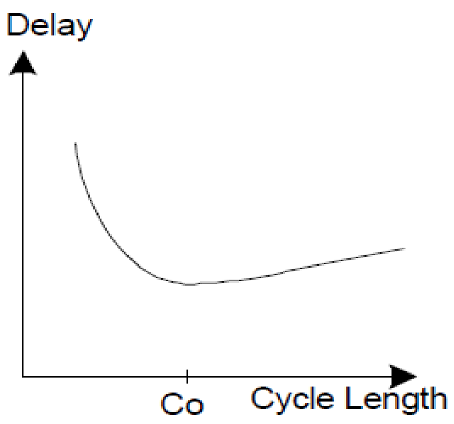


Figure 16: Delay – Cycle length relationship

[6] Headway is defined as the time distance from the tip of one vehicle to the tip of the next one behind it, expressed as the time it will take for the trailing vehicle to cover that distance.

Cycle Length for a "married" set of subsystems is a compromise. Since the sub-systems can be married under common cycle length condition, consequently approaching to the specific CL would be one of the main factors in this regards. All intersections within a sub-system operate on a common cycle length.

The other important point is the Optimum CL. Delay increases rapidly for Cycle Length below Co (optimum CL). Exact CL would not be critical as long as it is not less than Co. the aim and objective is to keep CL below user defined limits.

The Cycle Length is a function of the highest DS measured in the sub-system of the previous cycle. User defined equilibrium DS values used to determine relationship between measured DS and CL. The relationships are used to select a target CL toward which the actual CL moves.

By Defining the RL', which is the difference of RL (current revised CL) and last CL, it would be possible to record the moving direction of optimal CL. Weighted average of RL' (last three cycles) determine the final RL. Cycle Length normally moves toward final RL by +/- 6 seconds. CL can move up to 9 seconds if RL' for the last two cycles was higher than 6 seconds. (it allows response to steep change in demand)

2.4.1.2.5. Split Plan

Phase split refers to the division of the cycle into a sequence of green signals for the competing movements at each intersection and must reflect the relative demands for green time on each approach. SCATS determination of phase splits is essentially one of maintaining equal degrees of saturation on competing (representative) approaches. However, control may be biased to favor principal traffic movements when demand approaches saturation.

Four background split plans are provided to face different traffic condition. The split plan also specified the normal sequence of phases. Possible plans are examined in each cycle to determine the most "equisat" [7] plan for the next cycle. The new plan is determined while 3 of 4 votes (decision in each cycle) are the same.

[7] Equisat: DS on critical approaches equial.

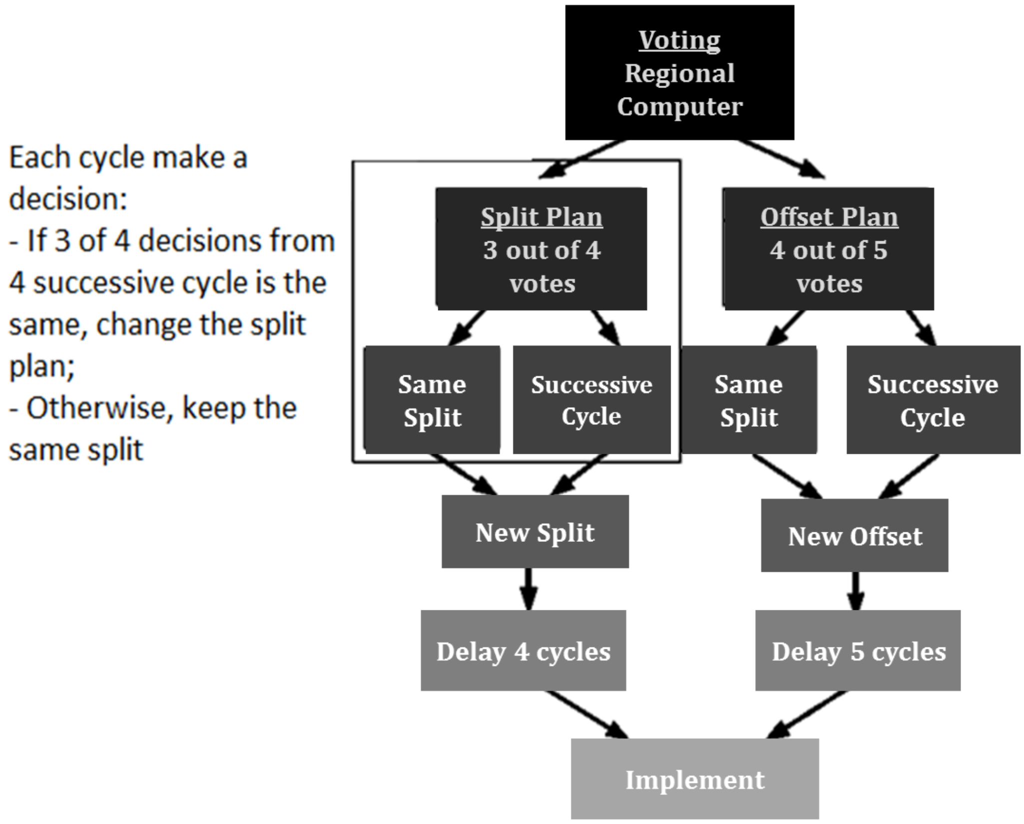


Figure 17: Split Plan Algorithm

2.4.1.2.6. Offset Selection

Offset plans are selected by comparing traffic flows on the links. Directional Bias values (DB's) are entered for each of four plans for each link. Weighted three-cycle average volumes (VK) are multiplied by the DB's and the results summed for each plan. The plan with the highest sum receives the vote.

A new offset plan is adopted when 4 of the last 5 votes are for the same plan. Two offset values; "a" and "b", are entered for each offset plan, and a CL range; CL1 and CL2, is entered for each plan. The offset adopted is "a" at CL1, "b" at CL2 and a linear interpolation for CL between CL1 and CL2 (can be disabled if "jump" desired).

Offset plans are selected by comparing traffic flows on the links. The offset is independent of cycle length and green split variation. It may be defined as function of cycle length to allow for queuing or link speed changes during heavy traffic:

(a) Shorten: to allow for increasing residual queuing as demand rises.

(b) Lengthen: to reflect the lower platoon spreads occurring in heaving traffic condition

The magnitude and direction of offset alteration is specified by the value and sign of A.

$$P' = p[1 + A * g(C)]$$

P’: the modified offset;

P: the basic offset;

A: the specified modifying factor (+/-);

g(C): linear function of cycle length; g(Cmax)=0; g(C)=1(C<0.75Cmax).

By taking advantage of above formula new (modified) offset plan would be calculated. The weighted three-cycle average volumes (VKs) are multiplied by the DB’s and the results summed for each plan. The plan with the highest sum receives the vote. Offset plan vote is calculated once per cycle. The same plan from 4 of 5 votes is the new plan. Offsets can be generalized and expanded For example:

- Arterial
  - Inbound
  - Two-way
  - Outbound
- Grid
  - E-W plan
  - N-S plan

2.4.1.2.7. Linking of sub-systems

Sub-systems are one or more intersections with common Cycle Length which have one main characteristic; only one of these intersections has “critical” status. In the other word this critical intersection requires dynamic split selection. All cycle length and split plan voting are carried out by considering to the critical intersection. Cycle Length and Splits at “minor” intersections in the subsystem are controlled by the critical intersection.

Sub-systems can “marry” to achieve coordination using a separate set of offsets. Two adjacent regions adopt the same common cycle time. In this regard the larger cycle time would be selected.

“Married” sub-systems have the same Cycle length. “Marriage” and “Divorce” is controlled through voting based on CL and volume (VK). This option can be occurred automatically.

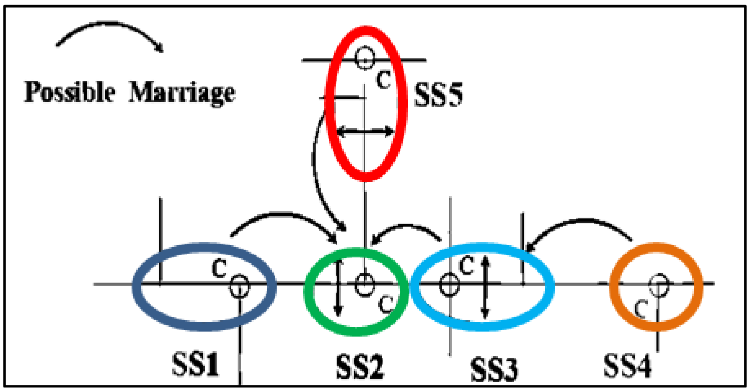


Figure 18: Linking of sub-systems

SCATS uses an index to decide the combination of sub-systems (SS):

- If the difference of Cycle Length at adjacent is less than 9s, the index +1;
- If the index = 4, the SSs should be combined as a new SS. The new Cycle length is set as the largest one of the original SSs.

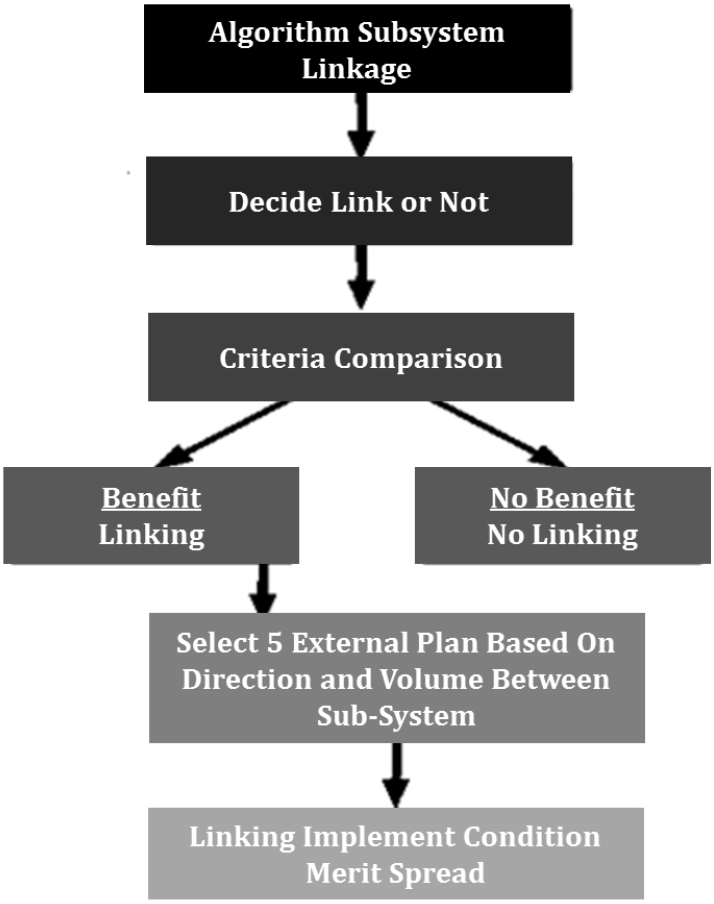


Figure 19: Algorithm of Subsystem Linkage

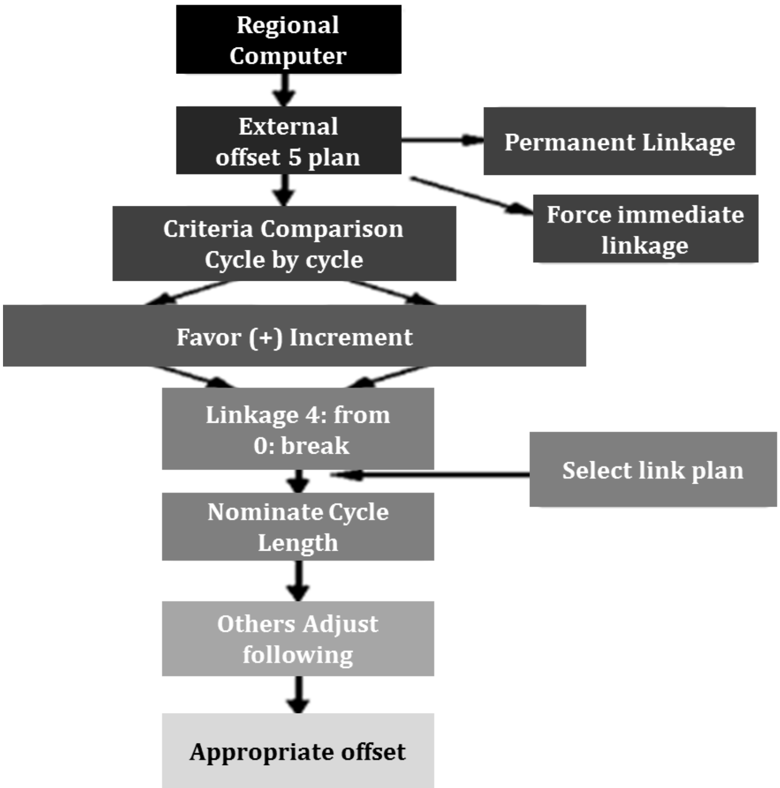


Figure 20: Linkage algorithm in wider view

2.4.1.2.8. SCATS and Oversaturation

SCATS Degree of Saturation can be higher than 100% which means it is located in oversaturated status. In this situation there would be a new definition; "Stretch effect" which means all stages share extra Cycle Length up to a limit CL. After limit CL the coordination stage gets all the extra CL which means a movement away from "equisat" states. SCATS allows the traffic engineer to decide which route should be favored, by how much and where the queue can be tolerated.

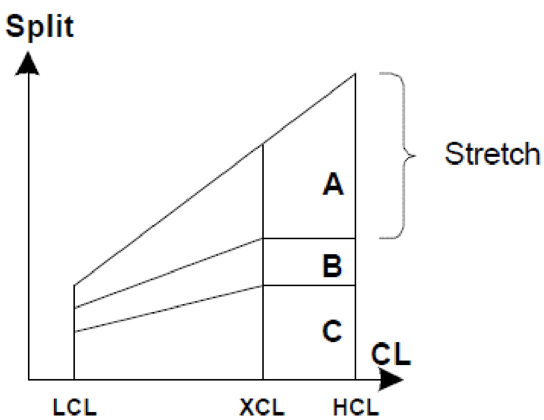


Figure 21: Oversaturation

2.4.2. Tactical Control

2.4.2.1. General Concept

SCATS tactical control refers to the lower level of control which is undertaken by the local controllers at each intersection. Tactical control operates under the strategic umbrella provided by the regional computer but provides local flexibility to meet the cyclic variation in demand at each intersection. Tactics essentially provide for green phases to be terminated early when the demand for the phase is less than the average demand and for phases to be omitted entirely from the sequence if there is no demand. The local controller bases its tactical decisions on information from the vehicle detector loops at the intersection, some of which may also be strategic detectors.

The tactical level of control is carried out in the local controller using exactly the same operational techniques as for isolated operation. The degree to which tactical control is able to modify the signal operation is entirely under the strategic control of the regional computer. Briefly, any phase may be omitted from the sequence if not demanded, may terminate early (before expiry of the time allocated by the strategic operations in the regional computer) under control of the gap timers or waste timers or the phase may continue to its maximum value. The action of these timers and vehicle actuated control in general is treated in the section on local controllers.

A basic difference from isolated operation is that one phase, usually the main road phase, cannot skip and cannot terminate early by action of gap and waste timers. This is because all controllers in a system must share a common cycle time to give coordination. Any time saved during the cycle as a result of other phases terminating early or being skipped may be used by subsequent phases or is added on to the main phase to maintain each local controller at the system cycle length (Dutta et al., 2008).

The combination of strategic control which varies the split, cycle time and offsets in response to gradual changes in traffic demand patterns together with tactical control which handles the rapid but smaller changes in demand cycle by cycle results in a very efficient operation of the signals on the street. The local controller bases on tactical decision by information from the vehicle detector at the intersection. Consequently in a brief summery it can be noted that any phase may be:

(a) Terminated early when demand is smaller than average demand

(b) Omitted entirely when on demand

(c) Continued to its maximum value

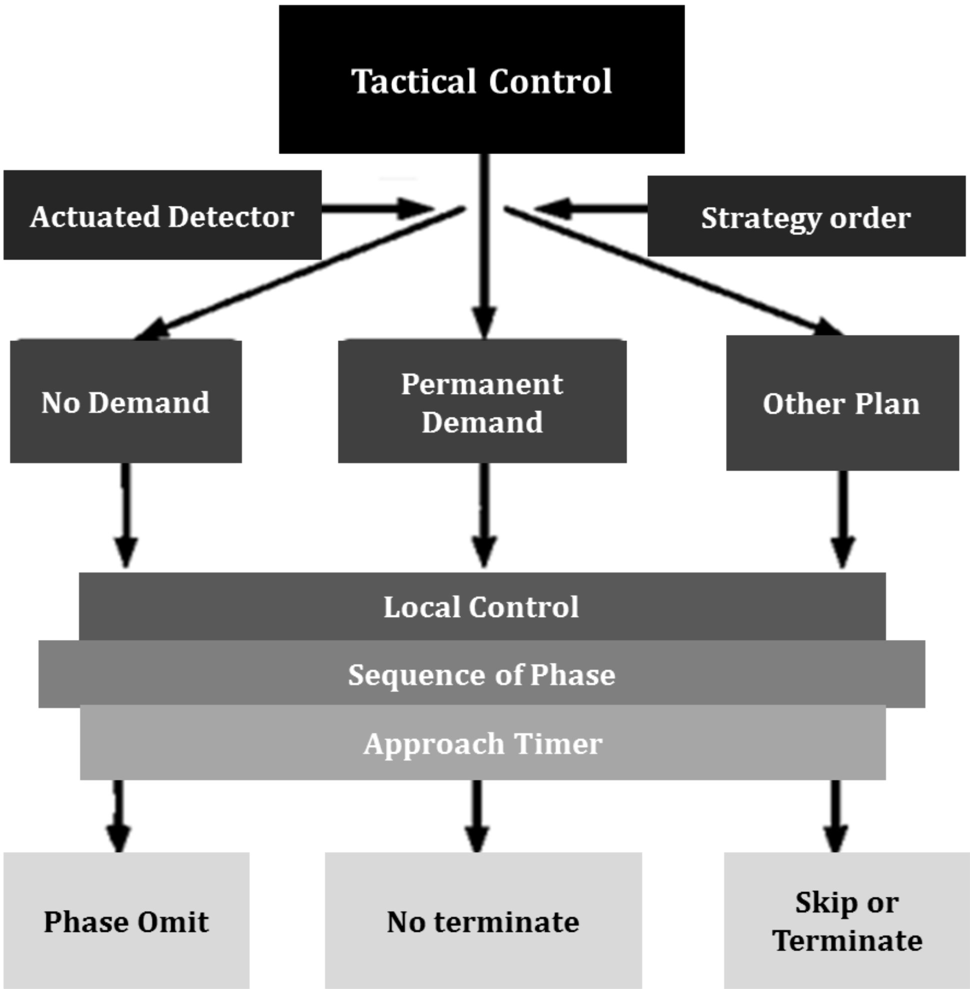


Figure 22: Tactical Control Algorithm

2.4.2.2. Local Controller Functions

Three separate fields would be discussed in detailed in the following that would cover almost all the aspects of local controller functions;

- Modes of operation
- Phase timing
- Detector logic

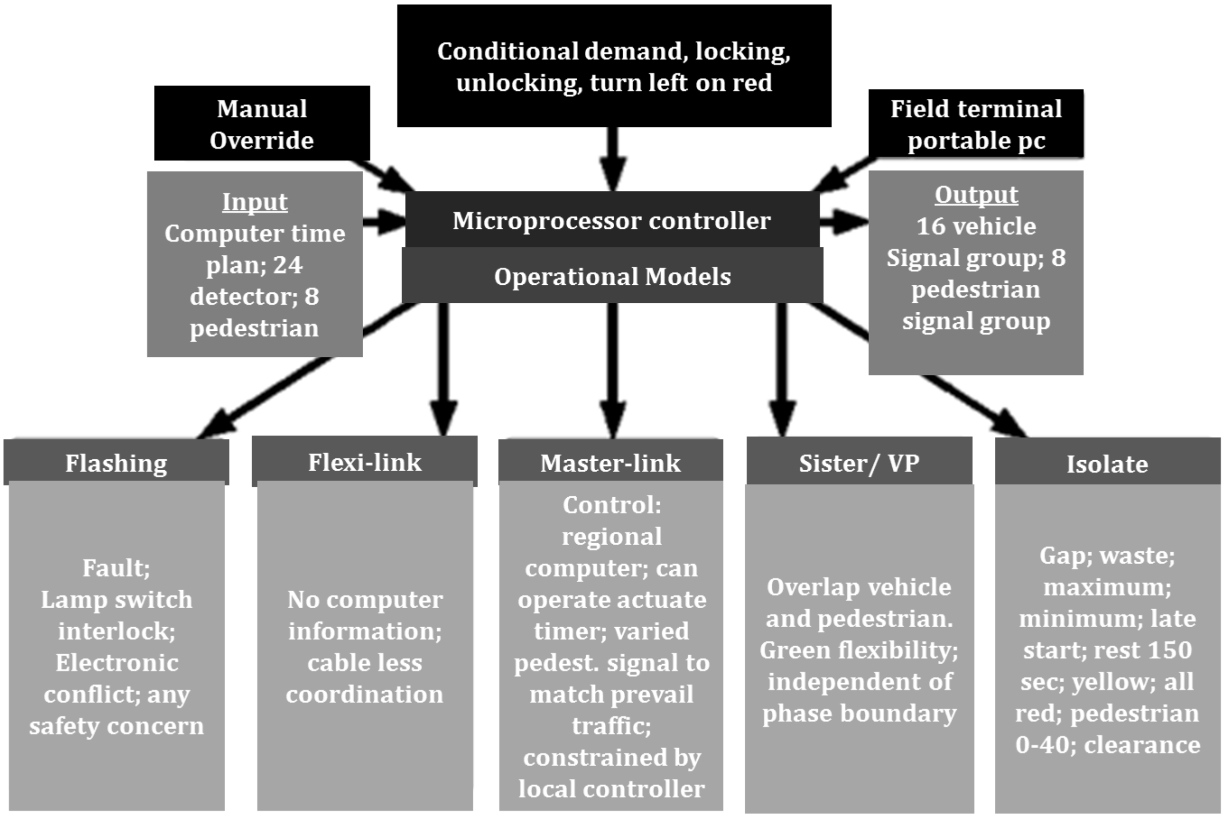


Figure 23: Local Controller Function Algorithm

2.4.2.2.1. Modes of Operation

2.4.2.2.1.1. Master-Link Mode

This is the real-time adaptive mode. In Master-link mode the regional computer determines the phase sequence, the maximum phase duration, and the duration of the walk displays for the pedestrian. The local controller may terminate any phase under the control of the local vehicle actuation timers or skip an undemand phase, unless prohibited by instructions from the regional computer.

The regional computer controls the phase transition points in the local controller, but subject to the local controller safety interval times being satisfied (e.g. minimum green, pedestrian clearance). On completion of the transition to a new phase, the local controller times, the minimum green, and minimum walk intervals, and then waits for a phase termination command from the regional computer. On receipt of the command to move to the next phase, the local controller then independently times the necessary clearance intervals (e.g. yellow, all red) for the phase termination. These safety settings prevent communications errors or regional computer faults from causing the local controller to produce dangerous signal displays, such as short greens or all-red periods (Dutta et al., 2008).

The termination of pedestrian walk signals is also under the control of the regional computer so as to allow the walk timing to be varied to match prevailing traffic conditions. As for the other settings, however, the duration of the walk signal cannot be less than the minimum time programmed into the local controller. Consequently in the other word it can be said that the controller operates in a coordinated system under the control of a regional computer.

The controller receives the split plan, offset plan, and cycle time to be implemented from the regional computers. To change stage away from a main road, permission is required from a regional computer. A side street can be gaped out when successive vehicles are greater than 5 seconds and return unused green to the main road. It can skip to a nominated stage when there is no demand.

2.4.2.2.1.2. Flexi-Link Mode

In the event of failure of a regional computer or loss of communications, the local controllers can revert to a form of time-based coordination known as Flexi-link. In this mode, adjacent signals are synchronized by the power mains frequency or an accurate crystal controlled clock. The phase sequence and duration of each, and the duration of walk displays are determined by the current plan according to the time of day. Local vehicle actuation facilities are still operational in this mode.

The local controller may terminate any phase under the control of the local vehicle actuation timers or skip an undemand phase, unless prohibited by instruction within the plan. Flexi-link is the usual fallback mode of operation (Dutta et al., 2008).

In general, characteristics of this phase can be summarized in following factors; It performs the coordination when Master-link fails to link to a central computer. In this regard it would operate at preset times and selected plan by TOD[8]. It can be used independently of a Master-link system. And last but not least it is a cable less linking.

2.4.2.2.1.3. Sister/VP Link Mode

For explaining this mode of operation, two definitions should be explained:

- A pedestrian Phase includes: Pedestrian Walk interval and Pedestrian Clearance interval;
- A Vehicle Actuation(AP) Timer allows for the early termination of any phase;

[8] TOD: Time of Day

The sister/VP link model is to coordinate the signal between vehicle actuated controller and pedestrian controller.

2.4.2.2.1.4. Isolated Mode

Signals may also operate in isolated mode, with local vehicle actuation (by detector loops) being the sole operating strategy. In Isolated mode the sequence and the maximum duration of each phase is as specified in the local controller time settings. The local controller may terminate any phase under the control of the local vehicle actuation timers or skip an undemand phase, unless prohibited by the local controller settings. Isolated mode may be specified as the fallback mode of operation.

This mode of operation can operate at isolated fixed time, isolate semi or full actuated control. It can specify time-setting, such as phase sequence, maximum duration, gap out, omitted, and waste time just by local controller.

2.4.2.2.1.5. Flash Mode

The normal signal display is replaced by flashing yellow displays on all approaches, or flashing yellow and flashing red to competing approaches. Provided communications are functional, signal operation can still be centrally monitored in Flexi-link, Isolated and Flashing modes. Any of the Master-link, Flexi-link, Isolated and Flashing Yellow modes may be applied by an operator using a SCATS workstation, or be programmed by time of day. Flashing Yellow is also the fall back mode if the controller has a fault.

In general, characteristics of this phase can be summarized in following factors; this mode of operation has the task to flash yellow or red/yellow display , to work as control sequence fault, lamp switching interlocking circuitry, and electronic conflict monitoring. This mode would be a kind of safety design. The important point here is that safety interval time cannot be altered in "RAM", therefore in fault the system would maintain in the safety interval time (Dutta et al., 2008).

2.4.2.2.2. Detector Logic

Detector logic is playing different roles for defining each control modes. The logic is used for the introduction of a phase which services a filtering right turn movement or an unprotected left-turn movement.

- Locking demand: once place, it remains even if detector does not sustain an output
- Non-locking demand: cancel of detector output indicates the vehicle has left.

2.4.2.2.3. Phasing Timing

Another aspect of local controller function is phasing timing. The timing of phases would be categorized in three separated categories. In the following these three categories are provided;

- **vehicle phase intervals**
  - Late start green: 0 to 20 seconds
  - Minimum green: 0 to 20 seconds
  - Reset green: 0 to 150 seconds
  - Yellow: 3 to 6.4 seconds
  - All red: 0 to 15 seconds.

- **Pedestrian phase intervals**
  - Pedestrian walk interval (0-40): display isolated or minimum walk time in Flexi-link and Master-link.
  - Pedestrian clearance 1 interval (0-40): flashing before any vehicle signal can step to yellow.
  - Pedestrian clearance 2 interval (0-40): flashing with vehicle yellow and all red.

- **Vehicle actuation timers**
  - Gap change: time between successive actuates of detectors exceeds a preset value (3-5 sec.)
  - Waste time change: accumulates (preset headway – detectors actuation) until waste time over preset value (6-10)
  - Maximum change:

    (a) In the case of isolated control mode, each phase has been set with a Max time.

    (b)In the case of Master-link mode: the maximum timer does not operate and the phase is terminated by a command from the regional computer.

    (c) In the case of Flexi-link mode: the point of terminating the phase is determined by the current plan.

2.5. SCATS Priority Systems

Five priority inputs are provided, one railroad and four vehicles. Vehicle priority inputs accept steady or pulsed signal for different preemption display. Preemption display (signal groups), ending overlaps and return stage can be selected. Preemption is a function of the controller, SCATS knows preemption is active. SCATS Route Preemption Control (RPC) System provides automatic emergency route control from a single input (e.g. fire station pushbutton). Monitor is provided for up to 10 intersections.

2.6. SCATS Arterial/Network Capability

Offset plans can be arrange for arterial or network use. Arterial plans are set up as: low Cycle Length, Direction 1, "Business Peak" and Direction 2. For a network the offset plans are independent for use on multiple coordination routes. All possible links will be operating. When SCATS is employed on a grid network, offsets are selected as dictated for the heavily traffic routes through the network. At all times, as many links as possible will be operating with defined offsets and these will be the links with the greatest flow. The remaining links, for which offsets cannot be defined because it would close loops, are those with the lowest traffic flow.

2.7. SCATS Virtues and Vises

2.7.1. SCATS Virtues

- SCATS showed great ability to handle unpredictable change of traffic volumes and patterns on special day and special times.
- It has the potential to handle the traffic patterns and volumes adequately.
- Demonstrated the ability to provide response to traffic demand dynamically.
- Can handle long pedestrian clearance time[9].
- Responsive to day-to-day and time-of-day fluctuations in demand.
- Responds well to traffic congestion resulting from crashes, clears backups quickly.
- During low volume traffic demand the traffic signal timing will adjust reducing overall delay.
- Provides an effective maintenance alarm system that reduces traffic delays due to equipment malfunction.
- Eliminates the need (and associated costs) for signal retiming typically performed every three to five years.
- Enhanced public transport time and reliability.
- Reduced fuel consumption.
- Reduced air pollution.
- Reduced delays.

2.7.2. SCATS Vices

- One of the week points of the SCATS adaptive traffic control system is that, with the stop-line detection philosophy, it is impossible to provide currently feedback information about the performance of signal progression.
- Another important disadvantage of this system is that, there is no traffic model in SCATS, the "adaptive" process is completed by the local actual control, which limits the use of an optimization methodology.

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

2.8. Trends of SCATS Deployment

2.8.1. Case Studies and results

It is mentioned previously that SCATS adaptive control traffic system was developed in Sydney, Australia by former constituents of the Roads and Maritime Services in the 1970s, used in Melbourne since 1982 and Western Australia since 1983. It is also used in New Zealand, Shanghai, Guangzhou, Amman, Tehran, Dublin, Rzeszów, Gdynia and soon in part of Metro Atlanta, among several other places. Also In Hong Kong, SCATS is currently adopted in the area traffic control systems at Hong Kong Island, Kowloon, Tsuen Wan and Shatin, In addition some areas of the US; Oakland County, Minneapolis and Michigan.

In this research some parts of United State of America which have deployed SCATS as their adaptive traffic control system for intersections are put under consideration. SCATS have been installed in Minneapolis (MN), Oakland Country (MI), and Arlington County (VA), while in other parts of USA this adaptive traffic control system did not find applicable.

Figure 24: SCATS adaptive control system deployment in USA

Number of intersections with SCATS;

- Minneapolis(MN) --- 71 Intersections
- Oakland County(MI) --- 405 Intersections
- Wilmington/Newark(DE) --- 68 Intersections

- **Oakland County 2001**

São Paulo is using SCATS on different areas of the city. System has been in operation since 1992. Funds have come from earmarks, STP, CMAQ, Locals, and Private Companies. Currently there are over 450 SCATS signals Over 500 by the end of 2001 (Piotrowicz, 2001).

Results in the regards of safety:

Site: Oakland County 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

Table 1: Reduction in the Severity of Accident (Oakland County)

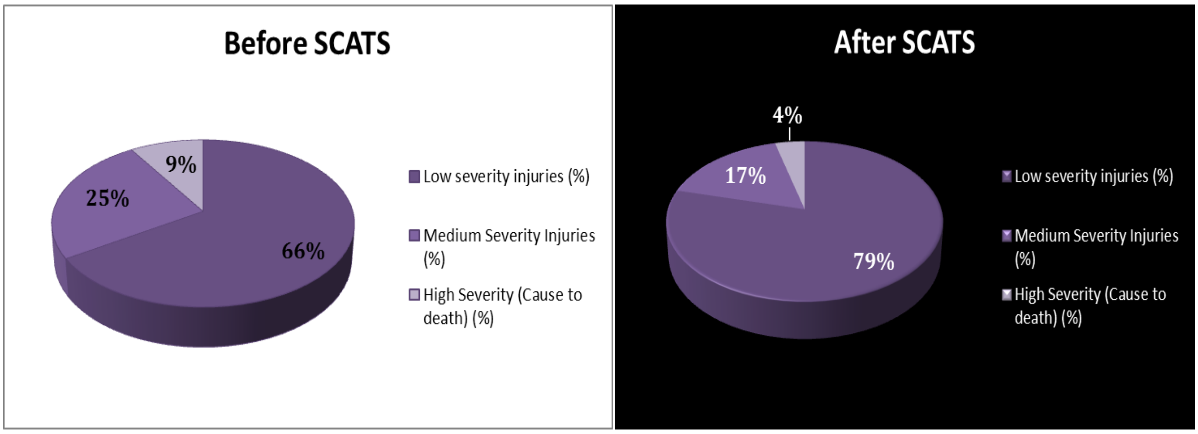


Figure 25: Reduction in the Severity of Accident (Oakland County)

Results in the regards of saving time:

Reduciton in Travel time using SCATS		
Orchard Lake Road		
(%)		
AM peak	OFF Peak	PM Peak
-20	-32	-7

Table 2: Reduction in Travel Time (Oakland County – Orchard Lake Road)

2.8.2. Result Interpretation and Conclusion

In the above figure the deployment of SCATS adaptive traffic control system is shown. The number of intersections which have been installed this adaptive control system is shown. These results are for two statistical censuses which have been done by TRB Signal Systems Committee. The first one had been done in the January of 2000 and the second one is for the January 2001. The outstanding remark of these statistics is that the results did not change between the year 2000 and 2001. Therefor this fact declares that in the United State of America the trend of deployment of SCATS adaptive control system is decreasing and it is not anymore applied by the government to the intersections. One of the reasons is that, intelligent transport system is an open source knowledge which has been improving day by day.

SCATS is already a recognized worldwide market leader in intelligent transport systems, however the New South Wales Roads and Maritime Services is continuing to develop SCATS to meet emerging technological, user and traffic demands.

The aim of all of these systems is to be more effective. In this regard some evaluation factors should be checked; "Effectiveness", how much this implementation is optimizing the intersection capacity, traffic flow, flow speed, and other transportation factors. "Safety", how much it decreases the number of accidents and deaths and injuries and also the seriousness of them. "Environment", how much applying this system reduces different kinds of pollutions in the surrounding environment. Reducing damages on the environment by decreasing traffic jams. Finally adaptive control system which are selected, are anticipated to be more effective and reduce the death and injuries rate and take care of environment and decrease air and noise pollutant by decreasing traffic jam and make the traffic more flowing.

Consequently many new applications and system would add to this adaptive control system and these new approaches which have less deficiencies and errors would take the place of vintage ones. Also in USA many other systems like SCOOT, OPAC, RHODES, LADOT and some recently added systems like InSync adaptive systems are deploying faster and faster. In continue some other adaptive traffic control systems would be discussed.


SCOOT

3. SCOOT

3.1. Introduction

3.1.1. What is SCOOT? (Overview)

The second reputable adaptive traffic control system is "SCOOT" which is going to explore in this chapter. Traffic congestion is an ever increasing problem in towns and cities around the world and local government authorities must continually work to maximize the efficiency of their highway networks whilst minimizing any disruptions caused by incidents and events. The traffic adaptive urban traffic control (UTC) system SCOOT, which is the acronym of Split, Cycle and Offset Optimization Technique, has been developed by TRL[10] to help authorities manage and control traffic on their networks. SCOOT is continually being improved through research by TRL funded by the Department for Transport (DfT) and the SCOOT suppliers.

Modern traffic signal control provides an important tool in the traffic manager's toolbox for managing the highway network and SCOOT is one of the world's leading adaptive signal control system. It coordinates the operation of all the traffic signals in an area to give good progression to vehicles through the network. Whilst coordinating all the signals, it responds intelligently and continuously as traffic flow changes and fluctuates throughout the day. It removes the dependence of less sophisticated systems on signal plans, which have to be expensively updated (Hunt, 1981).

Many benefits are obtained from the installation of an effective Urban Traffic Control system utilizing SCOOT, both reducing congestion and maximizing efficiency which in turn is beneficial to the local environment and economy. In the other word the characteristics of SCOOT can be summarized as below:

- World leading adaptive control system
- Customized congestion management
- Reductions in delay of over 20%
- Maximize network efficiency
- Flexible communications architecture
- Public transport priority
- Traffic management
- Incident detection
- Vehicle emissions estimation
- Comprehensive traffic information

---

[10] Transport Research Laboratory

Modern traffic management and control systems must account for all methods of transport in the urban areas and SCOOT provides effective priority for public transport without disadvantaging the normal traffic, allowing public transport vehicles to adhere to their schedule and hence provide a credible alternative mode of travel.

SCOOT has been demonstrated in over 200 towns and cities in over 14 countries around the world given proven benefits in reduced congestion and delay. These have been demonstrated several times with detailed studies highlighting the effectives of SCOOT urban traffic control as a tool for management of traffic and congestion.

3.1.2. What are the benefits of using SCOOT?

The benefits of SCOOT compared to alternative methods of control have been well documented. As an example, journey time surveys in Worcester (UK) and Southampton (UK) found that SCOOT control reduced delays substantially compared with Vehicle Actuation (VA) (i.e. none coordinated) signal operation. Typical delay reductions were 23% in Worcester and 30% in Southampton (Colyer, 1985), (Powell, 1985).

Comparisons of the benefits of SCOOT, with good fixed time plans, showed reductions in delays to vehicles of 27% at Foleshill Road in Coventry - a radial network in Coventry with longer link lengths. In practice, fixed time plans go out of date as traffic patterns change, by about 3% a year on average, so the benefits of SCOOT over an older fixed time plan would be even greater. On average, it is estimated that SCOOT would reduce delays by approximately 12% against up-to-date signal settings and 20% over a typical fixed-time system.

In unusual conditions (special events) in Toronto following a baseball game, delays were reduced by 61%, demonstrating SCOOT's ability to react to unusual events. Trials of the bus priority features in London have shown additional average reductions in delay to buses of 3 to 5 seconds per bus per junction.

3.1.3. How does SCOOT work?

The Kernel software at the heart of a SCOOT system is standard to all installations. The additional software (the "knitting" or UTC software) which links the SCOOT Kernel to on-street equipment and which provides the user interface is specific to the supplier. The user interface includes the data input to store information on the detector locations, physical layout of the road network and how the traffic signals control the individual traffic streams in the SCOOT database (Gordon, 2003).

Any adaptive traffic control system relies upon good detection of the current conditions in real-time to allow a quick and effective response to any changes in the current traffic situation. Detectors are normally required on every link. Their location is important. To provide good information in advance of the vehicles' arrival at the stop line SCOOT detectors are usually positioned at the upstream end of the approach link. Inductive loops are normally used.

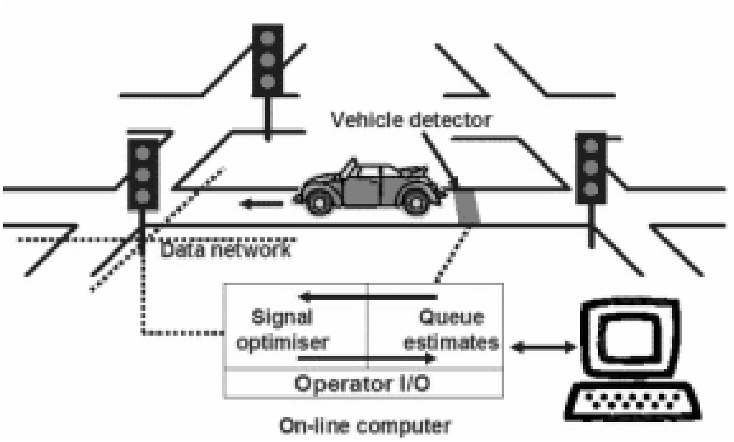


Figure 26: Graphical illustration of how SCOOT works

Information from the detectors is input to the SCOOT model, which models the progression of the traffic from the detector through the stop line. It takes due account of the state of the signals and any consequent queues. The operation of the model is summarized in the diagram and described below.

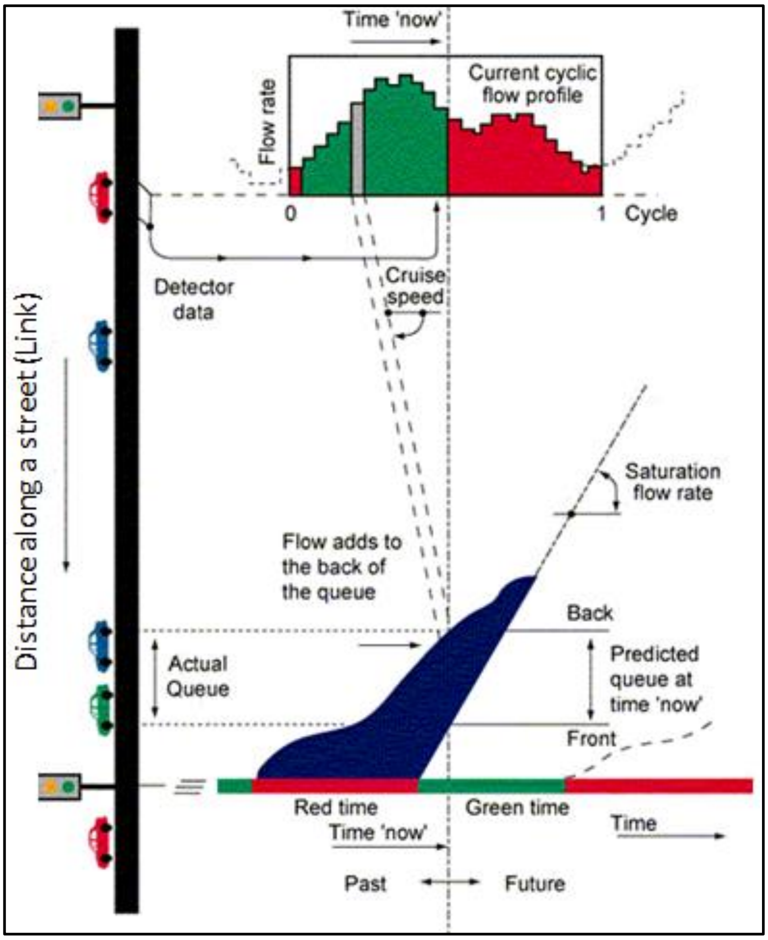


Figure 27: Cycle Flow Profile of the SCOOT model

When vehicles pass the detector, SCOOT receives the information and converts the data into its internal units and uses them to construct "Cyclic flow profiles" for each link. The sample profile shown in the diagram is color coded green and red according to the state of the traffic signals when the vehicles will arrive at the stop line at normal cruise speed. Vehicles are modeled down the link at cruise speed and join the back of the queue (if present). During the green, vehicles discharge from the stop line at the validated saturation flow rate.

The data from the model is then used by SCOOT in three optimizers which are continuously adapting three key traffic control parameters - the amount of green for each approach (Split), the time between adjacent signals (Offset) and the time allowed for all approaches to a signaled intersection (Cycle time). These three optimizers are used to continuously adapt these parameters for all intersections in the SCOOT controlled area, minimizing wasted green time at intersections and reducing stops and delays by synchronizing adjacent sets of signals.

The operation of the optimizers provides the necessary combination of responsiveness to traffic fluctuations and the stability to maintain coordination. The split optimizer optimizes every stage change, the offset is optimized each signal cycle for every node and the cycle time for each region is optimized once every five minutes or once every two and a half minutes when required to respond to rapid flow changes.

SCOOT signal timings evolve as the traffic situation changes without any of the harmful disruption caused by changing fixed time plans on more traditional urban traffic control systems. By the combination of relatively small changes to traffic signal timings, SCOOT responds to short term local peaks in traffic demand, as well as following trends over time and maintaining constant coordination of the signal network.

3.1.4. Influences on traffic management

In addition to the efficient control of traffic, SCOOT provides a wide range of traffic management facilities such as bus priority and gating techniques.

Throughout its life SCOOT has been enhanced, particularly to offer an ever wider range of traffic management tools. The traffic manager has many tools available within SCOOT to manage traffic and meet local policy objectives such as: favoring particular routes or movements, minimizing network delay, delaying rat runs[11] and gating traffic in certain areas of the city. Because of its efficient control and modeling of current conditions, SCOOT has much

[11] **Rat running**, **cut-through driving** or **shortcut**, is using secondary roads, cemetery roads, or residential side streets instead of the intended main roads in urban or suburban areas. People do it to avoid heavy traffic, long delays at traffic signals or other obstacles, even where there are traffic calming measures to discourage them, or laws against taking certain routes. Rat runs are frequently taken by motorists familiar with the local geography

more scope to manage traffic than less efficient systems. For instance, buses can be given extra priority without unacceptable disruption to other traffic.

SCOOT detectors are positioned where they will detect queues that are in danger of blocking upstream junctions and causing congestion to spread through the network. The traffic manager is able to priorities where such problems should be minimized and SCOOT then automatically adjusts timings to manage the congestion.

SCOOT naturally reduces vehicle emissions by reducing delays and congestion within the network. In addition it can be set to adjust the optimization of the signal timings to minimize emissions and also provide estimations of harmful emissions within the controlled area.

3.1.5. Where SCOOT can be used?

SCOOT was originally designed to control dense urban networks, such as large towns and cities. It is also successful in small networks, especially for areas where traffic patterns are unpredictable. With over 200 systems worldwide SCOOT is working effectively in a wide range of conditions in places as diverse as big congested cities: Beijing, Bangkok and London, to small towns or networks such as: Heathrow airport[12] and systems localized round individual junctions of the M25[13].

Many cities have well defined main radial routes with many signalized junctions and few, if any, traffic signals between the outer areas of the radials. SCOOT has been successfully used in such cities. The areas of Birmingham and Leicester used in the emissions trials are examples of radials controlled by SCOOT.

SCOOT has been mainly applied in United Kingdom. These are some places where are taking advantages of SCOOT adaptive traffic control system (SCOOT Installations):

- **UK**
  – 70+ locations (London to Aberdeen)
  – Heathrow Airport
- **Worldwide**
  Bahrain, Beijing, Dalian, Cape Town,
  Karachi(Pakistan), Larnaca(Cyprus), Limassol(Cyprus), Madrid,
  Nicosia, Santiago, Dubai
- **North America**
  Oxnard, Toronto, Red Deer, Minnesota, San Diego, Anaheim, Alexandria, Arlington VA

[12] Heathrow airport, United Kingdom
[13] M25 motorway, Sheley, UK

3.1.6. Chronology (The Development of SCOOT)

In urban areas where traffic signals are close together, the co-ordination of adjacent signals is important and gives great benefits to road users. Coordinating signals over a network of conflicting routes is much more difficult than coordinating along a route.

Early work developed off-line software to calculate optimum signal settings for a signal network. TRANSYT, developed by TRL, is probably the best known example. TRANSYT can be used to compile a series of fixed time signal plans for different times of day or for special recurring traffic conditions.

Preparing such signal plans requires traffic data to be collected and analyzed for each situation and time of day for which a plan is required. This is time consuming and expensive unless plans are updated regularly, as traffic patterns change they become less and less efficient. To overcome these problems, the concept of a demand responsive UTC system was developed. Initial efforts were not successful, mainly because of a continuing reliance on plans, either pre-prepared or dynamically developed.

TRL developed a methodology to overcome these problems. An on line computer continuously monitored traffic flows over the whole network, fed the flows into an on-line model, similar to that used in TRANSYT, and used the output from the model as input to its signal timing optimizers. These optimizers made a series of frequent small adjustments to signal timings to minimize the modeled vehicle delays throughout the network. This was the basis of SCOOT, which, has been continuously developed to meet the needs of today's traffic managers.

New features have been added as SCOOT has been developed. Traffic management features have been added and refined in each version. Major enhancements include:

- Version 3.12 included bus priority, database facilities and incident detection.
- Version 4.23 added estimates of the emission of pollutants.
- Version 4.5 enabled the bus priority to differentiate between different buses, For instance, to give more priority to late buses, enhanced the technique to "gate" traffic into sensitive areas and provided extra help to engineers setting up a system.
- SCOOT MC34, the latest version, has enabled the Kernel software to safely use data supplied by packet switched communications systems, provided a congestion supervisor and increased the priority available to buses by allowing stage skipping where it is appropriate (Bretherton, Bowen,1996), (Bretherton et al.,1998), (Bretherton et al.,2005).

Chronology

- **1975**
  Research version Glasgow
  (Scotland)
- **1979**
  1st installation Coventry
  (England)
- **1991**
  SCOOT version 2.4 had been released
  (First US installation)

3.2. A typical SCOOT system

SCOOT systems are designed to meet the user’s requirements. There will be a central processor hosting the SCOOT Kernel integrated with the company specific UTC software that controls communications to the on-street equipment and provides the operator interface. This processor and associated networked terminals may be installed in a control room. Alternatively for smaller systems, the processor may be installed in the authority’s server room and engineers control the system through client software on their desk top computers. In larger systems there may be a control room staffed by operators, with selected engineers also having system access from their desktops. This access may extend to viewing and controlling CCTV (Closed-Circuit Television) to compare on-street conditions with the SCOOT model. SCOOT can be integrated into a fault monitoring system to provide integral fault management and, if required, automatic fault reporting to the maintenance contractor 24 hours a day.

- **System basics**

Good traffic data is a prerequisite for successful operation and the detectors are an essential part of the SCOOT system. Inductive loops are most common, though other types of detector can be used. For best results, detectors are required on each link. Installing inductive loops, and maintaining them subsequently, is a significant element in the cost of SCOOT, although less than would be required if all the junctions were operated by isolated VA (Vehicle Actuation). Overhead detectors have been used successfully in some situations.

A SCOOT network is divided into "regions", each containing a number of "nodes" (signaled junctions and pedestrian crossings) that all run at the same cycle time to allow co-ordination. Nodes may be "double cycled" (i.e. operate at half of the regional cycle time) at pedestrian crossings or under saturated junctions. Region boundaries are located across links where co-ordination is least critical, e.g. long links. Data on the regions, nodes, stages, links and detectors will need to be stored in the SCOOT database.

When all the equipment has been installed and the network data input into the database, the system will need to be validated. Validation of SCOOT is the process of calibrating the SCOOT traffic model so that it reflects as accurately as possible the actual events on the street network. This is critical, to ensure effective performance of the system. Those parts of the system that have been validated can be operated under SCOOT control whilst further nodes are being validated. Once the system has been validated, the traffic management parameters can be set to manage traffic in line with the authority’s strategy.

3.3. Traffic information and data storage

The primary purpose of SCOOT is to control traffic signals in urban networks to optimize overall traffic performance in accordance with the traffic management policies of the local authority. However, in the process of optimization, the traffic model within SCOOT generates a large quantity of on-line traffic data, such as flow, delay, and congestion. Use of the data has been facilitated by the development of ASTRID[14], which automatically collects, stores, and processes traffic information for display or analysis. Data are available at an individual link level on all signal controlled links.

➢ **Information available and data storage**

ASTRID is the database used to store information derived from SCOOT systems. A standard setup will store the following data directly from SCOOT:

- Flow: flow in vehicles per hour as modeled by SCOOT
- Flow: flow in vehicles per hour derived from detectors
  (Best for links with one detector per lane)
- Delay: total delay in vehicles per hour
- Congestion: percentage of 4 second intervals when a detector is occupied by traffic.
  (This value is independent of the SCOOT model)
- Emissions estimates (version 4.0 onwards only)

Other information can be derived from these basic data, e.g. speed by combining delay, cruise time and link length. The data is available at the level of link, node, region, area or route (‘route’ is any pre-defined set of links). Both current and historic data is available.

[14] ASTRID: Automatic SCOOT Traffic Information Database

3.4. The philosophy

SCOOT coordinates the operation of all the traffic signals in an area to give good progression to vehicles through the network. Whilst coordinating all the signals, it responds intelligently and continuously as traffic flow changes and fluctuates throughout the day. It removes the dependence of less sophisticated systems on signal plans, which have to be expensively updated.

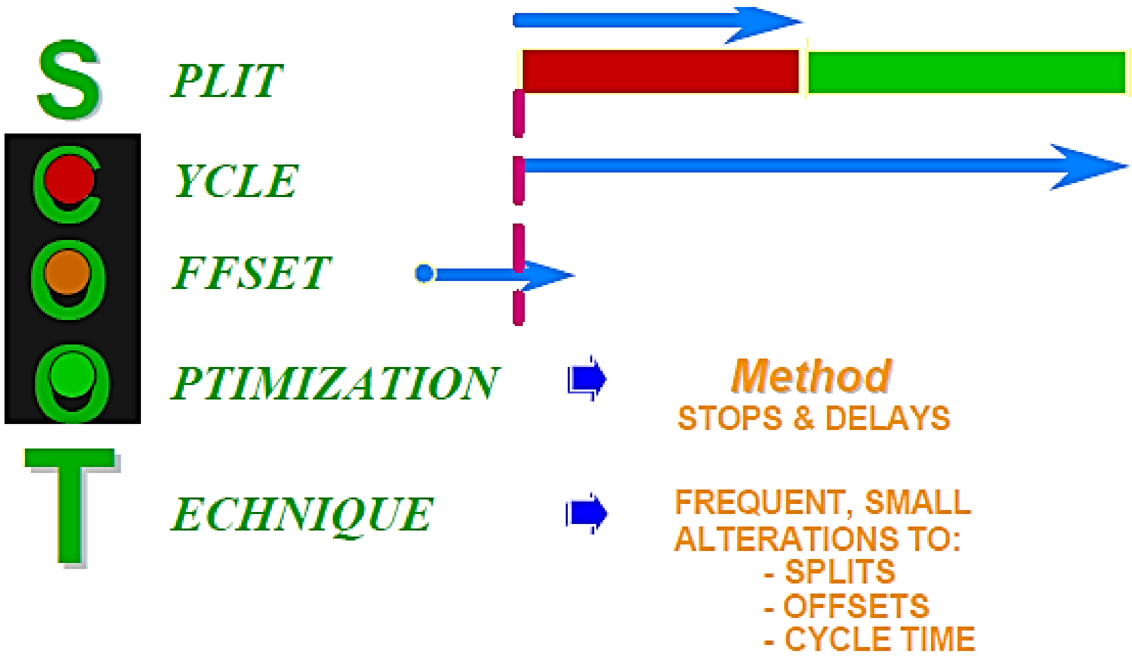


Figure 28: The SCOOT (Urban) Adaptive Traffic Control System

SCOOT is a "model-Based" urban adaptive traffic control system which uses TRANSYT software to compile a series of fixed time signal plans for different times of day or for special recurring traffic condition. This system need an online computer which continuously monitored traffic flows over the whole network, and fed the flows into an online model similar to that used in TRANSYT, and used the output from the model as the input to its signal timing optimizers. But the Kernel software is the heart of this system with taking advantage of additional software to connecting to on-street data.

SCOOT adaptive traffic control system has a pedigree for 20 years of development. Signal companies are the market of this system.

➢ **SCOOT Principles**

- Detector processing
- Cyclic flow profiles
- Traffic model
- Optimizers

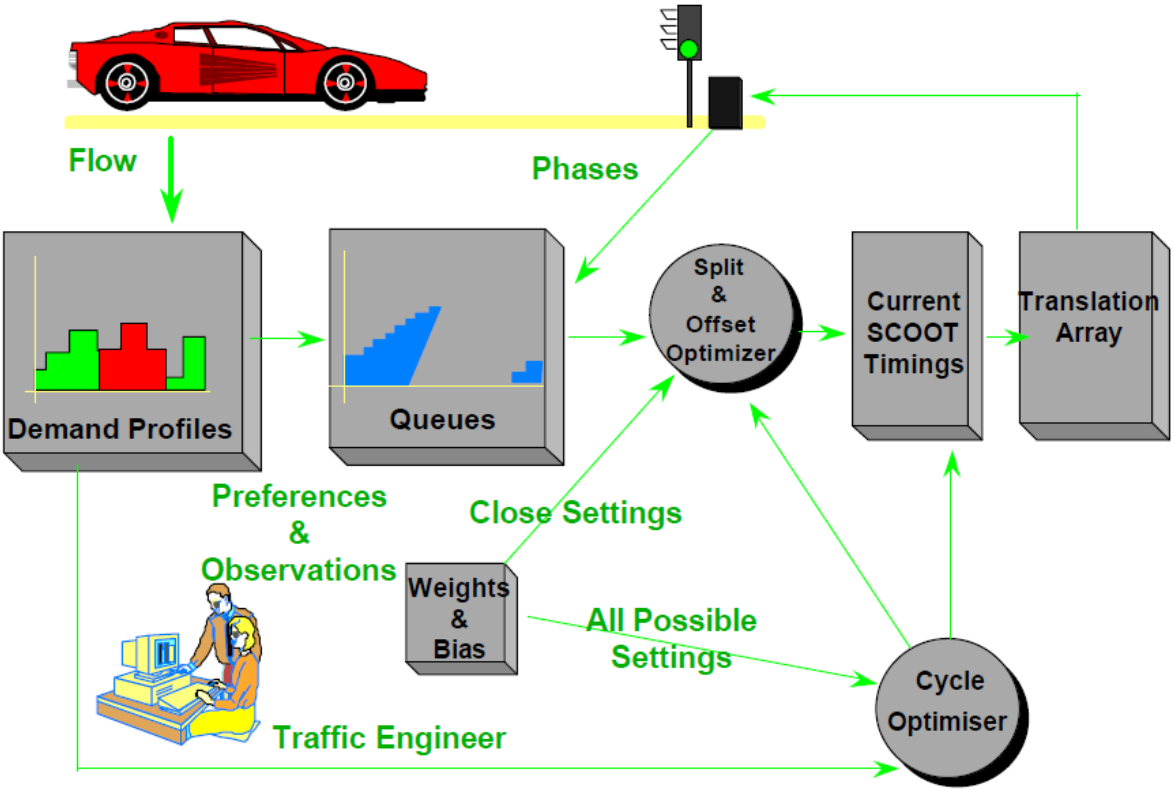


Figure 29: SCOOT schematic view

➢ **Philosophy highlights**

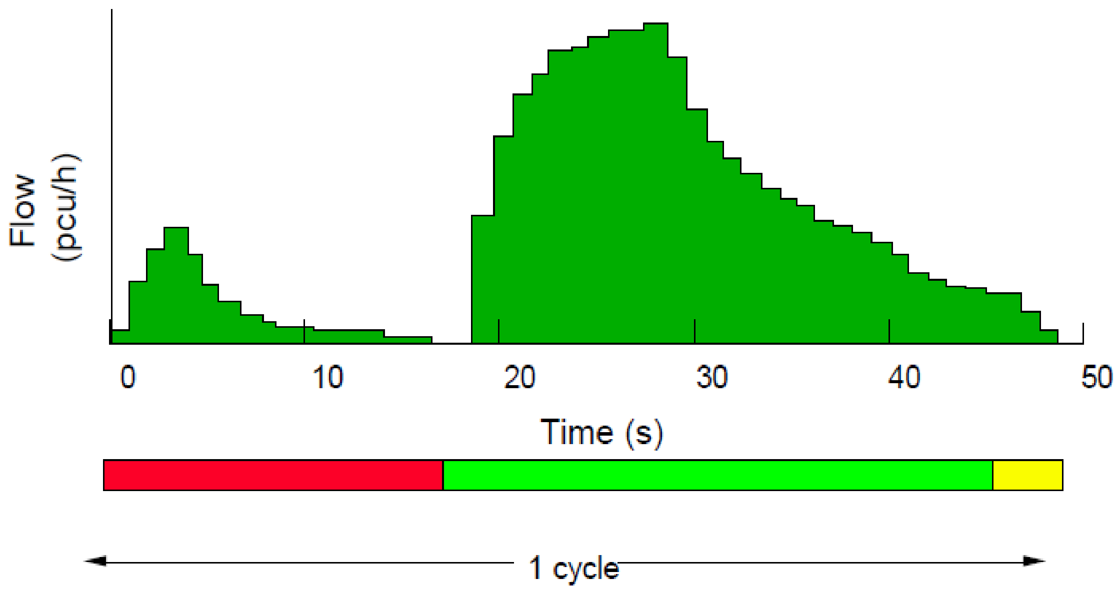
- Optimizes in real time
- One central computer – used to have 'back-up'
- "Elastic" coordination (incremental)
- Minimizes transients
- Responds quickly and accurately (Small prediction times = Accurate estimates)
- On-line measurement of cyclic flow profiles (CFP)

3.5. The Method

3.5.1. Cyclic Flow Profile

Cyclic flow profile enables estimation of number of vehicles which are approaching red phase. By this definition the queue length can be estimated. Also the time to clear the queue would be achieved. When vehicles pass the detector, SCOOT receives the information and converts the data into its internal units and uses them to construct "Cyclic flow profiles" for each link. Vehicles are modeled down the link at cruise speed and join the back of the queue (if present). During the green, vehicles discharge from the stop line at the validated saturation flow rate.

The data from the model is then used by SCOOT in three optimizers which are continuously adapting three key traffic control parameters - the amount of green for each approach (Split), the time between adjacent signals (Offset) and the time allowed for all approaches to a signaled intersection (Cycle time). These three optimizers are used to continuously adapt these parameters for all intersections in the SCOOT controlled area, minimizing wasted green time at intersections and reducing stops and delays by synchronizing adjacent sets of signals.



[15]

Figure 30: Cyclic Flow Profile

[15] PCU: Passenger Car Unit

3.5.2. Traffic Model

3.5.2.1. Model Parameters

- Basic time unit - 1 second
- Calculates TRANSYT type
- Performance Index:
  - Links can be weighted
  - Alternative MOE's (Measure of Effectiveness) can be weighted
- Provides real-time data
- Good queue prediction
- Delay
- Congestion
- Queue lengths
- Number of stops
- Occupancy (proportion of cycle time detector occupied) - Congestion measure

3.5.2.2. Data Requirements

- Detection on every link for which full optimization required
- Detectors generally located at upstream end of link
- Connection to central computer achieved via upstream intersection
- Links with no detection run fixed length or can have data derived from upstream links (Fixed length phases can be varied by time of day)

3.5.2.3. System Architecture

- Second-by-second command and monitoring system.
- Timing algorithms in central processor
- Utilizes the power of the local controller: minimums, clearance, local actuation and detector preprocessing handled by local controller
- Local controller deals with clearance and minimums
- Local vehicle actuation determined by traffic engineering priorities
- Hierarchical transmission system with flexibility to suit local traffic control needs

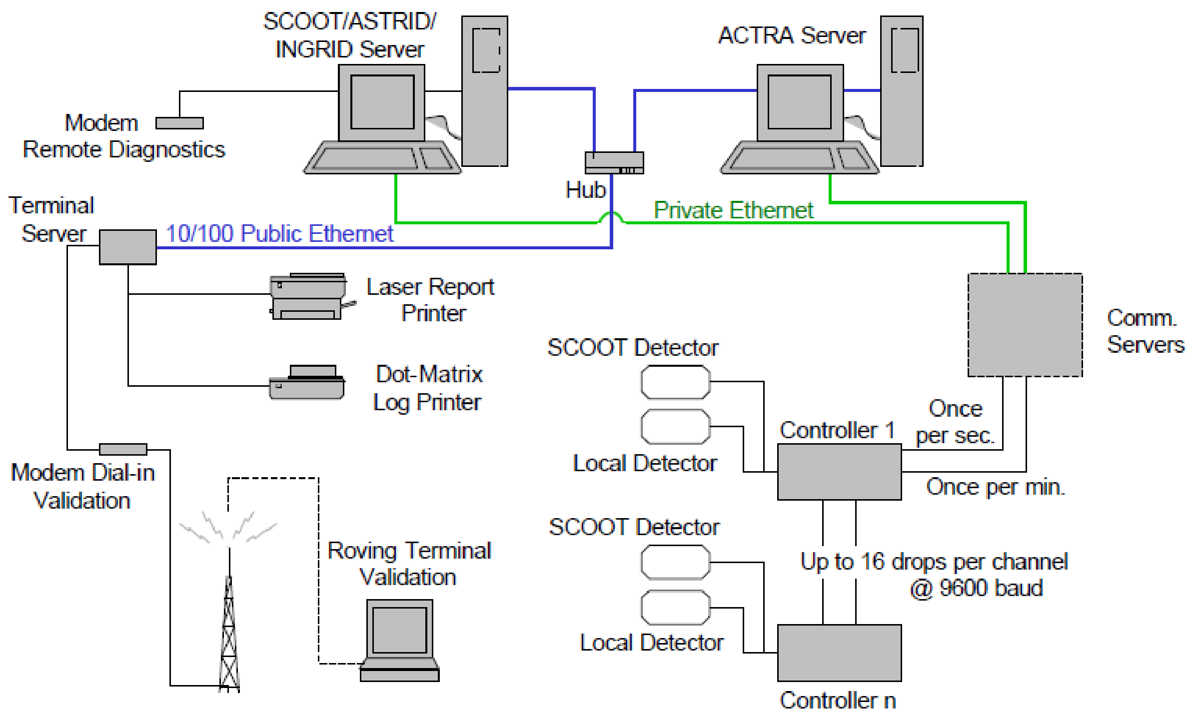


Figure 31: SCOOT Architecture

3.5.2.4. Central Computers Requirements

- SCOOT server
  - DEC Alpha workstation(s), running OpenVMS
- Operator workstations
  - PC running Windows 95/98/NT/2000
  - LAN connected via X-Windows emulation
  - Remote dial-ins via terminal servers
  - Interface to existing network(s) /and workstations possible
- Printers
  - Continuous feed log printer
  - Windows compliant report printer(s)

3.5.2.5. Local Controllers

- Use existing controller
  - Controller firmware upgrades (EPAC)
  - Addition of dedicated command unit
- Replace Controller
  - EPAC
  - 2070. 2070L, 2070N

3.5.2.6. Control Variables

Controlling variables are prerequisites factors in SCOOT Adaptive traffic control system. These factors can be summarized as following;

- Modeling uses measured vehicle demand (occupancy) and calculated queue length
- Optimization uses demand (flow profiles) and calculated delay and saturation
- Approach is to make small, regular changes to timings to minimize transients
- Dozens of parameters to allow the traffic engineer to tune system performance
  - A full library of default values is provided
  - These are changeable by time-of-day, or manually

3.5.2.7. Split and Offset Plans

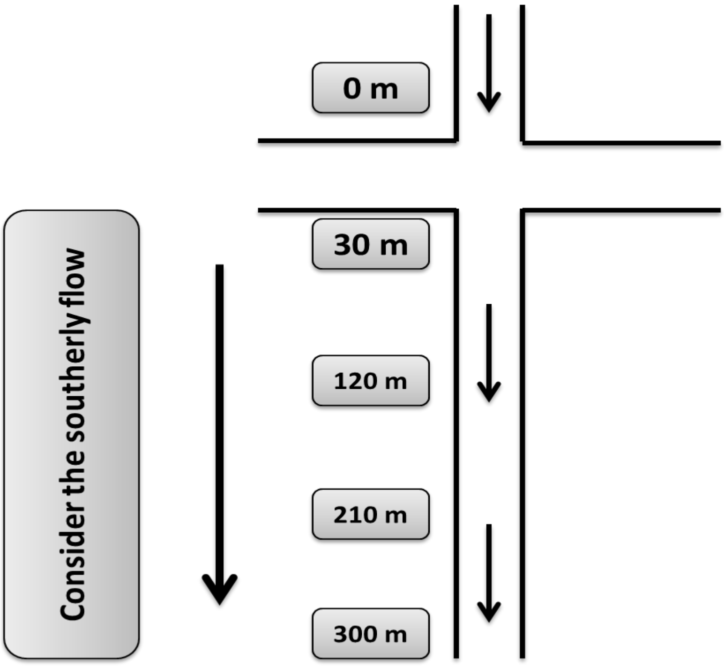


Figure 32: Upstream flow (upstream detector)

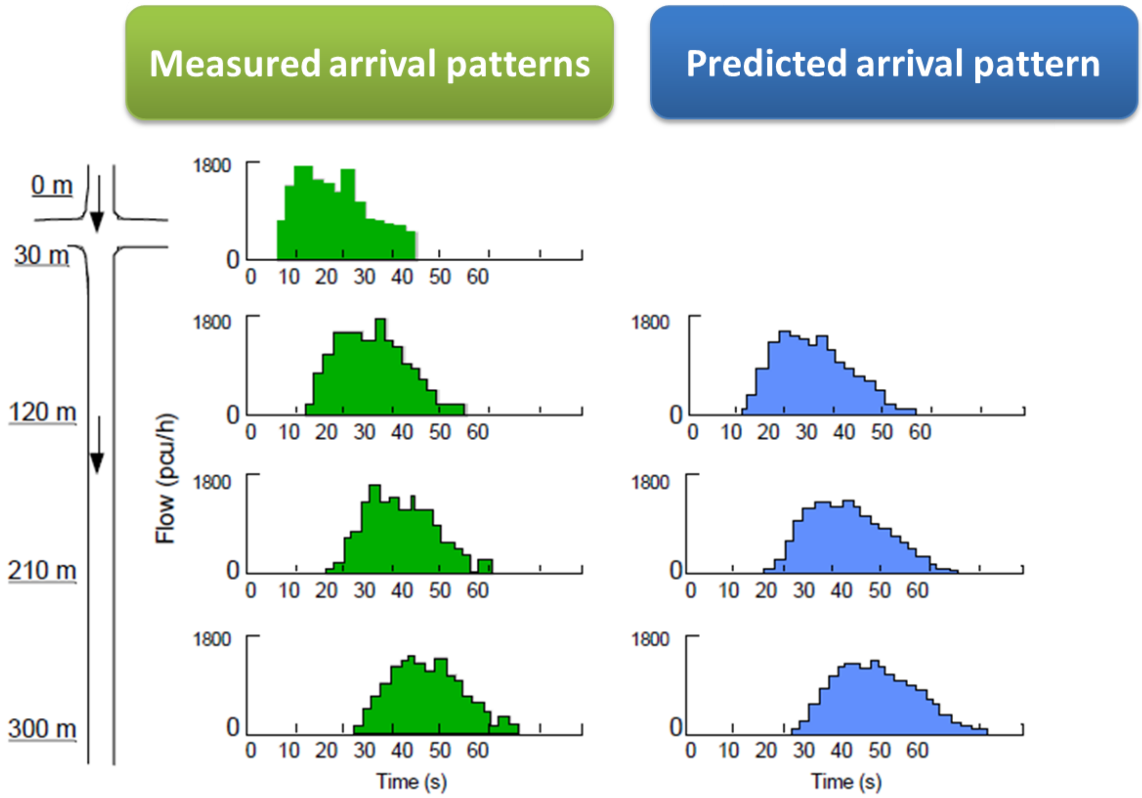


Figure 33: Comparison of Measured and Predicted arrival patterns

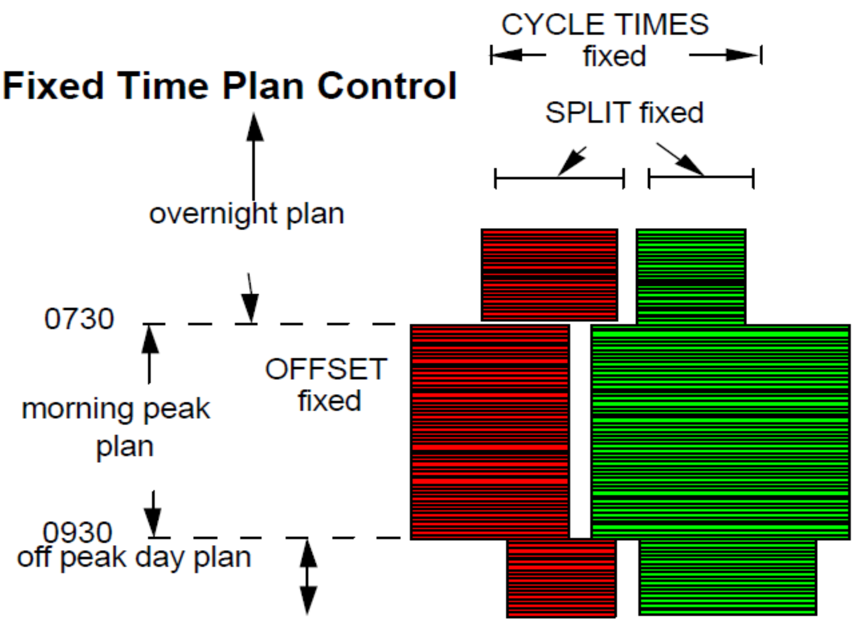


Figure 34: Fixed Time Plan Control (Split and Offset Plans)

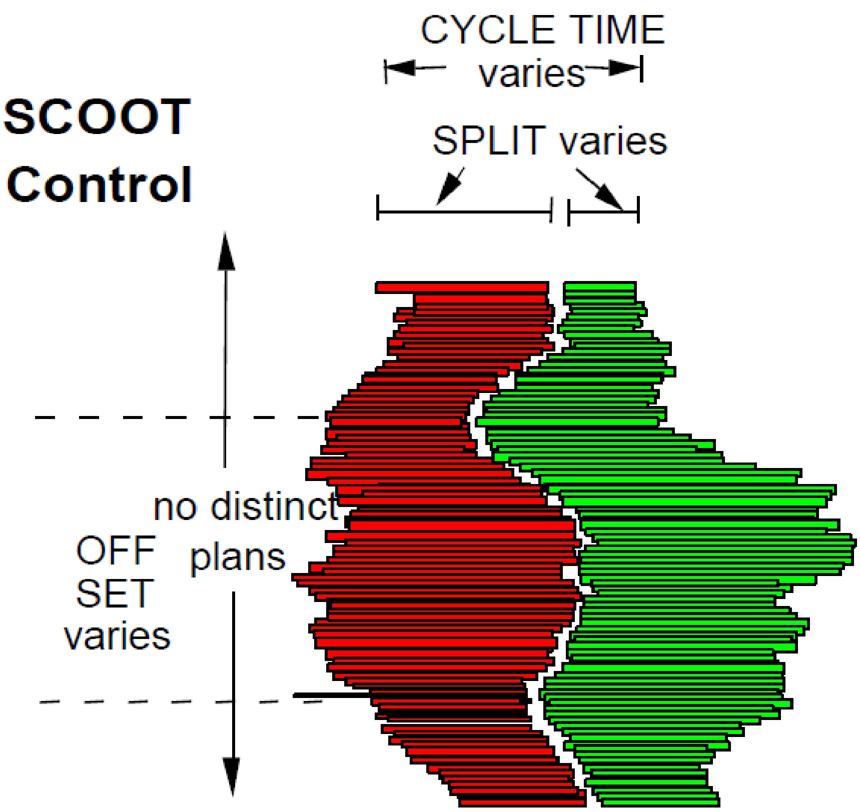


Figure 35: Variable cycle Time Plan Control (Split and Offset Plans)

- **Flow – Time of Day graph (Comparison variable and fixed Cycle time)**

In the following graph the comparison between variable and fixed time cycle plan is depicted. The major point is in the fixed time planning, a series of fixed time signal plans are deploying for different times of day or for special recurring traffic condition. Consequently these plans are predefined and do not act dynamically when there is variation in demand. But in the variable cycle planning the plan are modified and optimized regard to change in traffic flow. In the following graph both fixed time plan and variable cycle time are depicted.

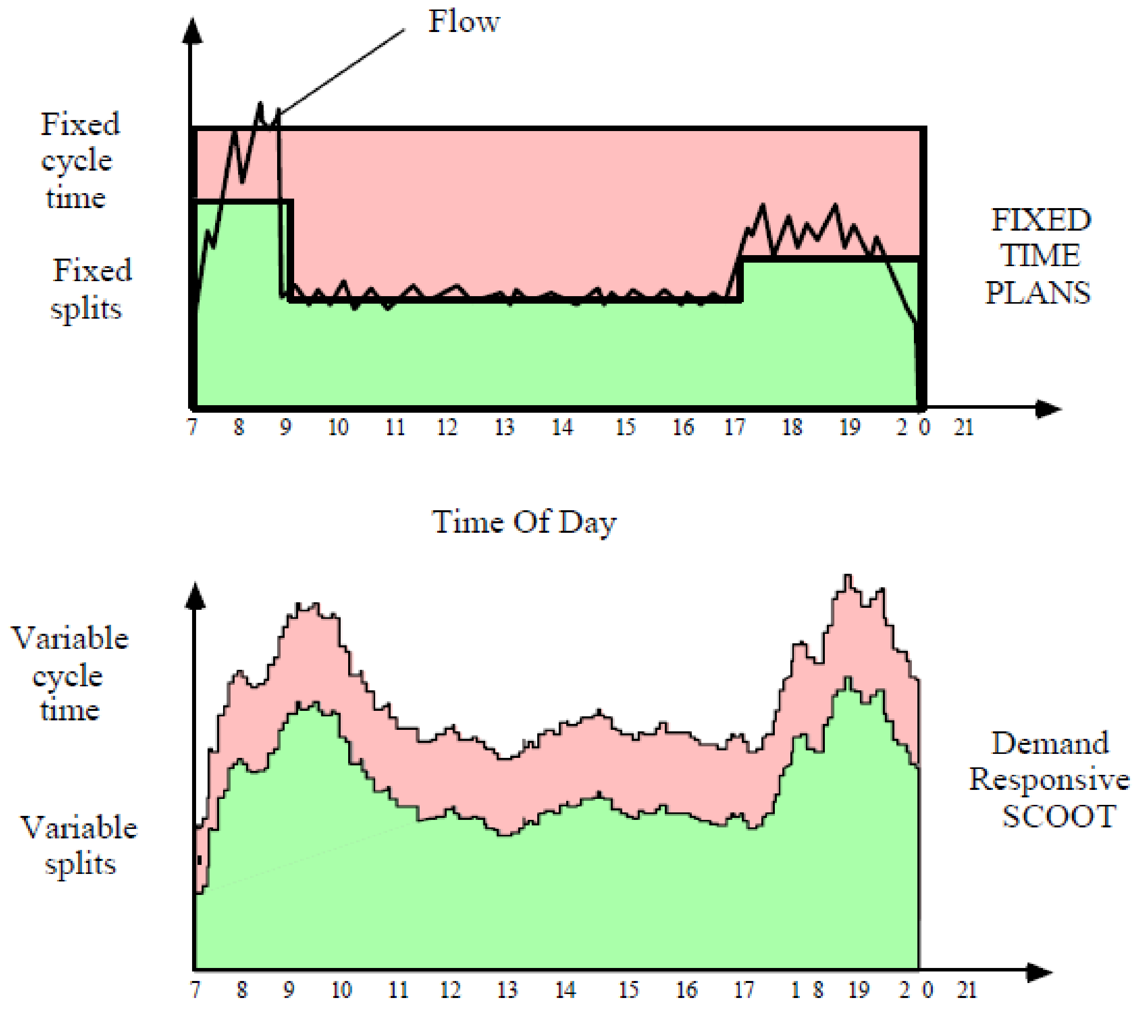


Figure 36: Flow – Time of Day graph (Comparison variable and fixed Cycle time)

- **Two Coordinated signals during one day of SCOOT control**

In the following graph the procedure of how the cycle length can be act for two coordinated signals at two intersections are depicted. The point is the time datum for both signals "A" and "B" is the start of green at signal "A". Consequently by start the cycle with green phase at signal "A", the other intersection signal can be in the middle of red phase as it is shown in the below. The axis of the graph are the phase time in second (Vertically) and the time of day in hour (Horizontally).

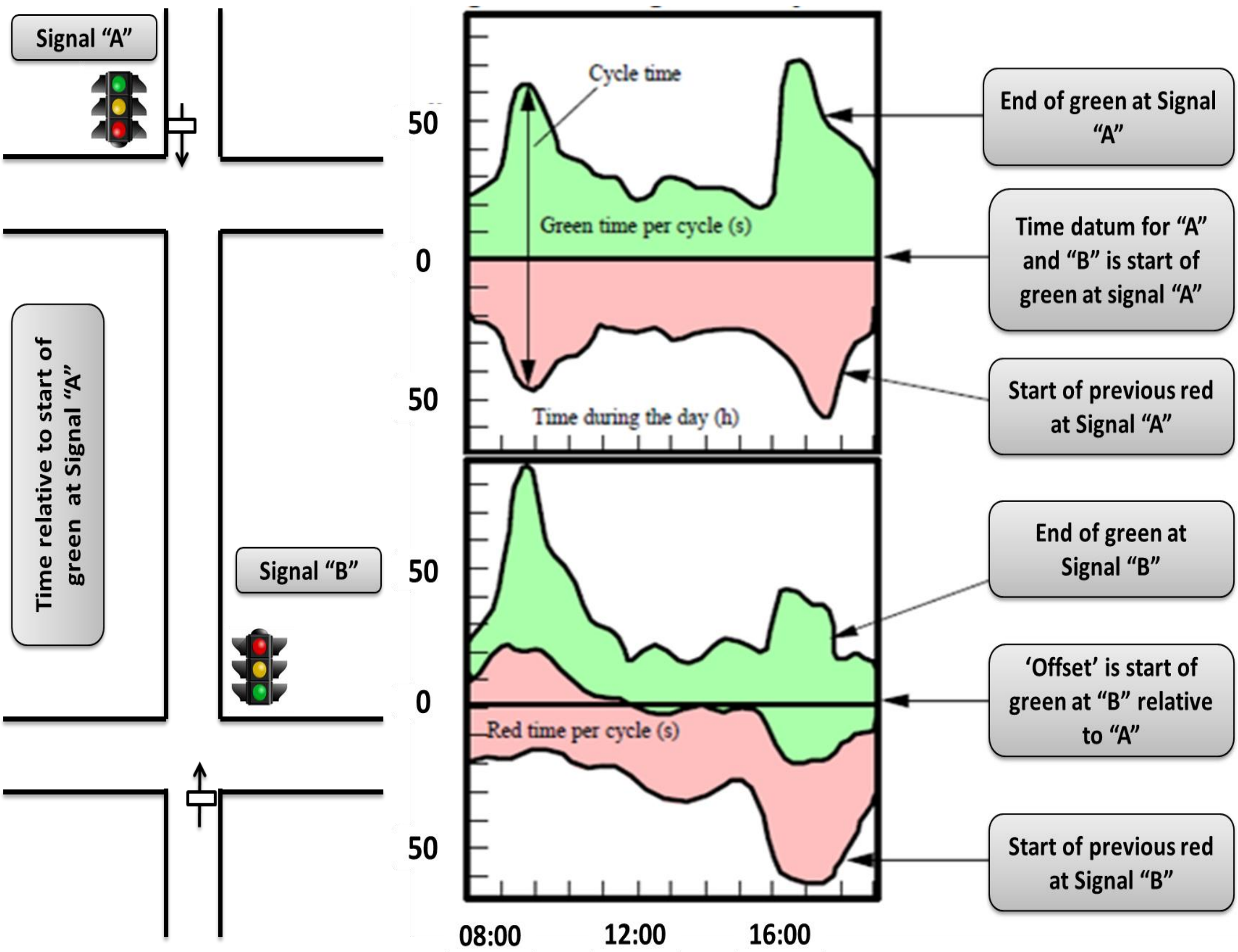


Figure 37: Two Coordinated signals during one day of SCOOT control

3.5.3. Detector Processing

3.5.3.1. Detection

The tasks that the detection does and the characteristics of its processing are summarized as below. Detectors in SCOOT put under consideration immediately the downstream flow of the previous intersection. Also pay attention to upstream of the stop line. Other factors are mentioned below.

- Early prediction of arrivals at stop line
- Recognizes faulty detectors
- Identifies blocking back queue
- Detection based on vehicle occupancy
- Detector is typically a loop, with length 2m in direction of travel
- Sampling rate is 0.25s

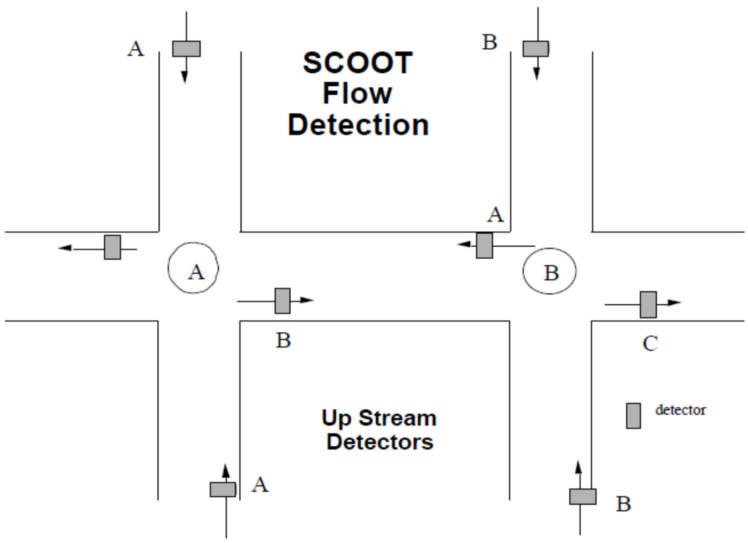


Figure 38: SCOOT Detector

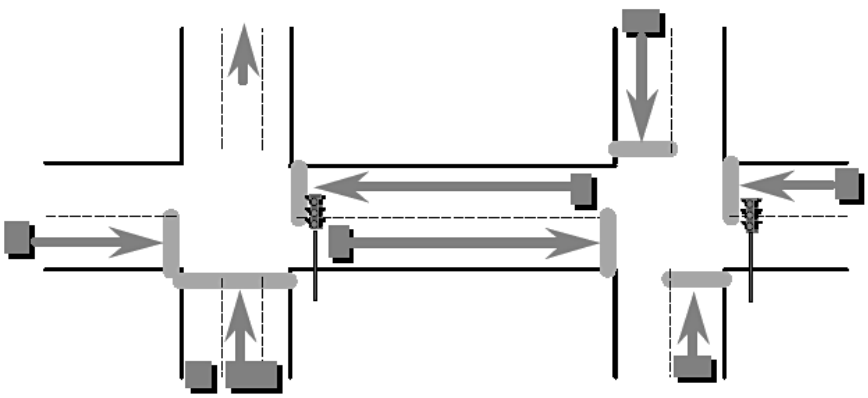


Figure 39: Positioning SCOOT Detector Loops

3.5.3.2. Regions

• Network subdivided into Regions

– Each region has homogenous flow characteristics

• Each region subdivided into links and nodes

• For each region, calculates degree of saturation for all nodes: x=q/s

– Ratio of detected flow (q) to saturation flow (s)

3.5.3.3. Critical nodes

• Identifies most critical node for each region

– Degree of saturation highest

– (Not always the same nodes)

• Activates Cycle Time Optimizer

–Co (Cycle Time Optimizer)

3.5.3.4. Generation of SCOOT Demand Profile

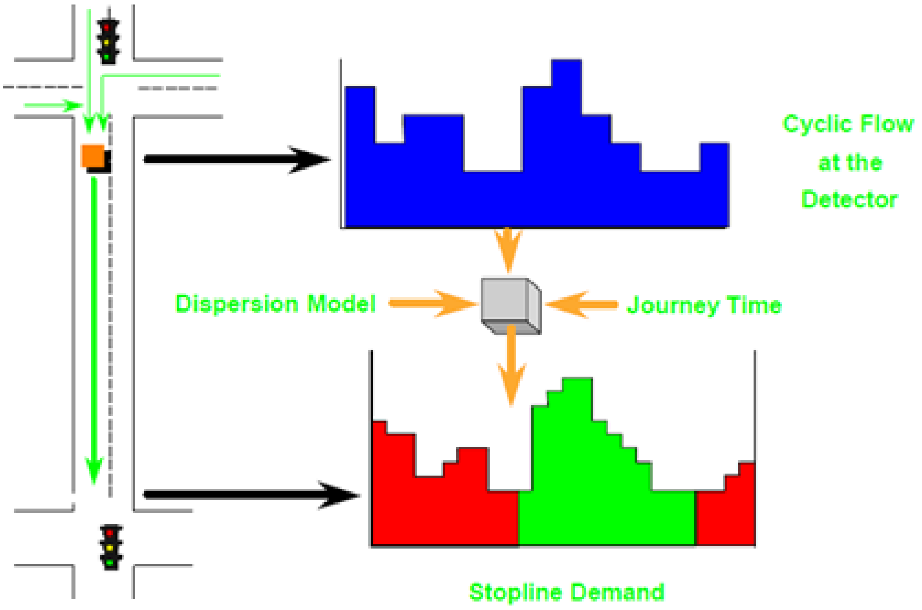


Figure 40: Generation of SCOOT Demand Profile

3.5.3.5. Queue Model

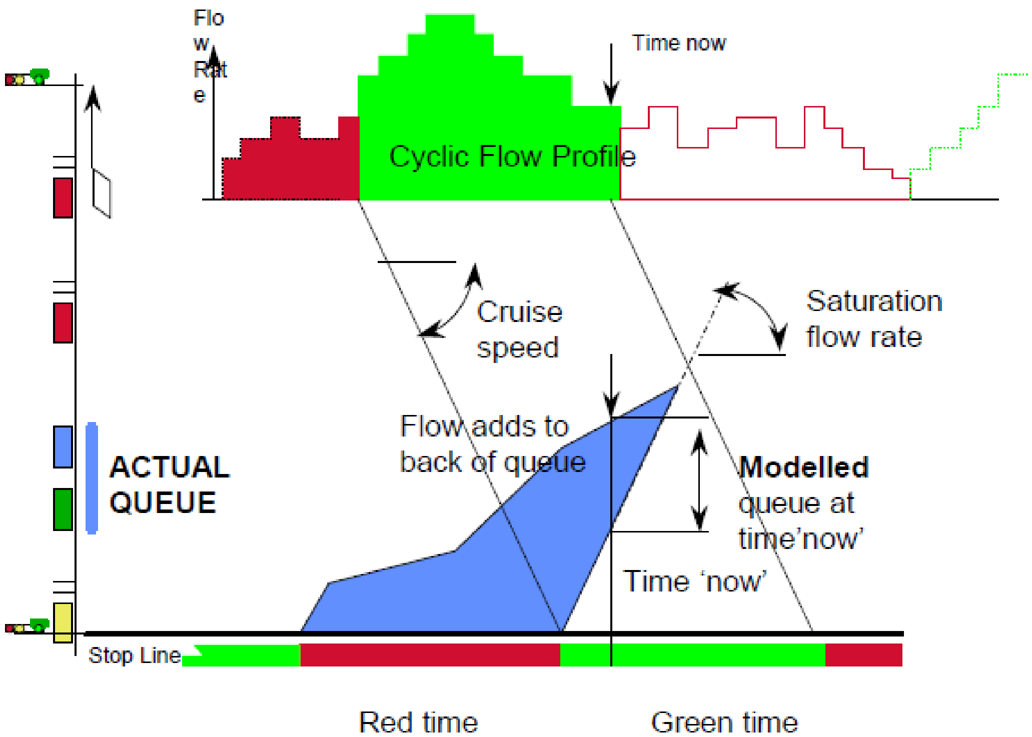


Figure 41: Queue Model

3.5.4. The Optimizers

3.5.4.1. Cycle Optimizer

- **Aim**

The main goal of this optimizer is to minimize the delay. Consequently decrease the travel time of vehicles. In this regard the Cycle optimizer would consider one region at a time.

- **Method**

The methods of the cycle optimizer, is started with calculating the optimum cycle time (CO) for critical node in the region under consideration. After this calculation it would apply common cycle time throughout the region. Regions are operated on a common cycle. After the optimization the coordination would be maintained. Other factors are as the follow:

- Considering double cycling for some intersections if it is needed and possible.
- Minimum practical cycle time for each node at 90% normal saturation or 80% target saturation.
- Consider range from MPCY[16] to maximum region cycle time.
- No preset critical node. Critical node can be change due to degree of saturation.

- **Frequency**
  - Usually every 5 minutes
  - Every 2.5 minutes when cycle rising
  - Every 2.5 minutes when cycle is falling (if required)
- **Constraints**
  - Maximum region cycle time
  - MPCY's of nodes
  - Minimum node cycle time
  - Forced single cycle or forced double cycle (if possible)
- **Feedback**
  - Stage demands taken into account
- **Cycle Adjustment**
  - Increments from 1 to 4 seconds (+/-) - (In 1 second units)
  - Intervals of not less than 2.5 minutes
  - Congestion measured for each link
  - Each region varied independently

[16] MPCY: Minimum Practical Cycle time

3.5.4.2. Split Optimizer

- **Aim**

The main goal of this optimizer is to equalize saturation plus congestion. In this regard the Cycle optimizer would consider one region at a time.

- **Method**

Split optimizer works like this; A few seconds before each phase change SPLIT optimizer decides to advance the phase, postpone it, or leave it alone like it was before. It can make a change in a cycle From 1 to 9 seconds (+/-). It would minimize the maximum degree of saturation on approaches to critical node. Split Optimizer seeks to balance the degree of saturation on all approaches, and avoids blocking-back. Other factors are as the follow:

  - Split calculation based on CFP[17] predictions.
  - Works in tandem with offset optimizer. (Subordinate to cycle optimizer)
  - All upstream and filter links at a node
  - Link merit values for advance, stay and retard
  - Move stage change time by -4, 0, +4
  - Revert to permanent change of -1, 0,+1

- **Frequency**
  - Once per stage change
  - 5 seconds before stage change time

- **Constraints**
  - Minimum and maximum stage lengths
  - Fixed length stages
  - Split weighting

- **Feedback**
  - Adjust optimizer for stages which do not appear

[17] CFP: Cycle Flow Profile

3.5.4.3. Offset Optimizer

- **Aim**

The main goal of this optimizer is to minimize delay, stops, and congestion. In this regard the Cycle optimizer would consider one region at a time.

- **Method**

Offset optimizer works like this; it operates on each node pairing and each cycle. CFP (Cycle Flow Profile) enables measurement of impact. Since this optimizer should optimize the time relation between too signals of two intersections and also phase portioning of each cycle, it should get information from detectors. Consequently upstream detection is available and enables prediction [time]. Other factors are as the follow:

- Seeks to improve traffic progression.
- Only looks up & down one node at a time (common cycle time ensures progression)
- Considering the link performance index (PI) for advance, stay and retard the phases. Minimize sum of PI's for all the links
- Move stage change time by -4, 0, +4

- **Frequency**
  - Once per region cycle time
  - During nominated stage
- **Constraints**
  - Offset weighting
  - Fixed and biased offsets
- **Feedback**
  - No account of stage demands

➢ **Cycle, Split, Offset Optimizer**

Optimizer	Frequency	Change Time (Seconds)
Split	Every stage change	-4, 0, +4 (Temporary) -1, 0, +1 (Permanent)
Offset	Once per cycle	-4, 0, +4
Cycle Time	Every 2.5 or 5 minutes	-4, 0, +4 (32 to 64) -8, 0, +8 (64 to 128) -16, 0, +16 (128 to 240)

Table 3: Cycle, Split, Offset Optimizer

3.6. Measures of Effectiveness (MOE's)

The optimization targeted in general at minimizing delay. In this regard the user specifies relative importance of stops and delay should be considered. In the following the main factor of effectiveness of each optimizers are explained.

- Split at a node balances degree of saturation on adjacent links
  - Subject to weighting parameters from the local traffic engineer
- Offset determined by node performance index
  - choose best offset to minimize stops and delays on all adjacent links
- Cycle time maintains all links at no more than 90% saturation

For achieving the above targets SCOOT need some data. In the following these data are demonstrated. One of the specific and important data is the "Event Driven messages". All of the following data can be processed by ASTRID[18] software. The "Event Driven messages" are gathering from SCOOT M02 / M03 / M04, which are;

- SCOOT M02 = link
- SCOOT M03 = node
- SCOOT M04 = region
- Stops (Vehicle. Stops / hour)
- Delay (Vehicle. Hour / hour)
- Flow (Vehicle / Hour)
- Congestion (Intervals / hour)

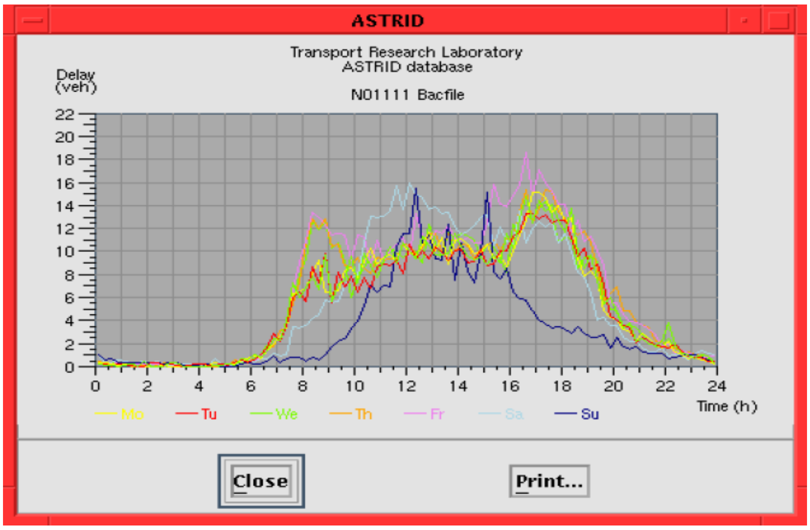


Figure 42: ASTRID Database

---

[18] ASTRID: Automatic SCOOT Traffic Information Database

3.7. Congestion Management

Congestion is an increasing problem in towns and cities. From the outset the optimizers in SCOOT have acted in a way so as to help to control congestion. SCOOT links are assigned a congestion importance factor (CGIF) when the system is set up. This allows SCOOT to operate basic queue management as it will act to minimize queues on links with a higher congestion importance. Over the years a number of additional facilities have been provided. These include 'local' facilities such as the ability to specify fixed offsets for congested conditions; SCOOT will automatically move the offset to these congestion offsets as congestion increases.

SCOOT also includes tools to carry out more sophisticated queue management such as the gating facility. Gating is used to limit the flow of traffic into a particularly sensitive area by restraining traffic on user specified roads. It can act at a distance so that queues can be relocated to areas where they are less of a problem. SCOOT MC3 has introduced a congestion supervisor to help engineers to obtain maximum benefit from the management facilities.

3.7.1. SCOOT Management

Congestion is a commonly used word, but less frequently defined. In urban networks, 'congestion' on a link becomes particularly important when the queue on the link spills back to exit blocks the upstream junction and prevents vehicles discharging from that junction. SCOOT detectors are normally located at the upstream end of the link. Consequently a stationary queue over the detector is an excellent indicator that the upstream junction is, or is about to be, exit blocked. 'SCOOT congestion' is defined as the proportion of the signal cycle that there is a queue over the detector. Continuous occupancy of at least 4 seconds is taken to indicate a queue.

3.7.2. Congestion Important Factor

SCOOT will respond to a stationary queue over the detector by increasing the green time to the congested link to reduce the queue and exit blocking. How much extra green time is given is controlled by the user by specifying the congestion importance factor for each link.

Where a major junction would be blocked the link will have a high importance, but entry links to the coordinated area, where there is not an upstream junction to block would normally have a small importance factor. The user is able to flexibly control the reaction to congestion depending on its network effects.

3.7.3. Short Links

Short links, whether in the general network or on the circulatory carriageway of a roundabout or gyratory are particularly sensitive to the offset along the link. A short link cannot store many vehicles; therefore, if the upstream junction is not green to the main feeder stage when the short link is green, that green time can be largely wasted; a potential major cause of congestion.

Maintaining a good offset on a short link can be a problem. Because it is a short link with little storage capacity, the queue in the 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 as well on critical short links as on longer ones.

The congestion offset facility has been provided to ensure good control and avoid loss of throughput on such links. In addition, users can set a fixed / biased offset on the link to permanently constrain the offset towards the desired value for congested conditions. Congestion offsets can also be used to select which approach arm will be green if exit blocking occurs.

3.7.4. Gating

A stronger form of action at a distance is provided through the SCOOT gating facility, which is designed to relocate queues away from sensitive areas of the network to more acceptable locations. A congestion offset can move a queue to a different arm of a junction; gating can relocate it to a completely different node.

The 'sensitivity' of an area may be due to environmental factors or lack of space for a bus-lane to by-pass the queues as well as for traffic reasons, such as to avoid lock-up of a gyratory. Gating is most beneficial to general traffic where:

- A gyratory may grid-lock, particularly if there is a restriction on a major exit.
- There is a substantial amount of cross-movement traffic.

The technique is not universally applicable, not least because there may not be anywhere acceptable to relocate queues to. Good benefits have, however, been found in trials: preventing lock up of the gyratory system in Kingston-upon-Thames[19], for bus priority in Southampton and reducing emissions in a local center on a major radial in Birmingham.

[19] Kingston-upon-Thames, United Kingdom

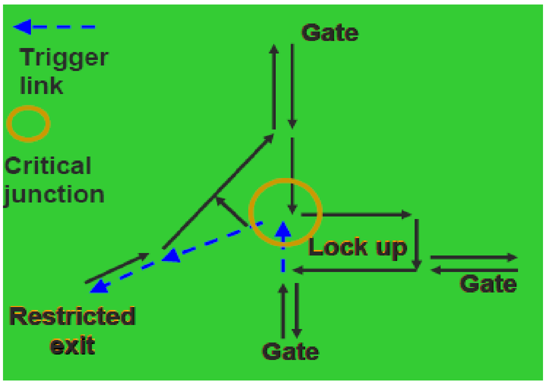


Figure 43: Gating in Kingston-Upon-Thames

In Kingston, traffic leaving the town center and gyratory system to the West is restricted by the capacity of the river bridge and roundabout on the far side of the bridge. The restrictions are all outside the SCOOT controlled area. The capacity is such that more traffic can leave the gyratory than can exit over the bridge. Without gating queues build back to the critical junction shown in above figure at busy periods. If the critical junction is exit blocked for long then the gyratory system will lock up. Once it has locked up, it takes a long time to recover resulting in very large delays (Wood et al., 2002).

With SCOOT gating, the links leading to the restricted exit are defined as trigger links as shown in above figure. Once the congestion or degree of saturation exceeds the critical value on any of these trigger links, the green time is reduced at each of the three entries to the gyratory, which are labeled 'Gate' in above figure. The degree of restraint increases with the number of trigger links that exceed their critical values. Queues build up on the gated links as the traffic is metered onto the gyratory, reducing the flow there. The resulting lower flow on the gyratory and fewer vehicles leaving towards the bridge keep the gyratory free-flowing and prevent lock up.

The trial showed that by avoiding lock up the network delay inside the gates reduced by 22%. In addition there was no increase in delay on the gated links. The delay imposed on the gated links by SCOOT gating was no greater than that previously caused on those links by lock up of the gyratory. It should be noted that such large reductions in delay are only likely when gating is used to impose the minimum delay at the gate needed to prevent the lock up of a gyratory. Using gating to relocate queues on a radial route will normally increase rather than reduce overall delay.

3.8. Pedestrian Facilities

3.8.1. SCOOT Modeling

When traffic signals are controlled by a UTC system they are all constrained to operate at the same cycle time, except that relatively quiet nodes may double cycle at half the region cycle time. Also, the pedestrian stage is called at the same fixed position in the stage order with its start time dependent on vehicle demand and coordination for vehicles. One consequence can be that pedestrians have to wait longer for an invitation to cross than they would if the crossing or junction were operating independently.

Pedestrian priority facilities have recently been developed for SCOOT in order to reduce waiting times at Puffin and Pelican crossings.

SCOOT models what is actually happening at crossings, it means that whether the pedestrian stage was called or not, by the use of feedback. In SCOOT MC3, the feedback has been enhanced to model the length of the variable inter-green at Puffin crossings and at junctions where Puffin type pedestrian facilities are used. It is strongly recommended that feedback is turned on at all pedestrian crossings and junctions with pedestrian facilities to take advantage of feedback and the resulting enhanced modeling.

3.8.2. Puffin and Pelican Crossing

Puffin and Pelican crossings operate in different ways. With Puffins, pedestrians are presented with near-side indicators and vehicle movements are positively controlled using conventional three aspect signals as at junctions. Pelican crossings use far-side pedestrian signals and do not positively control all vehicle movements. During the flashing vehicle amber it is individual drivers who decide whether to proceed. The rules are clear, that drivers should not move when there are pedestrians on the crossing, but the drivers are not held at a red signal.

The difference for SCOOT control of the two types of crossing is in the modeling of the length of the pedestrian stage. The variable inter-green at Puffin crossings can be modeled accurately using the new feedback facility, but the length of the flashing green man / flashing vehicle amber period used by pedestrians at a Pelican crossing cannot.

At Pelicans the feedback will be used to model when the pedestrian stage occurs and when it does not. At Puffins there will be the added advantage of correctly modeling the length of the pedestrian stage.

3.8.3. Double Cycling

Pedestrian waiting times for any control strategy are directly related to cycle time. Puffin and Pelican crossings are normally considerably less saturated than junctions in the same region; they have only two stages and the pedestrian stage is not as long as many vehicle stages. Therefore, when giving priority to pedestrians, the first action recommended within SCOOT is to force double cycling of all Puffin and Pelican crossings, unless the consequent extra vehicle delay will be prohibitive at a particular crossing.

3.8.4. Pedestrian Priority Strategy

Pedestrian priority strategies have been developed, which reduce pedestrian waiting times compared with existing SCOOT control.

The strategies work by reducing the time before the next pedestrian stage can be initiated on street. Within SCOOT the offset optimizer seeks the optimum time in the cycle that the pedestrian stage can run when it will cause minimum delay to vehicles. When a strategy is in operation the start time of the pedestrian stage can be advanced from the optimum time for vehicles. Under normal use, the priority strategy will still only allow one occurrence of the pedestrian stage per junction cycle time.

At heavily used crossings when the pedestrian stage is called in almost every cycle a strategy of advancing the start of the pedestrian stage from the vehicle optimum is not sensible. All that happen is that stage would start early in each cycle by the same amount. Therefore, the time between pedestrian stages would be the same as if they all started at the optimum time for minimum vehicle delay. There would be no benefit for pedestrians, but extra delay for vehicles. Such behavior is prevented in the strategies by limiting the change that the strategy can make to the pedestrian start time depending on how often the strategy reduced the time in the preceding cycles.

Hence, the benefits to pedestrians, reductions in their waiting times, will reduce as the pedestrian volumes increase. When the pedestrian stage is called every cycle, the priority strategies will have no effect.

The strategies are designed to provide the traffic manager with control over the level of priority afforded to pedestrians and the disruption to vehicular traffic. During the development several control parameters were investigated. In the recommended strategy the degree of priority to pedestrians is limited by the vehicular degree of saturation of the crossing and enhanced by the waiting time of pedestrians. How much the degree of saturation limits the priority is controlled by a user-variable parameter.

This strategy will provide useful reductions in pedestrian waiting times without risk of large increases in vehicle delays. Reductions approaching 20% were obtained at the test sites, but the benefits to pedestrians will be limited when the vehicles flows are high.

3.9. Bus Priority in SCOOT

3.9.1. Priority Techniques

SCOOT has a number of facilities that can be used to provide priority to buses. 'Passive' priority, which does not differentiate between vehicles, can be given to links or routes using split and offset weightings. As all vehicles on the weighted link receive a similar benefit, the level of priority that can be given is limited. 'Active' priority can be given to individual buses: extensions to prevent a bus being stopped at the start of red and recalls to start the bus green earlier than normal. In addition, in SCOOT MC3, intermediate stages between the current stage and the bus stage can be skipped.

Differential priority allows different levels of priority to be given to certain buses. As an example limited priority to late buses and high priority to very late buses, but no priority to those ahead of schedule. All these techniques are controlled by user set parameters to prevent the priority causing undesired extra delay to other vehicles.

3.9.2. Bus Detection

The SCOOT kernel software allows for buses to be detected either by selective vehicle detectors. It means that by using bus loops and transponders on buses, or by an automatic vehicle location (AVL) system. Bus loops, or AVL systems where bus detection points can be specified, have an advantage as they can be placed in optimum positions. The best location for detection will usually be a compromise between the need for detection as far upstream as possible and the need for accurate journey time prediction. Also, bus detectors need to be located downstream of any bus stop, as SCOOT does not attempt to model the time spent at bus stops. Depending on site conditions, a location giving a bus journey time of 10 to 15 seconds to the stop line is recommended.

3.9.3. Modeling

Buses are modeled by SCOOT as queuing with other vehicles. This allows buses to be given priority even though other vehicles may delay them. The effect of bus lanes can also be modeled, including those, which end before the stop line.

3.9.4. Priority

The signal timings are optimized to benefit the buses, by extending a current green signal (an extension) or causing succeeding stages to occur early (a recall) or by stage skipping. Extensions can be awarded centrally, or the signal controller can be programmed to implement extensions locally on street (a local extension).

For example, for the three stage junction illustrated in Figure 3-20, if a bus is detected towards the end of Stage "1" (which is a green period on Link "A") it will receive an extension (i.e. Stage 1 is extended) as shown in Figure 3-21.

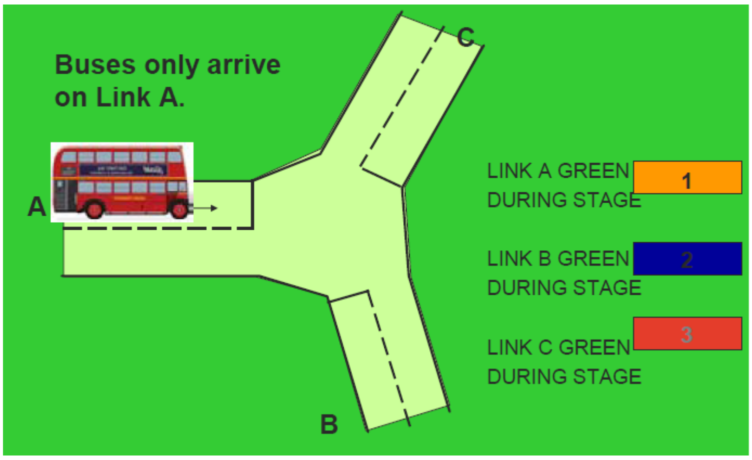


Figure 44: Priority Illustration, Three Stage Junction

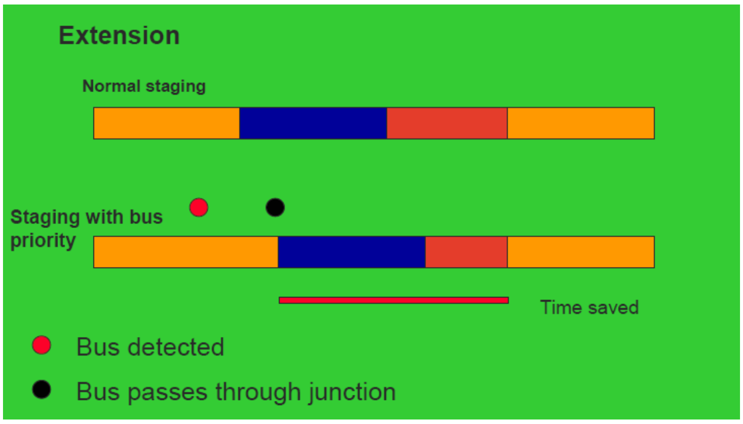


Figure 45: Extension

If the bus is detected during a red period it will receive a recall (i.e. stage 2 and stage 3 are shortened so that stage 1 starts earlier) as shown in Figure 3-22.

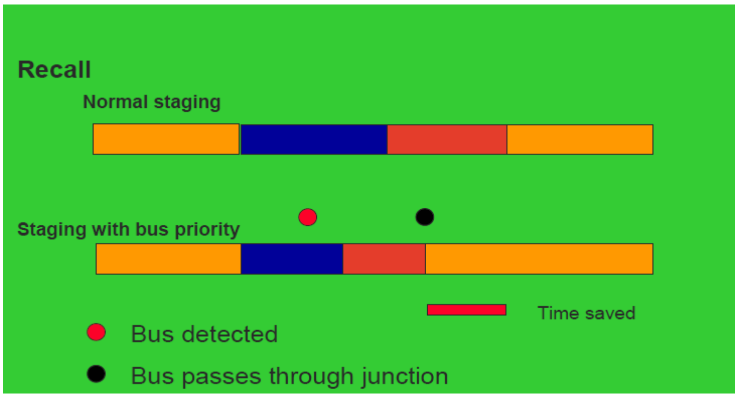


Figure 46: Recall

In SCOOT MC3 it may also benefit from stage skipping, when stage 3 is one that may be skipped. Figure 3-23 shows the result, where stage 2 has been shortened and stage 3 completely omitted from this cycle.

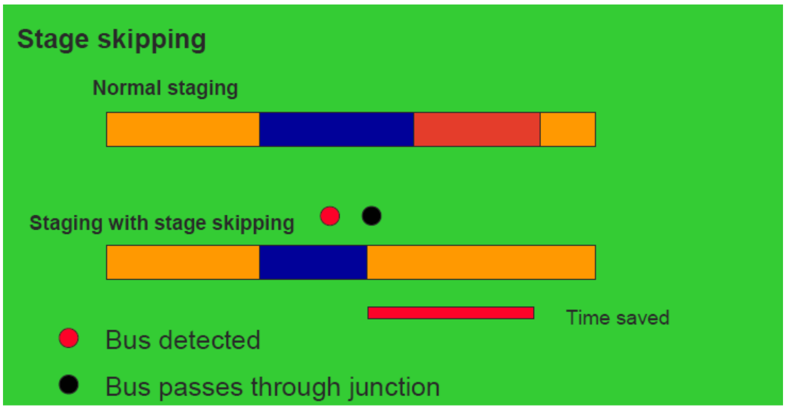


Figure 47: Stage Skipping

3.9.5. Local Extensions

Extensions awarded in the controller can be advantageous, as they eliminate 3 to 4 seconds transmission delay between out-station and in-station. That allows the system to grant extensions to buses that arrive in the last few seconds of green. The feature is especially important where link lengths are short, or where bus stops are located near to the stop line. SCOOT is still in control as it sends a bit each second to permit local extensions only when the saturation of the junction is sufficiently low. Techniques for programming the signal controller have been developed and implemented in London.

3.9.6. Recovery

Once the bus has passed through the signals, a period of recovery occurs to bring the timings back into line with the normal SCOOT optimization.

3.9.7. Stage Skipping

When a stage is skipped, this normal order is interrupted. Users anticipating their green could be caught out when the bus stage, rather than their expected stage, is given green. No adverse effects were observed in the trials in London where great care was taken with the implementation. It is recommended that the principles used in the trials should be adhered to:

- Main road stages should not be skipped
- Pedestrian stages should not be skipped – a possible exception is where the pedestrian phase being skipped occurs more than once per cycle.

When stage skipping is to be introduced at a junction the stage order should be reviewed, as it may be desirable to re-order the normal stage sequence. This is especially likely at junctions where it is not permitted to skip a particular stage.

3.9.8. Benefits of Bus Priority

The benefit to buses gained through providing SCOOT priority without stage skipping varies considerably, and is dependent on the scope for increasing or decreasing the lengths of signal stages. At junctions where the non-priority stages are already at or close to their minimum length, there is little scope for providing priority through recalls. Assuming that stages are not running close to their minimum length, the benefits of priority are then very dependent on the traffic conditions. Reduction in delay, as high as 50%, is achieved when the degree of saturation is low. At high degrees of saturation the reduction in delay is of the order of 5 to 10%. The increase in delay to general traffic is similarly dependent on the degree of saturation. At low degrees of saturation the increase is small and insignificant, whereas at high degrees of saturation the increase in delay to general traffic can be large. The disruptive effect of providing priority by recalls is much greater than by extensions. Giving recalls to buses on a side road can be particularly detrimental as it reduces the green time as well as disrupting the coordination along the main road.

The number of buses being given priority is also an important factor, particularly at higher degrees of saturation. Benefit per bus decreases as bus flow increases, due to competing/conflicting priority calls, but total passenger benefit remains substantial at bus flows, as high as 120 buses per hour per each junction.

Providing priority also offers a small but significant improvement in the regularity of buses. Providing priority only to those buses that are behind schedule can increase the improvement to regularity. Providing priority to late buses only, and therefore to fewer buses will also tend to increase the level of benefit to those late buses. However, considering all buses, the total benefit is likely to be reduced.

The benefits of stage skipping in SCOOT MC3 are in addition to those obtained through extensions and recalls. When restrictions are at their minimum level, stage skipping gives good benefits in the range 2.5 to 6 seconds per bus per junction, depending on the junction and flow conditions. Typically where the skipped roads are not too busy, the extra saving in delay, due to stage skipping, averages about 4 seconds per bus. At junctions where the links being skipped are busy, the benefit may be as low as 1 second per bus even if the skipping is uninhibited. This low benefit is due to an increase in queues of general traffic delaying buses.

On average there is a small increase of about 1 second per vehicle in the delay to general traffic when stages are skipped. The main disadvantage is to traffic on the side road being skipped. In some cases of low side road flows, there is an overall benefit to general traffic, since extra green is given to the busier main road. At junctions where the links whose green is skipped are busy, it is necessary to use the stage skipping saturation parameter to avoid large increases in delay to general traffic.

3.10. SCOOT MC3

SCOOT MC3 (Managing Congestion, Communications and Control), the latest version of SCOOT, enhances how SCOOT operates in four key areas: communications, congestion control, bus priority and puffin pedestrian facilities. In addition to the facilities available in previous versions, SCOOT MC3 has the following new developments:

- **Time stamping of data**

Communication systems are continually developing and analogue dedicated lines, which currently most SCOOT systems depend on, are likely to become increasingly expensive and ultimately not supported at all. A major new development has enabled SCOOT to make flexible use of new communication systems and remove the reliance on second-by-second communication. SCOOT has been modified to use time-stamped data to allow for inconsistencies and delays in data packet delivery. To accompany the time stamping development, the resolution at which SCOOT stores some of the flow data has been reduced from 4 seconds to 1 second. It is predicted that as long as any delays are of the order of only a few seconds the move away from guaranteed second-by-second communication will have a negligible operational effect.

- **Congestion supervisor**

From the outset the optimizers in SCOOT have acted to help to control congestion. Over the years a number of additional facilities have been provided. These congestion management features have been enhanced in SCOOT MC3 by the addition of a congestion supervisor. The supervisor runs continuously in the background searching for and analyzing congestion problems. It will report its results and help the engineer to make optimal use of all the facilities that are available in SCOOT to manage congestion. The aim of the supervisor is to continuously monitor congestion throughout the SCOOT controlled network, to identify links causing serious problems and to diagnose the probable reason for congestion emanating from those links.

- **Stage skipping for bus priority**

Enhanced bus priority in the form of stage skipping is now included in SCOOT MC3. If a bus arrives at such a time in the signal cycle that it would have to wait for a side road to be serviced, the existing bus priority would curtail the length of that side road. With stage skipping the side road can be completely omitted during this cycle, reducing delays to the bus waiting at the signals.

- **Puffin pedestrian facilities**

Puffin crossings introduced a variable inter-green as a means to provide a red period to vehicles that could be extended by on-crossing pedestrian detectors without extending the invitation to cross period to pedestrians approaching the crossing. This variable inter-green period, at Puffins and junctions with on-crossing detectors is modeled accurately in SCOOT MC3. The improved modeling reduces delay, particularly at junctions with Puffin facilities.

3.11. SCOOT Virtues and Vices

3.11.1. SCOOT Virtues

- SCOOT is founded on a rigorous model.
- It is based on theoretical basis.
- It is very suitable at coping with:
  - Heavy flows, close to saturation
  - Complex flow patterns
  - Unpredictable variations
- Provides copious data and available for time stamping data instead of second by second communication which is depend on analogue dedicated lines.
- Tends to favor the "Main Roads", (SCOOT put the first priority for the main road Just as TRANSYT software does.
- Flexible and controllable:
  - Double cycling
  - Plan weighting factors
  - Operates with most types of controller
- Installation advantages:
  - Installation in SCOOT needs minimal local knowledge.
  - It does not require intimate knowledge of the network.
  - Day by day it is becoming more self-validating.
- The SCOOT Personality:
  - Not as highly personnel dependent as some other adaptive traffic control systems.
  - Non hysterical, it copes with large flow change gently.
  - Sophisticated, it has so many facilities and options which make it outstanding system.
- Additional traffic management facilities:
  - Bus priority (Active and Passive priority by applying phase extension, Recall, or stage skipping).
  - Gating techniques.
  - Pedestrian facilities (Puffin and Pelican crossing)

3.11.2. SCOOT Vises

- Maintaining a good offset on a short link can be a problem. Because it is a short link with little storage capacity, the queue in the 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 as well on critical short links as on longer ones.
  But recently the congestion offset facility has been provided to ensure good control and avoid loss of throughput on such links. In addition, users can set a fixed / biased offset on the link to permanently constrain the offset towards the desired value for congested conditions.

- Another weak point of SCOOT urban traffic control system is it needs large installation base. In most of the cases there would be a problem with free space for installation.

- Detectors of SCOOT:
  - Detector dependent (as are all adaptive traffic control systems)
  - Detector Failure, up to 15% detector failure accommodated. (Performance degrades back to a fixed time plan if faults not rectified)
  - Lane detection

- Scope of SCOOT:
  - SCOOT adaptive traffic control system is still essentially tactical.
  - It has regional boundaries.
  - Unable to accommodate oversaturation.
  - It is just applied to urban, (Freeway interaction is unknown for this system)

3.12. Trends of SCOOT Deployment

3.12.1. Case Studies and Results

Figure 48: SCOOT System Deployment around the World

- SCOOT works on both Arterial Streets and Grid Networks
  - Arterial streets - examples
    » Toronto - Lake Shore Boulevard
    » London - Cromwell Road
    » Oxnard, Ca
    » Sao Paulo - Rio Branco
  - Networks - examples
    » Toronto - CBD
    » Dubai
    » London - West End
    » Madrid - Central area
- SCOOT works on networks from less than 10 intersections to higher than 1000.
  - Cambridge (UK) - 9 nodes initially
  - Sao Paulo (Brazil) >1000 nodes

SCOOT installations in USA and Canada with the detail about the vendors (PEEK, Transport for London, SIEMENS, and TRL) and number of intersections which were installed are brought in the following table:

City	Vendor	# of intersections
Anaheim, CA	EAGLE/Siemens	20
Arlington Cty, VA	EAGLE/Siemens	65
Halifax, NS	GEC	60
Minneapolis, MN	Siemens	55
Orange Cty, FL	EAGLE/Siemens	15
Oxnard, CA	GEC	20
Red Deer, AB	GEC	30
San Diego, CA	Peek	Status unknown
Toronto, ON	Siemens	240
University of Utah	System for research (CORSIM)	

Table 4: SCOOT Installation in USA and Canada

3.12.1.1. Results from SCOOT's Commercial Systems

The most recent survey results are listed in below:

- **SÃO PAULO 1997**

São Paulo is using SCOOT 2.4 and SCOOT 3.1 on different areas of the city. The survey was conducted by CET (Companhia de Engenharia de Tráfego) - the municipal traffic engineering company responsible for managing the city's traffic.

Results:

Time Period (Hour)	Delay benefits over previous control method: TRANSYT (%)
06:00 - 09:00	40
17:00 - 20:00	0
Average Benefit	20

Table 5: Rio Branco Avenue / Norma Gianotti Avenue: SCOOT 2.4.

Time Period (Hour)	Delay benefits over previous control method: TRANSYT (%)
06:00 - 10:00	41
10:00 - 16:00	53
16:00 - 20:00	0
20:00 - 23:00	43
Average Benefit	38

Table 6: Alvarenga St / Camargo St: SCOOT 3.1.

The annual financial benefits were also calculated for each area:

Area	Annual Benefits
	(US $)
Rio Branco Avenue / Norma Gianotti Avenue	637,000
Rio Alvarenga / Rio Camargo	976,000

Table 7: The Annual Financial Benefits

- **NIJMEGEN 1997**

“Witteveen+Bos” Consulting Engineers carried out the Nijmegen (Netherlands) trials in co-operation with the Transport Research Centre (AVV) and the Municipality of Nijmegen using SCOOT version 2.4. The SCOOT results were compared with those of fixed time plans and also with SCOOT with (SCOOT+ incorporated split weighting).

	Benefits of SCOOT over Fixed Time Plans	Benefits of "SCOOT +" over SCOOT
	(%)	(%)
Travel Time Benefits	11	14
Delay Benefits	25	33

Table 8: Travel Time – Delay Benefits

- **TORONTO 1993**

Metro-Transportation undertook a "before" and "after" study of Toronto's SCOOT system between May and June 1993. Toronto was using SCOOT 2.4 at the time.

System: Toronto, Canada				
Previous Control: Fixed Time Plan				
Reduction using SCOOT (Average)				
(%)				
Journey time	Dealy	Stops	Fuel Consumption	Emissions
8	17	22	5.7	3.7 (Hydrocarbons) 5 (Carbon monoxide)

Table 9: Toronto SCOOT System

- **BEIJING 1989**

SCOOT version 2.3 was installed in Beijing with the capability of controlling cycle traffic as well as motor vehicle. Previously Beijing's urban traffic control was uncoordinated. A survey was carried out by the Beijing Research Institute of Traffic Engineering (BRITE) to assess the benefits of this SCOOT system. The results were as follows:

Time of day	Reduction using SCOOT (Average on all routes)		
	(%)		
	Journey Time	Delay (stopped time)	Stops
07:00 - 08:00 (Bicycle peak)	7	41	26
08:00 - 09:00 (Vehicle peak)	16	32	33
12:30 - 13:30 (off peak)	4	15	14
17:00 - 18:00 (Bicycle / Vehicle peak)	2	19	29

Table 10: Beijing SCOOT System

- **WORCESTER 1986**

SCOOT was introduced in Worcester (United Kingdom) in the autumn of 1984. Soon after, the DoT[20] and Hereford and Worcester County Council commissioned Transport Planning Associates to undertake an assessment of SCOOT over previous isolated VA (Vehicle Actuation) control and TRANSYT fixed time plans.

Previous Control	Reduciton in Journey time using SCOOT			Reduction in delay using SCOOT			Reduction in fuel used		
	(%)			(%)			(%)		
	AM peak	OFF Peak	PM Peak	AM Peak	OFF Peak	PM Peak	AM Peak	OFF Peak	PM Peak
Fixed-time TRANSYT	5	3	11	11	7	20	5	0	6
Isolated Vehicle Actuated	18	7	32	13	15	23	10	4	9

Table 11: Worcester SCOOT System

The replacement of isolated signal control by SCOOT in Worcester was estimated to save 180,000 vehicle hours per annum or £750,000 p.a. at 1985 prices. The use of SCOOT rather than Fixed Time UTC also showed considerable saving which was estimated to be 83,000 vehicle hours or £357,000 p.a.

- **LONDON 1985**

SCOOT operation began in early 1984 in London around the area of Westminster. An assessment of SCOOT was completed by GLC (Greater London Council) which showed that widespread implementation of SCOOT could be recommended.

[20] DoT: Department of Transport

Previous Control	Reduction in journey time using SCOOT	Reduction in delay using SCOOT	Reduction in stops using SCOOT
	(%)	(%)	(%)
Fixed-time	8 (Cars) - 6 (Buses)	19	5

Table 12: London SCOOT System

- **SOUTHAMPTON 1985**

Hampshire County Council commissioned the Transportation Research Group (TRG) of the University of Southampton to carry out an assessment of SCOOT in the Portswood/St. Denys area in 1984/1985, United Kingdom.

Previous Control	Reduction in journey time using SCOOT			Reduction in delay using SCOOT		
	(%)			(%)		
	AM Peak	OFF Peak	PM Peak	AM Peak	OFF Peak	PM Peak
Isolated Vehicle Actuated	18	-	26	39	1	48

Table 13: Southampton SCOOT System

- **COVENTRY 1981**

SCOOT was assessed in two areas in Coventry (England) by TRL. Foleshill Road is a major arterial connecting the center of Coventry with the M6 highway. Spon End is a network of streets in the western suburbs of Coventry.

System	Previous Control	Reduction in journey time using SCOOT			Reduction in delay using SCOOT		
		(%)			(%)		
		AM Peak	OFF Peak	PM Peak	AM Peak	OFF Peak	PM Peak
Coventry - Foleshill Rd	Fixed-time TRANSYT	5	4	8	23	33	22
Coventry - Spon End	Fixed-time TRANSYT	3	0	1	8	0	4

Table 14: Coventry SCOOT System

3.12.1.2. Bus Priority Survey Results

- **LONDON 1996**

The Transportation Research Group (TRG) carried bus priority field trials in areas of Camden Town and Edgeware Road in London as part of the PROMPT project. The Camden network consisted of 11 nodes and 28 links. The Edgeware Road site was a linear network consisting of 8 nodes and 2 pelican crossings. The bus routes were surveyed for the periods 07:00 - 12:00 and 14:00 - 19:00 (Waterson et al., 2003).

Site: Camden Town			
Strategy	Reduction in Bus Delay		Gain in Vehicle delay
	Sec/bus/link	(%)	Sec/veh/link
Central Extensions	0.2	1	1.7
C.E. + Recalls	3.7	17	5.3
Local Extensions	4.2	19	0.4
L.E. + Recalls	4.8	22	5

Table 15: London Bus Priority SCOOT System

Following results (50% saturation) show that greater benefits can be obtained where there is more spare capacity.

Site: Camden Town Low Saturation Level: Average 50%			
Strategy	Reduction in Bus Delay		Gain in Vehicle delay
	Sec/bus/link	(%)	Sec/veh/link
Central Extensions	4.8	44	-0.1
C.E. + Recalls	7.5	68	-1.6
Local Extensions	7.5	68	-1.2
L.E. + Recalls	7.8	71	-0.6

Table 16: London Bus Priority SCOOT System – Low saturation level

Site: Edgeware Road			
Strategy	Reduction in Bus Delay		Gain in Vehicle delay
	Sec/bus/link	(%)	Sec/veh/link
Local Extensions	2.8	33	-0.1
L.E. + Recalls	3.1	35	4

Table 17: London Bus Priority SCOOT System – Edgeware Road

- **SOUTHAMPTON (LANCES HILL) 1994/1995**

The trial for bus priority was carried out in the Bitterne area of Southampton at the junction of Lances Hill and Maybray King Way. The ROMANSE office of Hampshire County Council carried out the trial. Normal SCOOT operation (with no bus priority) was compared with SCOOT + Central Extensions and Recalls.

Site: Lances Hill - Southampton	
Time Period	Reduction in Journey time
	(%)
Morning Peak	60.7
Off Peak	3.6
Evening Peak	36.8
All Periods	41.7

Table 18: Southampton Bus Priority SCOOT System

3.12.2. Results Interpretation and Conclusion

The measured benefits of SCOOT depend on the efficiency of the previous method of control and on site factors, such as the distance between junctions and the flows of vehicles. Early results showed that SCOOT achieved an average saving in delay of about 12% when compared with up-to-date TRANSYT fixed-time plans. This result was important because TRANSYT is used worldwide and known to set a high standard on which other traffic responsive systems have failed consistently to improve.

Research by Bell (1986) suggests that SCOOT is likely to achieve an extra 3% reduction in delay for every year that a fixed-time plan "ages". Further, the effects of incidents have been excluded from many of the survey results to ensure statistical validity. Since SCOOT is designed to adapt automatically to compensate for ageing and incident effects, it is reasonable to expect that, in many practical situations, SCOOT will achieve savings in delay of 20% or more.

3.12.2.1. Comparison of SCOOT and SCATS

In the graphs below the deployment of two adaptive traffic control systems in United State of America are being compared. These results are published by TRB[21] Signal System Committee. The first figure is related to the results of January 2000, and the second figure is related to January 2001.

[21] TRB: Transport Research Laboratory

- **Comparison between the number of installations of SCOOT and SCATS in USA: (January 2000 and 2001)**

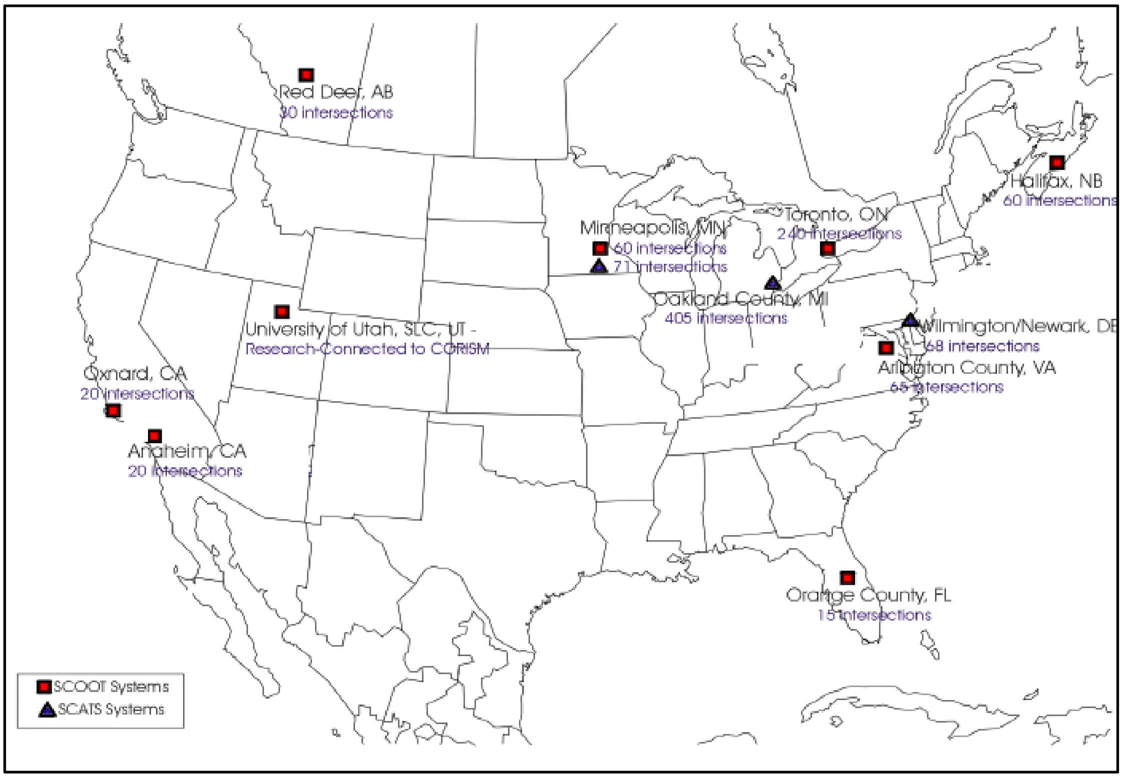


Figure 49: Comparison between SCOOT and SCATS – January 2000

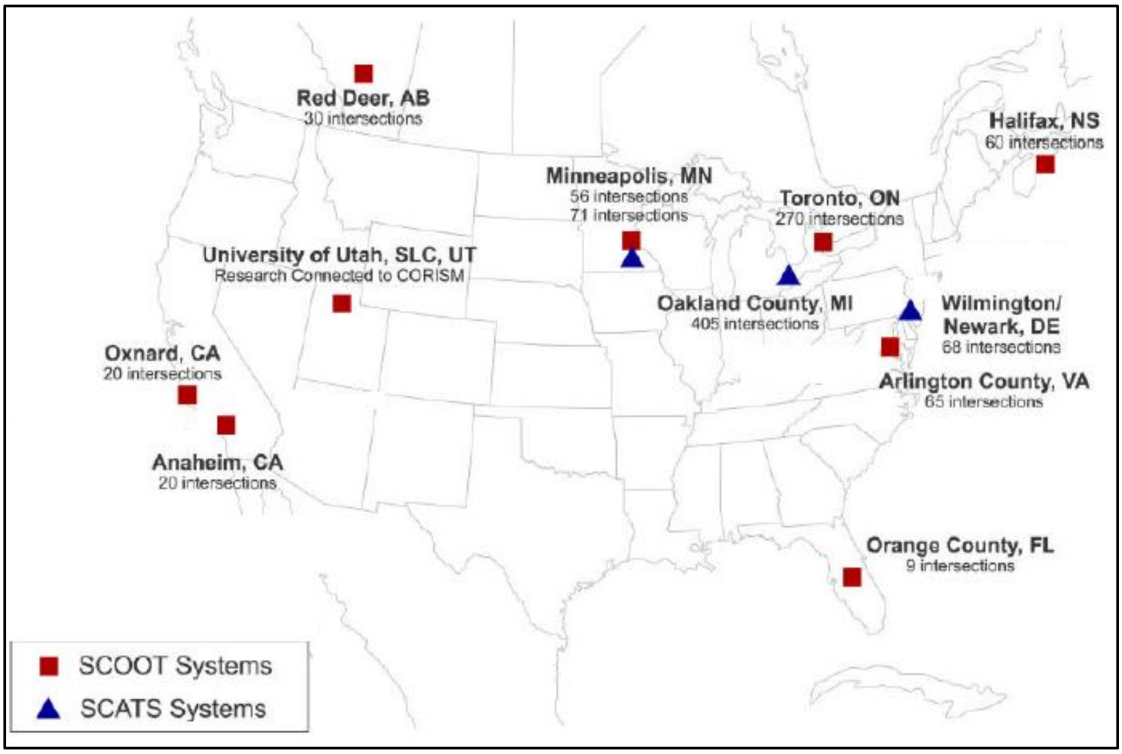


Figure 50: Comparison between SCOOT and SCATS – January 2001

INSYNC

4. InSync

4.1. Introduction

In this chapter another traffic control system would be introduced and some case studies would be put under consideration to study about the virtues and vices of this control system and to make a comparison at the end.

The InSync adaptive traffic control system is an intelligent transportation system that enables traffic signals to adapt to actual traffic demand. As of March 2012, traffic agencies in 18 U.S. states have selected InSync for use at more than 650 intersections. This system was developed by Rhythm Engineering at first. Rhythm Engineering is a reputable company which works in field of transportation and mostly in United State 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, respectively. Mounted video cameras determine the number of vehicles present 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. InSync's dynamic phasing and dynamic green splits enable the traffic signals to use green time efficiently.

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.

4.1.1. Deployment

Day by day more U.S. traffic agencies select InSync than other adaptive traffic control systems, because of its digital not analog feathers. Therefore this more usage makes the fastest growing such system in U.S. history. With more than two million vehicles driving through InSync intersections each day, the system allows millions of American motorists to take an advantage of smarter traffic flow.

Trial as of May 2013 (Census)			
	Deployed (Amount)	Scheduled (Amount)	Total (Amount)
Intersections	687	213	900
Corridors	117	38	155
Cities	39	24	75
States	21	14	25

Table 19: InSync Breadth of Deployments

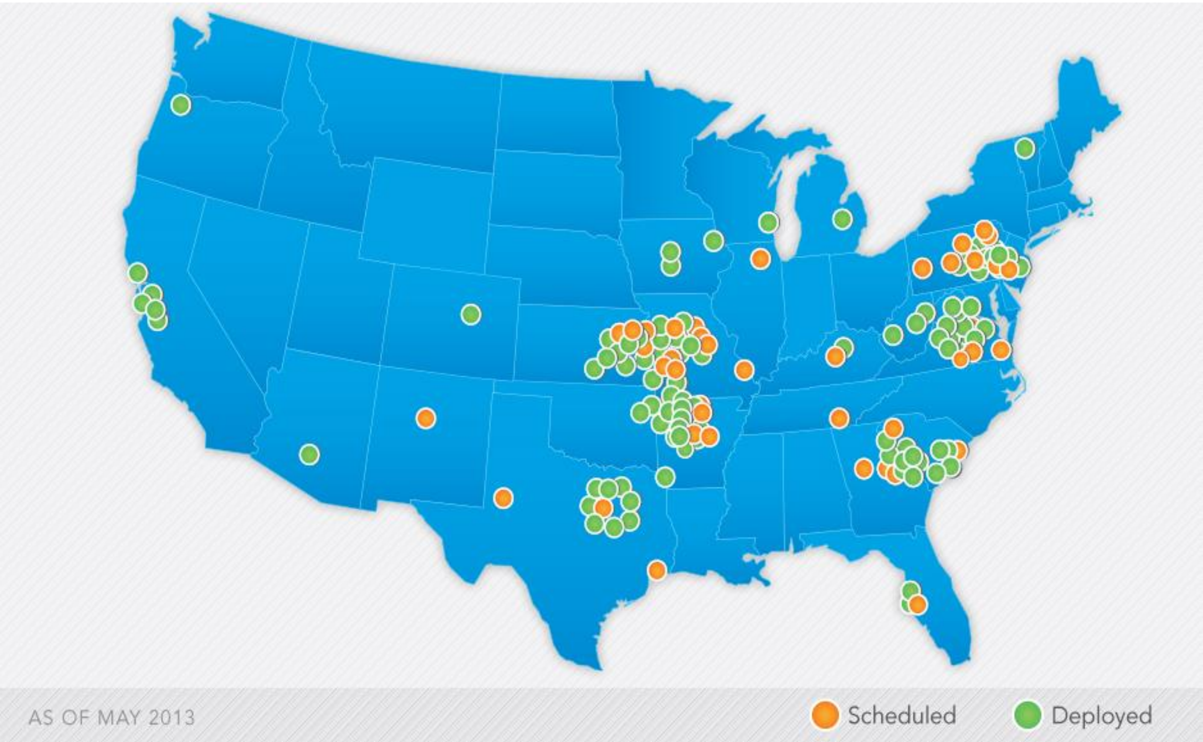


Figure 51: InSync Breadth of Deployments

Arizona, Arkansas, California, Colorado, Florida, Georgia, Illinois, Iowa, Kansas, Kentucky, Michigan, Missouri, New Jersey, New Mexico, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Vermont, Virginia, West Virginia, and Wisconsin.

4.1.2. The Birth of InSync

When developing InSync in 2005, "Rhythm Engineering" used new approaches to the transportation engineering industry. Instead of developing incremental improvements to existing traffic control tools and methods, they imagined other possible traffic control tool.

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 appreciate what conditions will exist in the next few minutes.

This is a substantial departure from other traffic management systems. Nearly all traffic control systems today use digital hardware but remain constrained by analog thinking such as common cycle lengths, set sequences, fixed offsets and standardized allotment of green time, or splits. The InSync Processor is instead a modern state machine, meaning it can dynamically choose which phases to serve and instantly adjust and coordinate service and green time. By adapting to actual traffic demand, InSync is superior to predetermined signal timing plans that estimate traffic demand based on a small historical sampling and generalize those results across years of traffic signalization.

As a conclusion one of the outstanding characteristics of InSync is this ability that constantly monitors and flexibly serves actual demand in the best way possible that enables it to produce such astounding before-and-after results (Selinger, Schmidt, 2009).

4.2. The InSync Model

The InSync Model has consisted of three components. These three main components are unique, make a big difference compare to other traffic control systems, and they are related to real-time adaptive model:

1 Digitize signal operation

Convert traffic signal operations from analog to digital in order to break free from the constraints of linear thinking.

2 Local optimizer

It utilizes the Local Optimizer to minimize delay at individual intersections.

3 Global optimizer

To coordinate progression along a series of intersections on a corridor or network, explore these three concepts to learn how InSync makes decisions that measurably improve traffic.

4.2.1. Digitize signal operation

Even the latest traffic controllers still conform to the operational concepts of analog electromechanical controllers from the early twentieth century. Modern controllers are constrained in their sequencing, green splits, offsets, cycle lengths and relative cycle lengths, all of which reduce a system's ability to serve actual traffic demand.

In contrast to this, InSync uses a digital state machine. It can flexibly adapt to actual traffic conditions based on real-time inputs and algorithmic decisions.

There is a big difference in Insync compare to SCATS and SCOOT adaptive control traffic systems that is caused by 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.

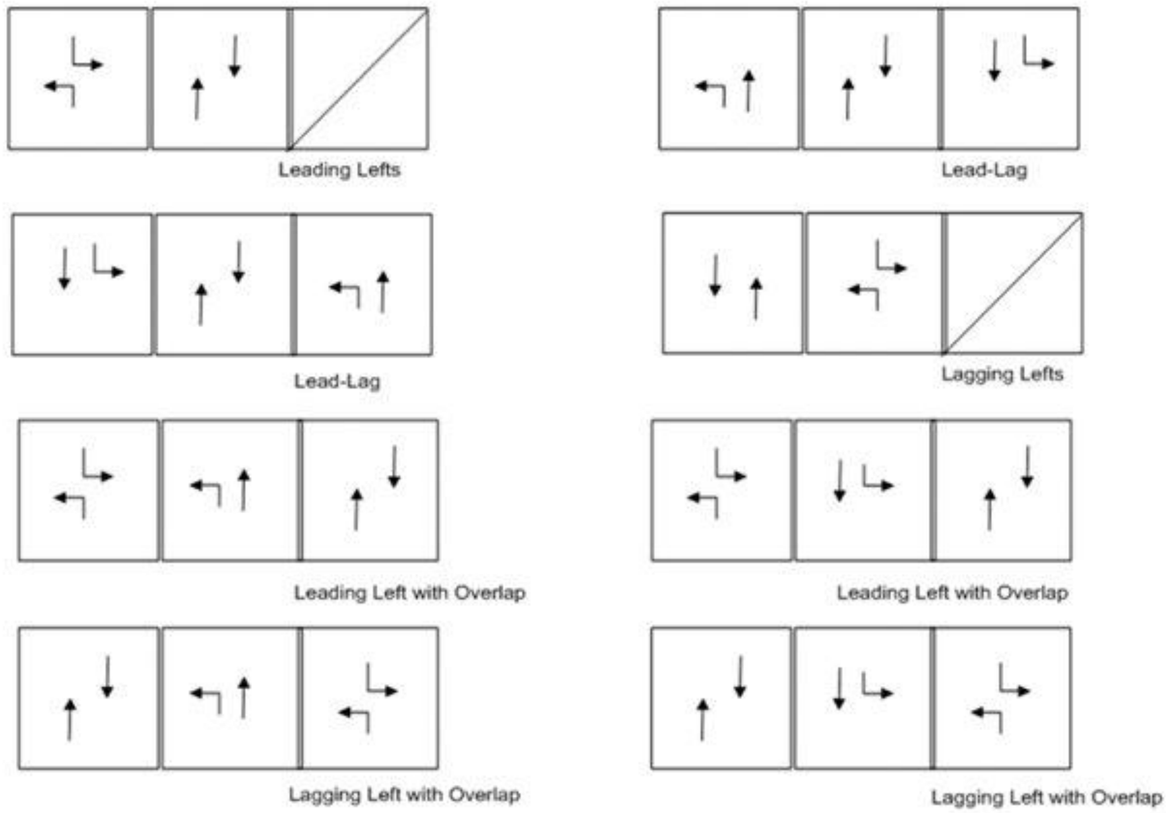


Figure 52: InSync Sequences in Conjunction

This chart shows the eight north-south sequences used in conjunction. InSync simplifies a wide range of signalization possibilities to digital choices so it can quickly adapt to actual demand. This is "Sudden access" which is the major difference to other ATCS[22].

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 actual traffic conditions. (Using standard sequences, InSync maintains all safety considerations while not being constrained by the ring-and-barrier[23]).

---

[22] ATCS: Adaptive Traffic Control System

[23] Ring and Barrier: Traffic control system organizes phases by grouping them in a continuous loop (or ring) and separating the crossing or conflicting traffic streams with time between when they are allowed to operate, either by making the movements sequential or adding a barrier between the movements. The ring identifies phases that may operate one after another and are typically conflicting phases organized in a particular order.

4.2.2. Local optimizer

InSync's local optimizer focuses on minimizing summed delay at each individual intersection. The system does this by constantly measuring volume (the number of vehicles) and delay (the time vehicles spend waiting) at each intersection, then making instant decisions about how to best reduce those numbers.

4.2.2.1. Greedy Algorithm

A greedy algorithm is the ideal choice for signalization because the finite number of signal states and green time durations allow rapid solutions in order to serve real-time traffic demand.

Given the inputs of number of vehicles in the queue and their delay, the algorithm considers each possible signalization solution as well as its constraints and objectives as defined by the configuration.

InSync's algorithm performs this analysis constantly and may alter its conclusion as frequently as every second. The result would be like this that cars move through the intersection as soon as possible.

4.2.2.2. Counting Vehicles

This adaptive control system must count cars quickly and accurately to keep this perpetual math equation going. On most InSync deployments, video detection cameras facing each approach handle this task. Once the cameras are mounted and accessible via a secure Ethernet connection, detection zones are drawn along the contours of each lane and subdivide each detection zone into segments. By counting how many segments have vehicles in them, InSync always knows second-by-second, how many vehicles are in each lane and how long they've been waiting.

Figure 53: InSync Counting Vehicles method

By measuring the percentage of occupancy for each approach, InSync serves green time commensurate with actual demand thus not wasting green time by over-serving an approach or reducing service levels by under-serving an approach.

4.2.2.3. Intelligently Fully-Actuated

Rather than merely recognizing vehicle presence, InSync's optimization process takes into account the wait duration and number of vehicles present in each queue to maximize efficiency in green time allocation. Additionally, the system's digital architecture and artificial intelligence enable a dynamic choice of optimal signal states.

To make traffic flow efficiently, InSync identifies the best phase combinations based on actual traffic demand. This design maximizes efficiency and clears queues without wasting green time on empty approaches.

4.2.2.4. Adaptive Characteristics of Local Optimization

InSync has three different adaptive characteristics in its local optimization. The system’s flexibility with phasing, sequencing and green time allocation enables it to adapt to actual demand.

Phasing

Phasing is the first way in which InSync adapts to demand at the local level. It uses a digital state machine rather than a fixed timing plan, allowing it to spontaneously choose the phases and sequences that best serve actual traffic demand. The system continuously measures queue and delay at each approach, which allows it to calculate demand. Since InSync is unconstrained by cycles, the system determines priority so it can serve approaches from highest priority to lowest priority. The system chooses from the states (concurrently permissible phasing) available to it and requests the traffic controller actuate green lights accordingly.

Sequencing

The second way InSync adapts to actual traffic demand is with sequencing. The local traffic engineer can select allowable sequences using CentralSync software. InSync draws from the available sequences but can skip a particular phase in the sequence whenever there is no demand for service. This provides the best possible use of green time for vehicles waiting at or approaching the intersection.

Green time allocation

The third way InSync adapts to demand at the local level is in its green time allocation. In addition to actuating phases, InSync adjusts green time according to the volume of demand and intersection geometry. If there are a low number of vehicles demanding service, less green time is allocated. By not serving green time to empty approaches and instead distributing time to those approaches with demand for service, all approaches benefit.

4.2.3. Global optimizer

InSync's global optimizer ensures vehicles experience as few stops as possible. The global optimizer does so by synchronizing all traffic signals in an InSync network of intersections (such as on a corridor). By creating and serving "green tunnels," InSync's software improves the travel time and safety of motorists, while reducing the carbon footprint of their daily commutes.

4.2.3.1. Green Tunnels to Ensure Progression

InSync minimizes stops and congestion along a road through coordinating signals to move traffic at a desired speed. As a result, InSync's global optimizer frees up existing roadway capacity by keeping traffic moving through a series of intersections.

To create progression, the system schedules green tunnels based on demand. These tunnels are synchronized bands of green lights progressing platoons of vehicles through the corridor. Communications between signals allow the downstream signals to anticipate the arrival of platoons given their knowledge of segment travel times. In this way, InSync can predict platoon arrival, serve the coordinated movement a green signal and avoid slowing or stopping progression. Vehicles traveling close to the speed line can expect to travel through the InSync intersections without stopping.

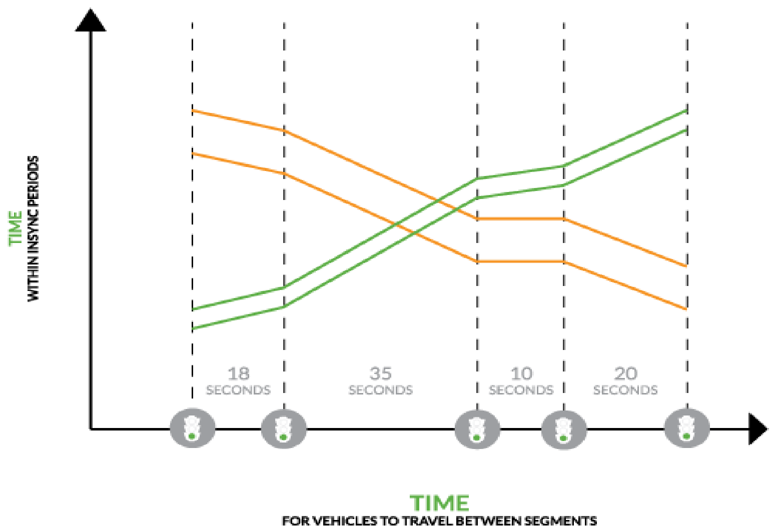


Figure 54: InSync Intersection Timeline

By anticipating the arrival of platoons, InSync reduces delay caused by slowing down, stopping and start up. This attribute allows more vehicles to progress through a series of intersections and reduces fuel use, harmful emissions and the circumstances conducive to traffic accidents.

4.2.3.2. Adaptive characteristics of Global Optimizer

InSync initiates green tunnels throughout the day. Tunnel frequency and duration are determined by traffic demand within user-defined ranges. As traffic needs change, InSync can vary the duration and frequency of green tunnels to best support traffic conditions.

- **Tunnel Duration**

The fourth adaptive property of InSync (in addition to phasing, sequencing and green time allocation) is its flexibility with tunnel duration, which is the ability to alter the green time served to a coordinated movement. If the traffic volume on the coordinated movement approach at an intersection decreases and reaches a minimum threshold, InSync can truncate the duration of the green tunnel at that intersection. The intersections downstream also have the independent ability to truncate the tunnel if demand decreases. This ensures coordinated green tunnels, while scheduled, remain adaptive to real-time traffic demand. The extra time is distributed to the local optimizer to minimize intersection delay.

- **Period Length**

The fifth adaptive property of InSync is period length – the time between serving the coordinated movements. A period is the time interval from the start of a tunnel to the start of the same tunnel later in time. If configured to allow dynamic period lengths, InSync can alter the frequency of green tunnels within a certain range. By adapting period length to real-time traffic demand, it generates more or fewer green tunnels inside a given timeframe.

4.2.4. Architecture

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, respectively. Mounted video cameras determine the number of vehicles present 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.

The architecture is almost similar to other adaptive traffic control system. It would starts from the streets by local detectors. Video cameras would count the number of vehicles and collect the data related to the demand. Afterward these data would send to the processor in an Ethernet system. In this part data would processing and used for both local and global optimization.

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. InSync's dynamic phasing and dynamic green splits enable the traffic signals to use green time efficiently.

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.

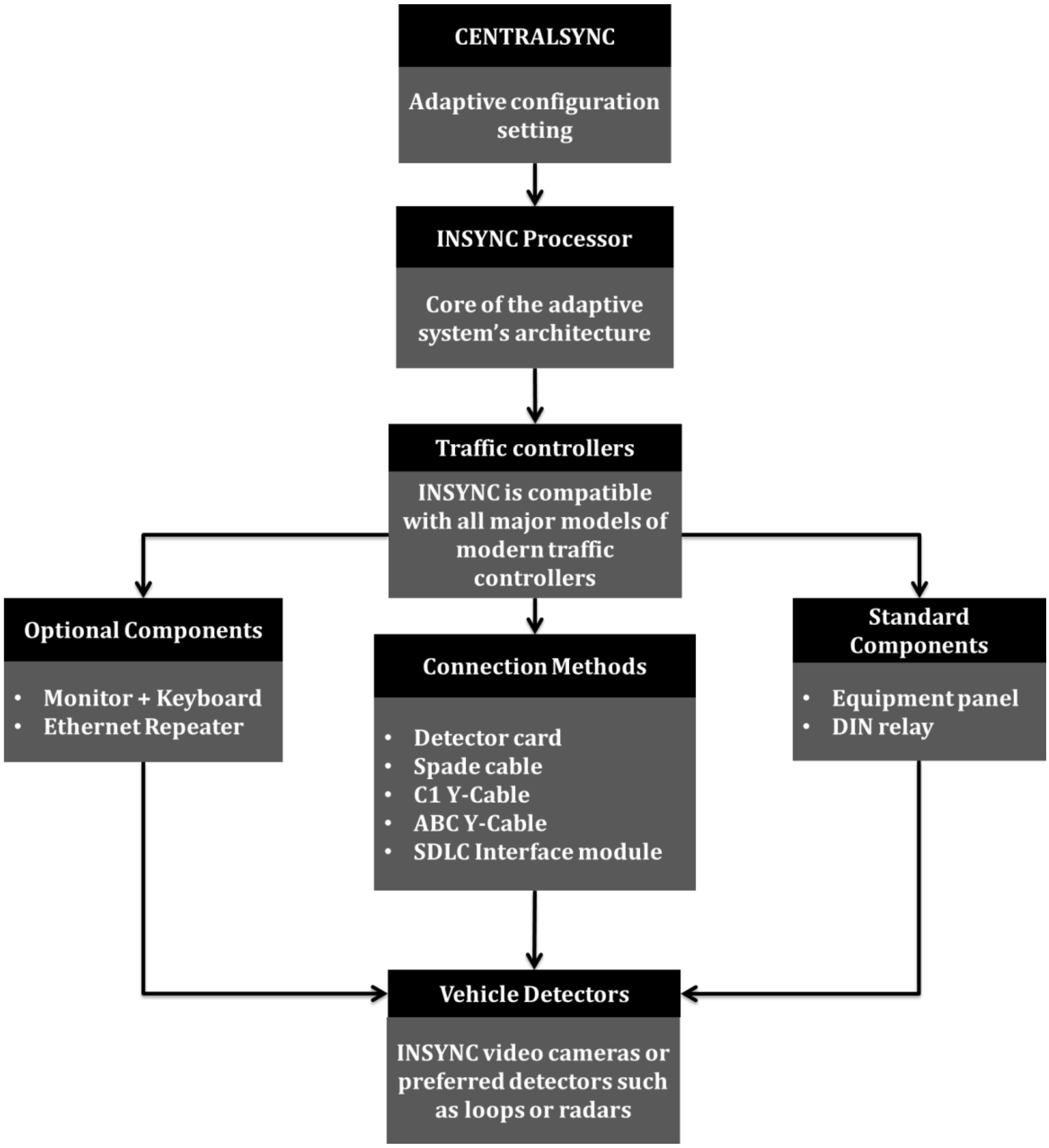


Figure 55: InSync Architecture

4.2.5. Detectors

InSync is available in three different detector options. Depends on the vulnerability of the intersection and the level of the exposure of the area, operating agents should make a comparison between "InSync", "InSync Tesla" and "InSync Fusion" to see which is the right solution for the concerned traffic.

INSYNC Detectors			
	INSYNC	INSYNC: TESLA	INSYNC: FUSION
Vehicle Detection	Video detection provided	Such as loops, cameras, magnetometers, radar or microwave	Integrate both video detection and detection devices
Benefits	Monitor live camera views of intersections from any web browsers: Great value - like getting video detection for free	Save the installation cost and time associated with installing cameras: use preferred detectors	Nearly 100% error-free detection accuracy, best performance possible

Table 20: InSync Detectors comparison

4.2.5.1. INSYNC

The standard InSync system includes up to four Samsung ® IP detection cameras per intersection, with an option of adding additional cameras. The cameras detect and measure traffic demand and make this possibility to monitor the intersections from any web browser. Further, InSync is compatible with all traffic controllers and cabinets and achieves industry-leading traffic improvement results.

4.2.5.2. INSYNC Tesla

In addition to InSync's compatibility with controllers and cabinets, "InSync-Tesla" can leverage the existing and preferred detection devices. This detector option saves the installation cost and time associated with adding cameras. Rather than using InSync video detection, "InSync-Tesla" accepts any detection input, including most third-party cameras, loops and radar. Stop-bar detection is required on all lanes.

4.2.5.3. INSYNC Fusion

For the highest performance, "InSync-Fusion" combines detection, queue and delay data from the InSync cameras, with the added accuracy and familiarity of existing or preferred detection devices, such as loops and radar.

Legend of above signs

InSync Video Detection

Non-InSync Video Detection

Inductive loops

Other detection devices (including magnetometers, radar or microwave, among others)

All InSync systems include the following (per intersection):

- 1 InSync Processor
- Up to 4 cameras for vehicle detection and DIN Relay (InSync and InSync:Fusion only)
- 1 360º Monitoring Camera (InSync:Tesla only)
- 1 Equipment Panel for power and Ethernet connectivity
- Connection to controller (choose from Detector Card, C1 Y -Cable, ABC Y-Cable, SDLC Interface Module or Spade Cable)
- CentralSync software and access to the InSync WebUI

4.3. InSync Components

InSync is compatible with all models of traffic signal cabinets, controllers and detection devices. There is no need to throw out the equipment which have been already installed and purchase new detection devices, servers or central system software. By simply plug previous equipment into InSync, and instantly the controllers and signals are transformed into artificially-intelligent traffic-moving machinery.

4.3.1. Processor

The processor is the heart of the InSync system. This computer, installed in the traffic signal cabinet at each intersection, holds all the artificial intelligence of the adaptive system. The InSync Processor gathers and calculates detection information from all sources available (such as video cameras, loops and pedestrian intercepts) and then determines the service priority for each approach. The processor places only two calls to the existing traffic controller to actuate signal phases.

As a modern, digital state machine, the processor can choose whichever state will best serve traffic demand. InSync then sends the appropriate call to the controller and the signals adapt to traffic demand immediately.

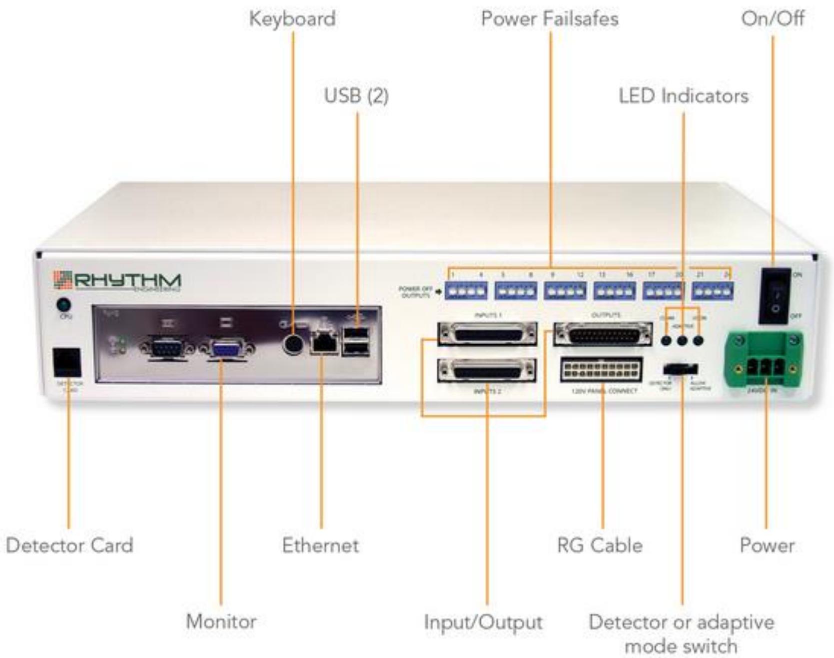


Figure 56: InSync Processor

4.3.2. Detection Camera

InSync's proprietary video detection uses high-performance Samsung IP® digital cameras to measure real-time traffic occupancy, queue length and delay. Each camera is installed in a weatherproof enclosure and connects to both power and Ethernet.

Figure 57: InSync Detector Camera

4.3.3. Equipment Pannel

The Equipment Panel is the power and communications hub of the InSync system at each intersection. It provides a safe, reliable DC power supply and an Ethernet switch, both of which support the InSync Processor and cameras. The Equipment Panel has a number of safety mechanisms including lightning arrestors to protect the networking equipment and a fuse block to protect the power leads to the cameras.

If detection cameras are used, the Equipment Panel also connects to a DIN Relay to ensure that camera power is automatically restarted in the event of a lock-up or power failure. By streamlining communications between the cameras and InSync Processor, the Equipment Panel makes sure InSync has the ability to instantly and quickly process detection data.

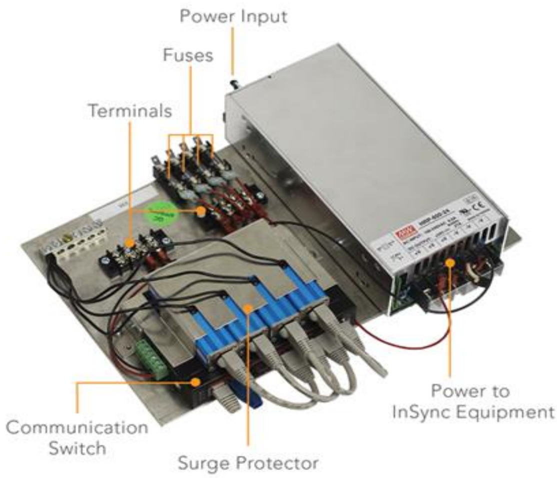


Figure 58: InSync Equipment Pannel

4.3.4. User Software

4.3.4.1. CentralSync™

CentralSync, the software companion to InSync, is a Windows-based configuration program. The software enables engineers to easily and quickly create, modify and deploy traffic management variables and strategies using a map-based interface.

CentralSync's features include time-space diagram views, editing of progression protocols, geographic mapping of intersections, adjustments to phasing, and viewing and editing of other configuration settings. Modifications can be uploaded and downloaded remotely by the operator.

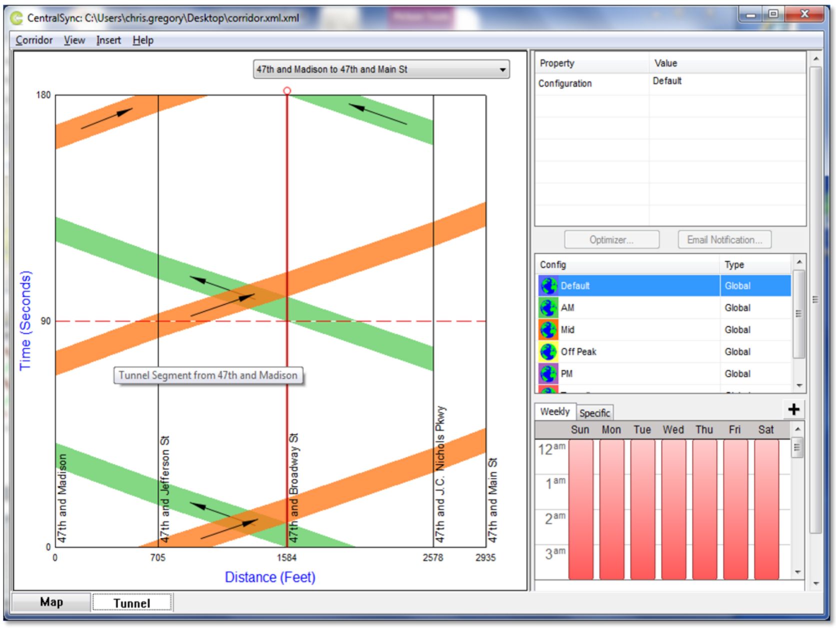


Figure 59: CentralSync Software

4.3.4.2. WebUI

The InSync Web User Interface (WebUI) gives live and interactive access to the traffic conditions on focused InSync corridor. By using any Internet browser (no special software required) camera views of every approach are available and access the individual InSync Processors and traffic data.

In addition, the status of adaptive operations is possible to check, check detector calls intercepted by InSync, check communications status and, if ever necessary, place manual calls or turn off adaptive traffic control. Data such as traffic counts, delay and level of service are stored automatically for 30 days.

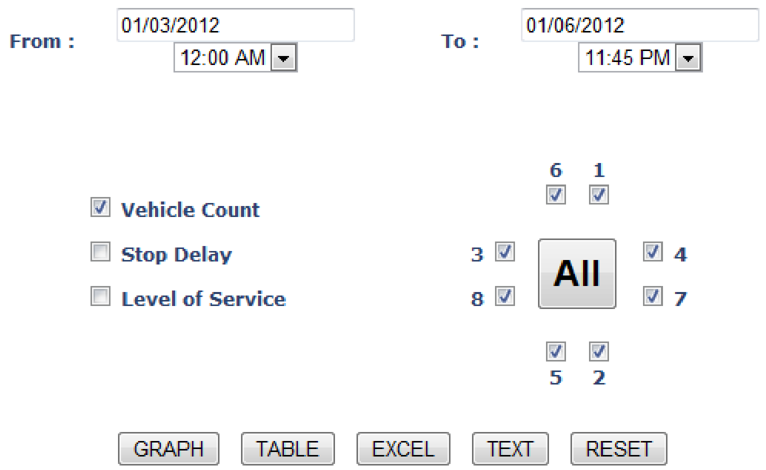


Figure 60: Traffic Data Statistics

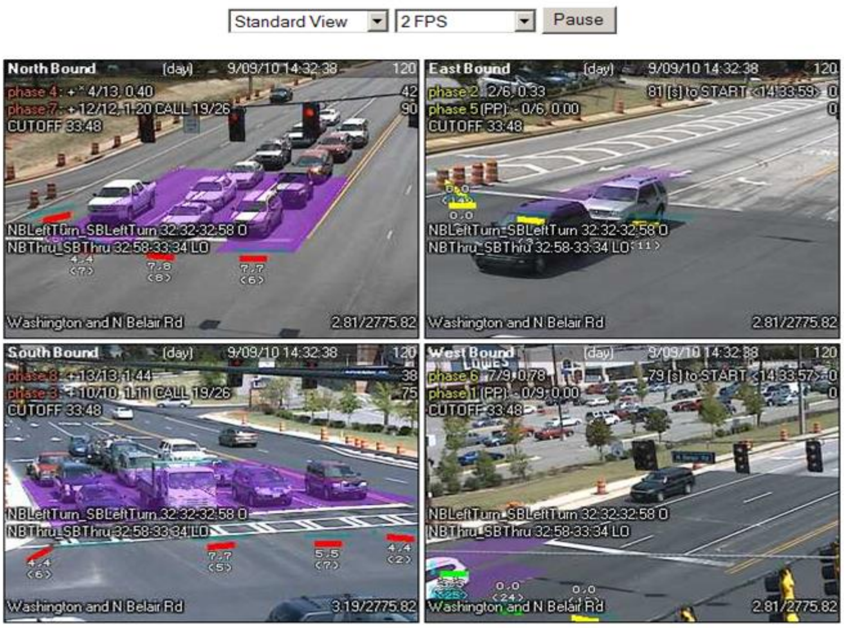


Figure 61: Web User Interface (WebUI)

4.4. Data and Reporting

InSync records a tremendous amount of data. Second-by-second details about what the system detected and its past operations are available in searchable, exportable reports. This data can be very useful in determining trends, reviewing what happened at an intersection at a particular moment in time or evaluating InSync's performance.

4.4.1. Statistics

The WebUI offers a Statistics Database. The operator can submit a query of InSync's statistics by entering the date range, time range and type of data that would like to see (vehicle counts, stop delay or level of service). The WebUI can generate the statistics report in four different ways – as a table or graph displayed in a web browser, or as a text or comma-separated values (.csv) file for download.

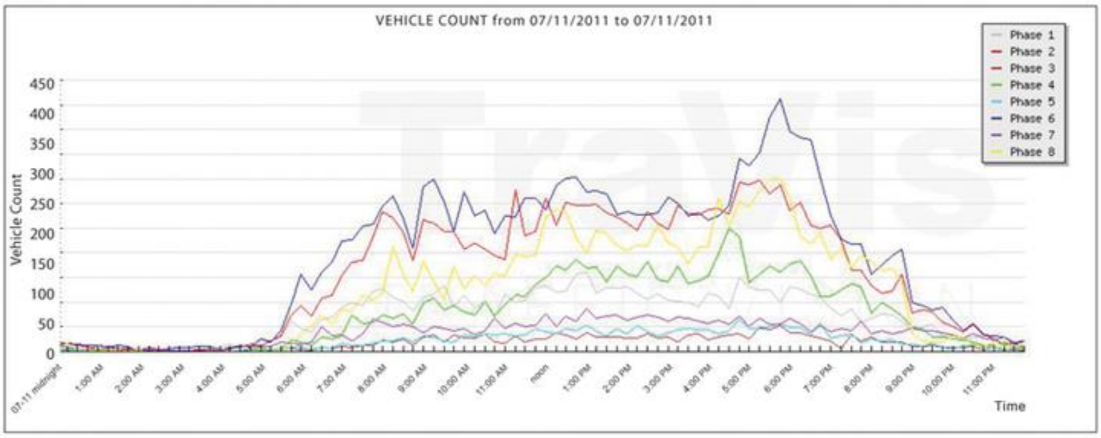


Figure 62: Illustration of statistics report for InSync

4.4.2. History viewer

The WebUI also offers a History Viewer. This allows the operator to see precise historical phasing and intersection information for particular days and times of day. The data is available to be displayed graphically within the web browser or as a .csv file for download. The History Viewer uses icons to show exactly which movement InSync served at particular times of day, the duration of the movement and other conditions at the intersection at that time, such as queue lengths and wait times.

At the global level, the operator can see coordinated movements served and any adaptive qualities applied to the coordinated movement such as whether the tunnel was truncated due to low demand, or whether the period length (time between tunnels) changed. Pedestrian call and preemption data are also available, allowing the operator to see and determine the reason for InSync's decisions.

4.5. InSync Virtues and Vices

4.5.1. System Integration

InSync integrates effortlessly with existing traffic operations software such as central systems, advanced traffic management systems (ATMS) and other infrastructure used to manage networks of intersections.

While central systems deliver many benefits, they also have certain limitations. Although InSync has the benefit of a central system but meanwhile by adding InSync' real-time adaptive traffic controls, increases its capabilities. With InSync's universal compatibility, integration with a central system is seamless and causes no disruptions. The two operate in parallel without interfering with each other.

4.5.2. Integrate InSync with Centralized Control

At intersections outfitted with InSync, the local traffic controller operates in free mode. If desired, the traffic practitioner can use the central system to switch from InSync's adaptive control to a traditional timing plan; InSync then functions in detector mode to pass calls directly to the controller. The operator can reengage InSync's adaptive functionality just as easily.

InSync adds to the central system's monitoring and reporting functionality with live camera views and traffic data that can be easily accessed, exported and archived in real-time. If the central system's vehicle and system detection inputs are independently submitted for each phase, the central system can continue to monitor and report on intersection conditions and operations. Adding InSync improves centralized visibility and control rather than diminishing it.

4.5.3. Save Agency Time and Resources

Most of the adaptive systems that come packaged with central systems rely on timing plans. This requires the agency to create and maintain coordinated timing plans. InSync requires no such outlay of agency resources because it does not use timing plans.

4.5.4. Mitigation of the Risk of Failure regard to Central System

The InSync model is based on a fully distributed intelligence network. For every intersection that is enhanced with InSync, an InSync Processor is installed in the traffic cabinet for that intersection. By contrast, central system-based adaptive solutions rely on intelligence residing on a central server. If that central server or communications between the central server and intersections fail, the system is rendered useless, potentially causing chaos on the roadways and in the offices of the traffic agency and IT department. InSync's distributed design eliminates the loss of functionality caused by disruption to centralized intelligence.

4.5.5. Failure Mitigation

InSync is designed with robust failure mitigation capabilities that allow it to control traffic even when the system experiences some form of failure. In any failure scenario, InSync attempts to send email and SMS notifications to designated staff so they are immediately alerted of potential problems. Local staff can review the situation by looking at camera views and other settings through a standard web browser, rather than having to make an emergency trip to the troubled traffic signal or the traffic management center.

4.5.5.1. Detection Failure

When cameras or other detection devices are compromised or disabled by severe weather such as extreme fog, snow, rain or a lightning strike, InSync accesses its historical data collected from the previous four weeks of operation. Using this data, InSync determines the likely demand for the affected intersections at the given day and time and serves traffic optimally.

4.5.5.2. Communication Failure

If communications are interrupted or lost, InSync continues both its local and global optimization. The system will continue to minimize delay at each individual intersection and serve scheduled green tunnels without interruption. This allows InSync to continue at near-optimal performance even if communications fail between cabinets. InSync will attempt to automatically generate notifications to one or more email addresses when it detects disruption of the communications network.

4.5.5.3. Hardware Failure

If the InSync Processor or other auxiliary hardware fails, detector calls will go directly to the controller. The controller can then run its coordinated time-of-day plans or operate fully-actuated, depending upon settings in the controller. Depending upon the type of failure, local staff can attempt to review the situation by looking at camera views through the WebUI, or by accessing processors through a remote desktop connection. In a worst-case scenario, manual calls can be placed to controllers through the WebUI.

4.6. Application and Case Studies

Public transportation agencies use InSync as a toolbox for fixing a wide range of traffic challenges. They are classified here under three broad categories:

- Roadway geometries,
- Traffic conditions
- Integrating non-vehicular traffic.

4.6.1. Roadway Geometries

Many traffic engineering challenges relate directly to the arrangement, or geometry, of the intersections.

4.6.1.1. Arterial Corridors

Motorists who travel on arterial corridors can experience many stops, much delay and unnecessary frustration if the traffic signals are not synchronized. Those waiting on the side streets often feel they are being ignored.

InSync is coordinating progression along a corridor while simultaneously minimizing delay for the side streets at each individual intersection. The technology is not affected by challenges such as odd spacing of the intersections, variable traffic flow, achieving progression in both directions, or the need to balance main and side street needs.

- **Case Study**
  - Lee’s Summit, Missouri Route 291 Corridor/ USA:

Lee’s Summit, Missouri Route 291 Corridor/ USA					
Improvement as a result of census					
Reduction in Stops	Reduction in Delay	Increase in Average Speed	Reduction in Travel Time	Reduction in Emissions	Reduction in Fuel Usage
(%)	(%)	(%)	(%)	(%)	(%)
84	72	27	23	23	10

Table 21: Lee’s Summit improvement by InSync

4.6.1.2. Intersection Network and Intersecting Arterials

InSync can optimize entire traffic signal networks, or groups of non-linear signals. Currently InSync is used in multiple networks of more than 50 signals and additional networks involving intersecting arterials or other unique, non-linear geometries.

To accomplish signal optimization in a network, InSync relies on its digital and dynamic capabilities to precisely coordinate multiple movements within the network. Being unconstrained by fixed cycle lengths, sequences and splits, InSync is one option for customizing signal operations to unique and/or complex geometries and traffic objectives.

Arterial corridors that intersect present a challenge because both roadways experience heavy traffic volume and their need for progression is equal. If not perfectly engineered, the needs of the two arterials can be at odds with each other.

Columbia County, GA's deployment is a prime example of how InSync uses its artificial intelligence and adaptive capabilities to solve this problem. The county installed InSync along two corridors in Evans, GA: Washington Road and North Belair Road. Both corridors experience heavy retail and residential traffic, and both average more than 40,000 vehicles daily. The InSync system coordinates progression along both corridors including at their common intersection

- **Case Studies**
  - Evans, Washington Road, Columbia Country/USA:

Evans, Washington Road, Columbia Country/USA					
Improvement as a result of census					
Reduction in Stops	Reduction in Delay	Increase in Average Speed	Reduction in Travel Time	Reduction in Emissions	Reduction in Fuel Usage
(%)	(%)	(%)	(%)	(%)	(%)
77	81	40	34	23	17

Table 22: Evan/Columbia Country improvement by InSync

  - Grapevine, TX / Dallas Area/USA:

Grapevine, TX / Dallas Area/USA					
Improvement as a result of census					
Reduction in Stops	Reduction in Delay	Increase in Average Speed	Reduction in Travel Time	Reduction in Emissions	Reduction in Fuel Usage
(%)	(%)	(%)	(%)	(%)	(%)
47	42	23	16	9	8

Table 23: Grapevone, TX / Dallas improvement by InSync

4.6.1.3. Freeway Interchanges

Freeway interchanges affect traffic due to the heavy volume of vehicles trying to get on via an entrance ramp or get off via an exit ramp, especially during rush hour. InSync works in this situation because it flexibly serves the sequences and amount of green time needed to intelligently progress traffic through a left-turn onto an entrance ramp, or from an exit ramp left-turn through the entire interchange. Frequently re-serving the approaches with the highest demand, such as the left-turn bays, increases storage capacity, clears queues of vehicles and keeps vehicles moving through and out of the network.

- **Case Studies**
  - San Ramon, California/USA:

San Ramon, California/USA					
Improvement as a result of census					
Reduction in Stops	Reduction in Delay	Increase in Average Speed	Reduction in Travel Time	Reduction in Emissions	Reduction in Fuel Usage
(%)	(%)	(%)	(%)	(%)	(%)
56	51	27	27	14	15

Table 24: San Ramon, California improvement by InSync

4.6.2. Traffic Conditions

InSync can be useful in tough traffic engineering challenges. Wherever better signalization has the potential to improve conditions on the roads, InSync intelligently optimize signal operations with noticeable results.

4.6.2.1. Saturation

When there are too many vehicles and not enough road capacity, there would be a couple of alternatives in front of transportation engineers. They can build additional lanes or roads, or they can find a way to maximize every inch and second of existing capacity.

InSync is the sustainable, technology alternative to multimillion dollar road construction projects. By having greater flexibility and intelligence than traditional traffic control systems, InSync increases throughput, freeing up existing road capacity and reducing the duration and severity of saturation.

- **Case Study**
  - Upper Merion, PA/USA:

Upper Merion, PA/USA					
Improvement as a result of census					
Reduction in Stops	Reduction in Delay	Increase in Average Speed	Reduction in Travel Time	Reduction in Emissions	Reduction in Fuel Usage
(%)	(%)	(%)	(%)	(%)	(%)
21	34	35	26	N/A	N/A

Table 25: Upper Marion,PA improvement by InSync

4.6.2.2. Special Events

Even the best coordinated timing plans cannot adapt to the dramatic shift in traffic caused by special events such as concerts, sporting events, weather-related evacuations or holiday shopping traffic. Traffic always fluctuate a few percentage points up or down, but some special events cause traffic volume to quadruple. Perhaps more importantly, events send an unpredictable rush of single-direction traffic along a route that does not often experience such demand (World Health Organization, 2009).

InSync adjusts traffic signals to serve these changes in traffic demand as they occur. It is not burdened by the conventions of fixed sequences, fixed cycle lengths or lags in responsiveness. InSync intelligently changes its phasing, sequencing and green times.

- **Case Study**
  - Columbia, Missouri/USA:

Columbia, Missouri/USA					
Improvement as a result of census					
Reduction in Stops	Reduction in Delay	Increase in Average Speed	Reduction in Travel Time	Reduction in Emissions	Reduction in Fuel Usage
(%)	(%)	(%)	(%)	(%)	(%)
73	56	26	20	19	12

Table 26: Columbia, Missouri improvement by InSync

4.6.2.3. Road Diet

A road diet, or lane reduction, reduces the number of travel lanes and/or effective width of a road in order to achieve systemic improvements. Reducing road capacity can also negatively impact traffic flow, leading to congestion. However, InSync proves a valuable tool in implementing a road diet.

One example of this is the Borough of Carlisle, PA's deployment of InSync along 23 intersections, PA/USA. The purpose of this project was to take the four lanes of Hanover and High Streets down to two lanes with a center turning lane and bicycle lanes on each side. Having fewer lanes was expected to slow traffic through the downtown, preserving the community's heritage while making it safer for pedestrians. By detecting real-time traffic demand and changing the lights accordingly, InSync keeps the flow of traffic on the main roads moving at the design velocity without stopping, more than offsetting the effects of the decrease in capacity.

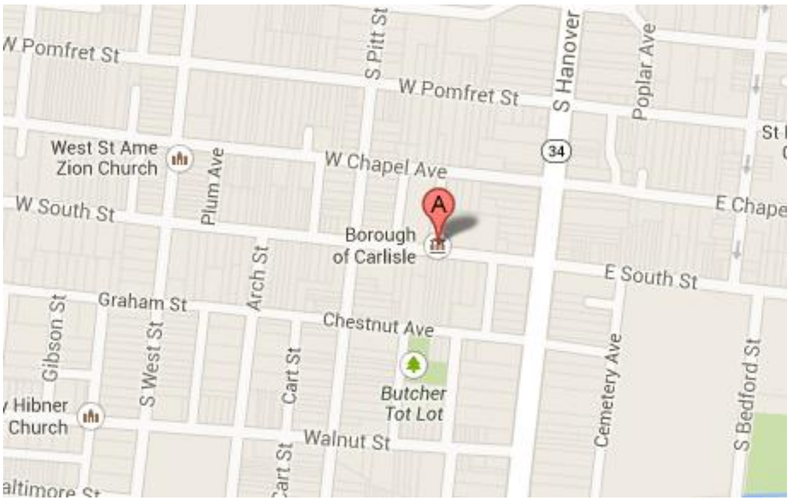


Figure 63: Borough of Carlisle, PA improvement by InSync

4.6.3. Integrating non – vehicular Demand

Non-vehicular demand such as that caused by pedestrians, trains and emergency vehicle preemption are important factors to consider when optimizing a signal network. In some cases they are significant contributors to congestion, while in almost all cases they at least represent a roadway user that must be adequately planned for.

4.6.3.1. Pedestrian Traffic

InSync minimizes the impact of pedestrian push buttons on vehicular service levels. By intercepting the pedestrian call and waiting until it can coordinate the pedestrian movement along with vehicular traffic, InSync refrains from interrupting the progression of dozens of vehicles passing through an intersection. In nearly all cases, this creates no noticeable difference for the pedestrian.

The City of Salinas, CA, installed InSync at five intersections to manage the high pedestrian and vehicle traffic along Main Street. InSync incorporates pedestrian calls into its local optimization and global coordination to ensure that pedestrians can cross the street safely without disrupting traffic flow.

- **Case Study**
  - Salinas, California/USA:

Salinas, California/USA					
Improvement as a result of census					
Reduction in Stops	Reduction in Delay	Increase in Average Speed	Reduction in Travel Time	Reduction in Emissions	Reduction in Fuel Usage
(%)	(%)	(%)	(%)	(%)	(%)
64	69	69	39	N/A	N/A

Table 27: Salinas, CA improvement by InSync

4.7. Results Interpretation and Conclusion

Crash data from police agencies in multiple states show InSync measurably improves roadway safety. By reducing vehicle stops, delay and travel time, InSync reduces the potential for conflict and thus prevents crashes and saves lives.

Dangerous conditions that increase the chance for accidents are decrease on InSync roads. These include stop-and-go congested traffic or poorly timed traffic signals that appear to the motorist as a sudden yellow light that encourages red-light running.

- **Documented Results (reduction Percentage)**

Performance measurement						
In 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 28: Performance Measurement in Terms of Reduction by InSymc

- **Safety Results**

Performance Measurement			
Safety Results			
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 29: Safety Results by InSync

4.7.1. Differences of Insync Compare to SCATS and SCOOT

The main difference between Insync and "SCATS/SCOOT" adaptive control traffic systems is related to the InSync model. The InSync Model has consisted of three components. These three main components of InSync are unique, and they are related to real-time adaptive model:

- **Digitize signal operation**

Convert traffic signal operations from analog to digital in order to break free from the constraints of linear thinking

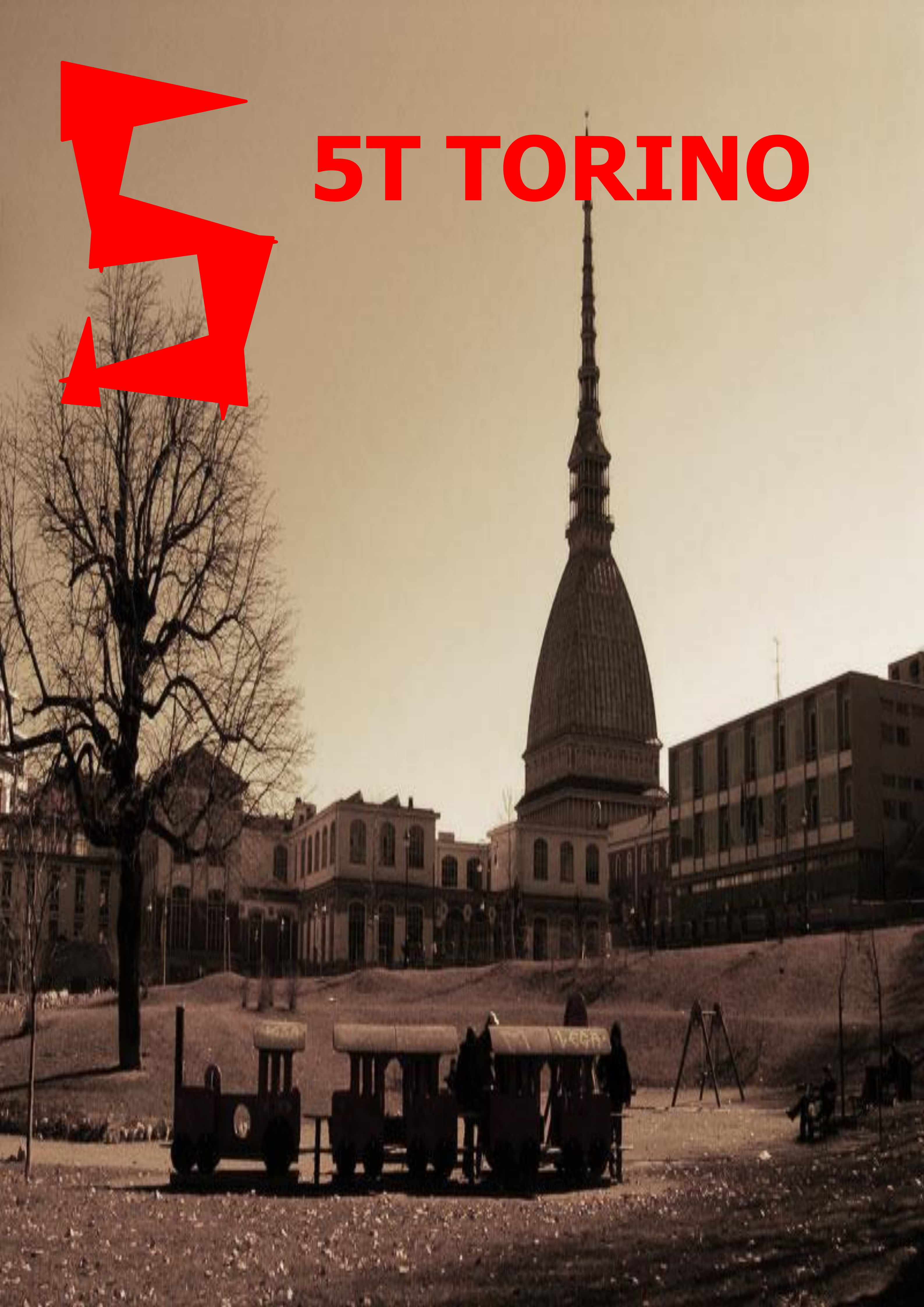
- **Local optimizer**

To minimize delay at individual intersections

- **Global optimizer**

To coordinate progression along a series of intersections on a corridor or network, explore these three concepts to learn how InSync makes decisions that measurably improve traffic.

These differences in the model cause big differences in the procedure of the way INSYNC react to traffic junction. In the favor of these differences INSYNC is not dependent on Cycle, Split and offset plan. Consequently it can have sudden access to any phase which acts in a best way to traffic flow fluctuations.


5T TORINO

5. 5T Torino

5.1. Introduction

In the previous chapters, three different adaptive traffic control systems were considered and specific case studies have been put under study. In this chapter the control center of Turin "5T Project" would be presented which includes overall traffic monitoring, urban traffic control, parking systems, and limited road access control and user information.

Meanwhile "Utopia", the adaptive traffic control system which has been used in Turin for controlling around a half of all the signalized intersections in town, would be discussed.

5.1.1. Turin Urban Profile

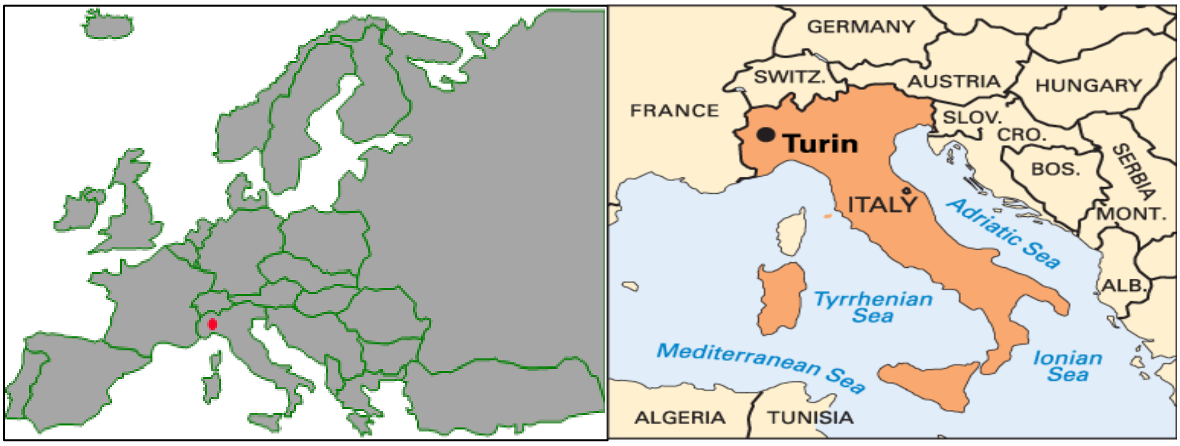


Figure 64: Turin/Italy

Turin is the second major business (after Milan) and cultural center in northern Italy, capital of the Piedmont region, located mainly on the left bank of the Po River.[24]

Turin is the fourth urban area of Italy. The city can be inscribed within a circle of 10 km radius, while the metropolitan area within a circle of 20.

First capital of Italy, the city has grown in the twentieth century as a center of development of industry and innovation. It reached its maximum of population in mid-seventies, 1.2 million inhabitants. Since then there has been a continuous decrease of population of the city, now the inhabitants are slightly more than 0.9 million. The metropolitan area itself has decreased from 1.7 million in 1979 to 1.5 million in 2000. In 20 years there has been a decrease of about 25% of the city population, and the weight of the surrounding area has increase from 30% to 40% of the metropolitan area population.

In the same period the personal motorized mobility has increased by about 65% (up to

[24] http://en.wikipedia.org/wiki/Turin

the present value of 1.97 trips/day) and the modal split has increased more than 40% in favour of the use of the private car (present modal split 27% public transport, 73% private car). The motorized mobility has grown (in the 80's, while in the 90's it has been steady) thanks to the diffusion of the private car.

Motorization rate and using car for transportation has increased by about 50% in the period, to the present value of about 1.5 cars per household.[25]

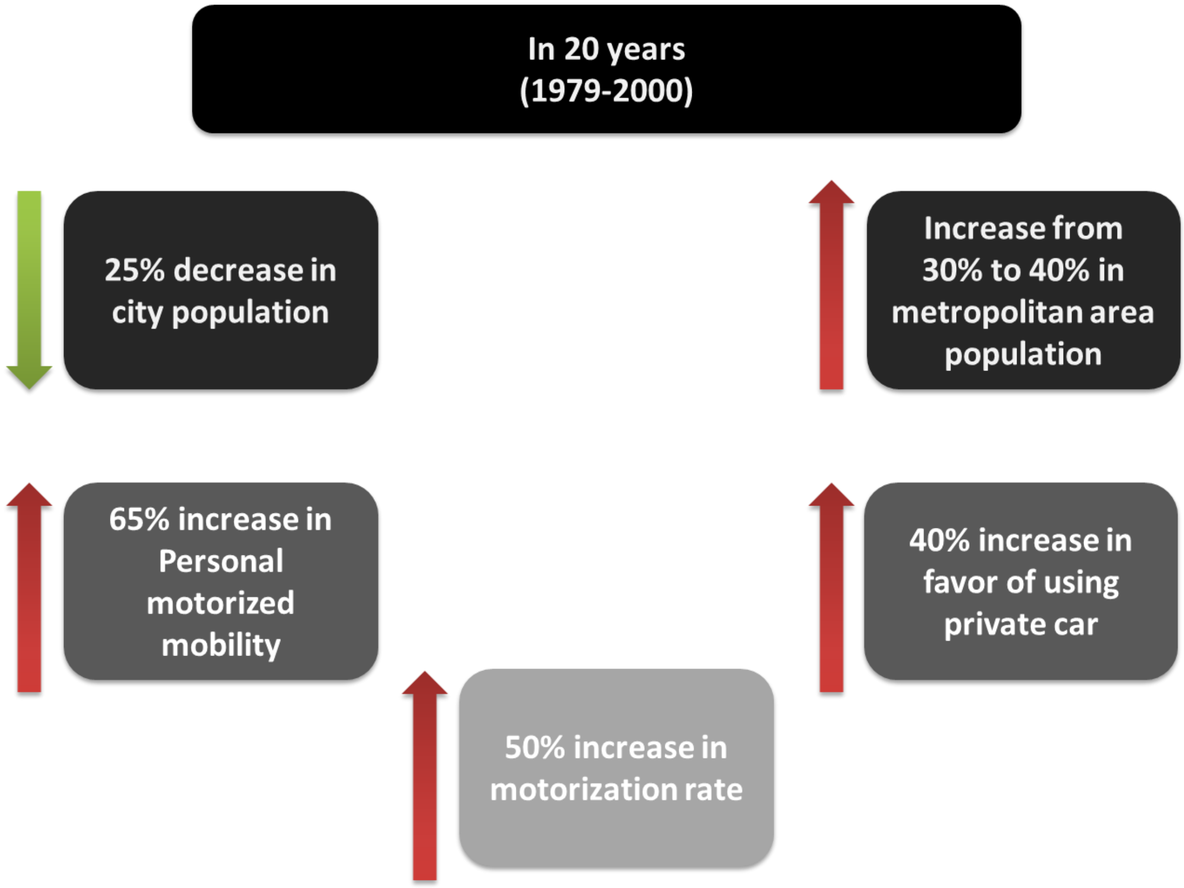


Figure 65: Statistics in the Time Interval 1979-2000, Turin/Italy

[25] *P. Gentile: An Integrated Approach to Urban Traffic Management Conference on Smart CO2 Reductions, Turin, 2-3 March 2000*

5.1.2. 5T Project History Review

- **1992**

  In this year the city of Turin started a large-scale project in mobility telematics named 5T (Telematics Technologies for Transports and Traffic in Turin), which embodies the conceptual framework and the results of two big projects: The QUARTET Project financed by the EU and of the "Environment and Traffic project" financed by the Italian Environment Ministry.

  The Turin 5T System has been developed and implemented right across the city of Turin. It was consisting of nine subsystems (Urban Traffic Control, Public Transport Management, Environment Control, Parking Control, Information Media Control, Collective Information (VMS), Automation Debiting, Maximum Priority, Route Guidance), together with an overall City Supervisor, which integrates all the other sub-systems actions into a general mobility/environment strategy and manage them.

- **1997**

  Turin has focused on a comprehensive evaluation of the IRTE (Integrated Road Transport Environment) system. The 5T project was tested during a two-year experimental phase which ended in 1997. The measured effect of the 5T System was a reduction of the average O/D[26] trip time by 21% for the resident in the area affected by the system.

- **1998-1999**

  The 5T System has been maintained in 1998-99 at the functional levels reached during experimentation. In the same period the process of the transformation of the 5T Consortium – which has generated 5T – into a new company in charge of all developments of transport telematics in Turin has been accomplished.

- **2000**

  In year 2000 5T convert from the project Consortium into the Consortium company 5T s.c.r.l.[27] (ATM, AEM, FIAT, CSST, Mizar)

- **2006**

  The Torino organizing committee of XX Olympic Winter Games has charged 5T to develop and manage the Traffic Operation Centre (TOC) as the core of the Olympic transport system.

- **2008**

  In this year 5T becomes a company totally owned by local public bodies.

---

[26] O/D: Origin - Destination

[27] Società Cooperativa a Responsabilità Limitata

5.2. 5T Objectives and Mission

In the early 90's, when government of Turin noticed that they had increase trend in the weight of the metropolitan area population, personal motorized mobility, and increase in inclination of using private car; mobility government had decided:

- Calling for an integrated intervention strategy, both on private and public transport;
- Aiming at the substitution of large part of private car trips by the use of public transport;
- Requiring a public transport better service quality in order to reach the objective;
- Recognizing the need of the development of public transport infrastructural interventions on the long terms, and of mobility telematics applications on the short period.

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

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

The 5T Project long-vision goals and prediction in the start of the project, where stated as it follows: when extended over the whole urban area 5T would grant:

- Average origin-destination travel time: - 25%
- Mobility related air pollution and energy consumption: - 18%
- Improve modal split towards the public transport.

5.2.1. Background

The Consortium which was incorporated in order to manage the project is presented in the following graph:

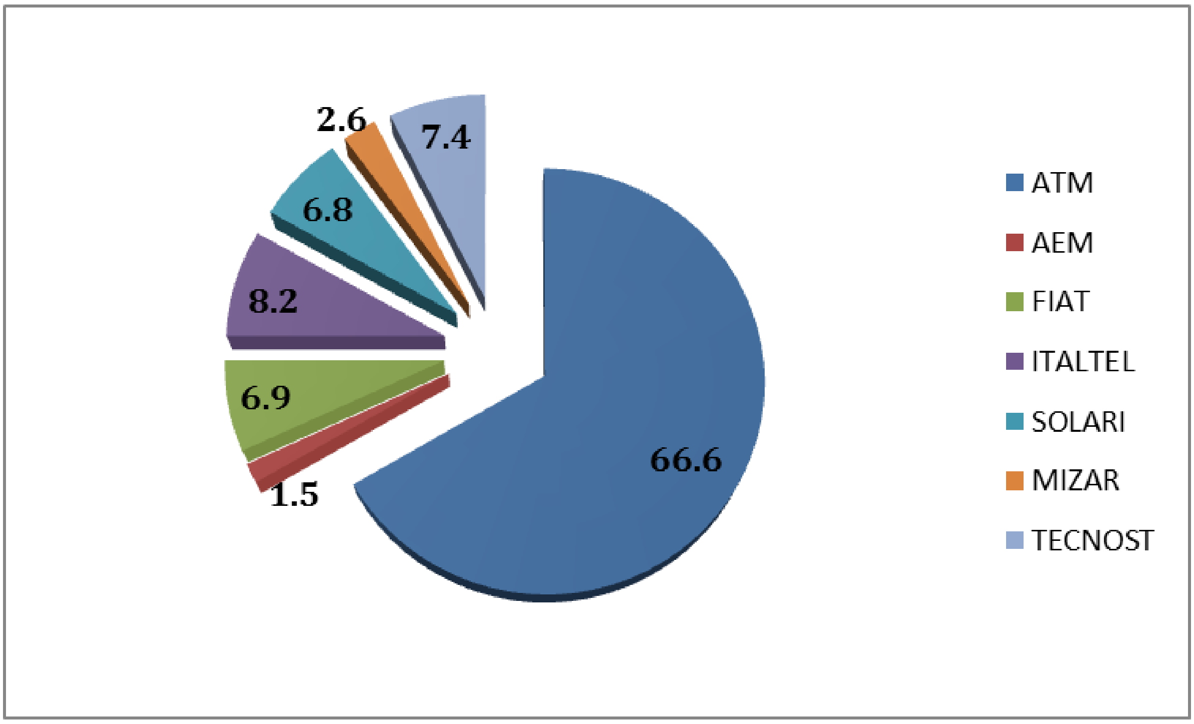


Figure 66: 5T Consortium

The total cost for the project, realization and experimentation of 5T Project was 23.6 billion Lire (12.2 million Euros), which was provided by different share portions by different shareholders:

- The Project has been financed by the Consortium Partners for 14.2 billion Lire (7.4 million Euros).
- A contribution of 3.7 billion Lire (1.9 million Euros) has come from the Italian Environment Ministry ("Environment & Traffic in Turin" project).
- The European Union has contributed to the Project by 5.7 billion lire (2.9 million Euros) ("QUARTET" project, its extension, and "QUARTET PLUS" project).

5T Consortium had seven partners. The public partners ATM, the Turin public transport company, and AEM, the Turin energetic company, had a share of 68%. The city of Turin assisted 1.5 billion Lire (about 0.8 million Euros) to support ATM effort (Mizar atomization, 2012).

5.3. Implementation

The 5T System in Turin came out of the integration of pre-existing and on purpose developed subsystems. The System has been designed with an open architecture, to fit with all existing development and to allow further applications extension.

The basic characteristics, which lead to shaping the architecture, have been based on following factors:

- To have autonomous systems co-operating by a data network and a common data dictionary, which means to have a common language to communicate;
- To save costs by sharing common facilities;
- To implement a supervisory function in order to grant a common mobility/environment strategy to the action of all subsystems.

The 5T System has integrated 10 transport telematics sub-systems. In the following graph these subsystems have been depicted:

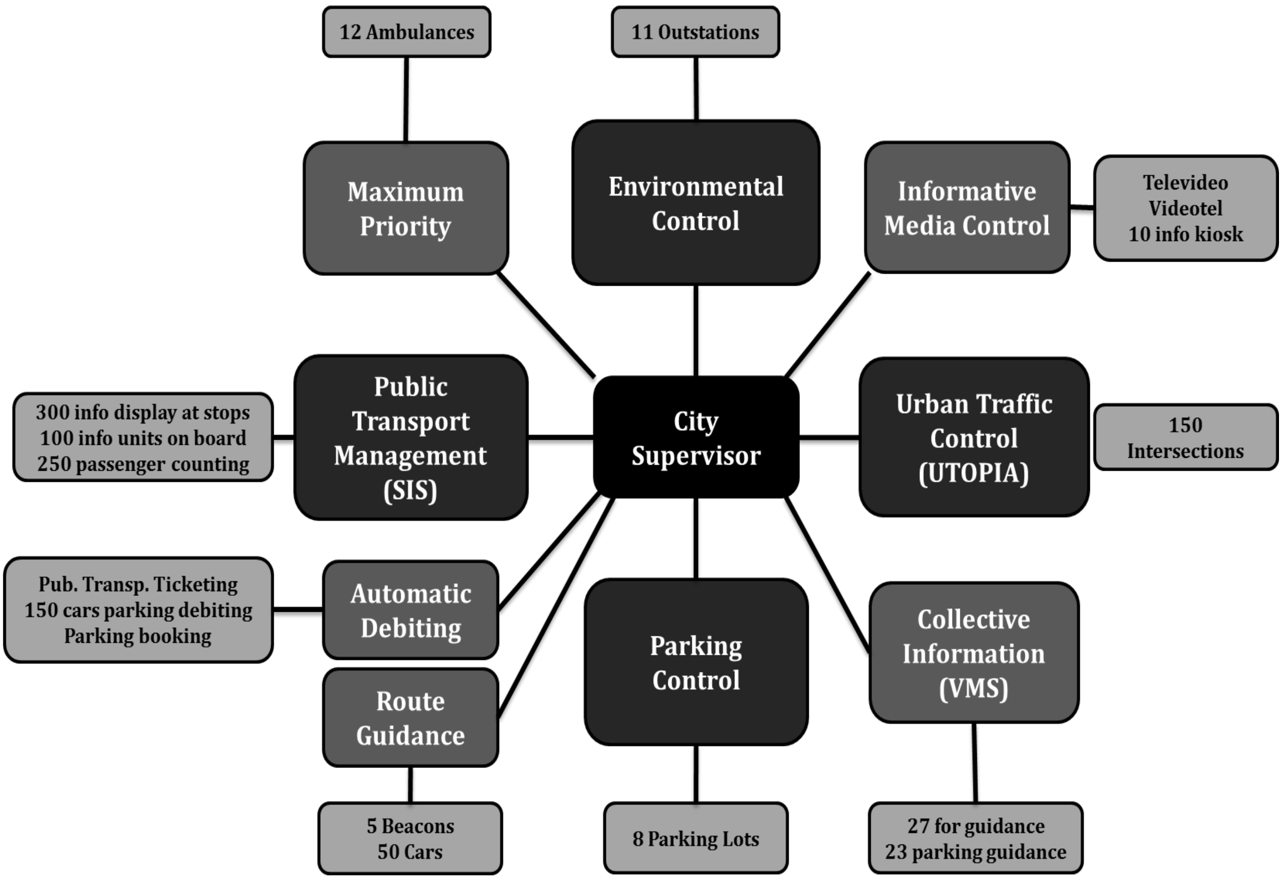


Figure 67: 5T Sub-Systems (numbers are related to year 2000)

"City Supervisor" has a big role in the system; it coordinates actions of all the subsystems. It is the subsystem in charge to monitor and estimate on-line the mobility and environment state of the city of Turin and to provide a feasible and common control strategy to the other 9 subsystems of 5T that can influence directly the traffic behavior (Foti, 2009).

5.3.1. 5T Subsystems and Functions

- **The City Supervisor** grants the subsystems integration in order to generate the best service to the citizens' mobility together with the urban environment protection. It is the most innovative development of the entire project.

In every few minutes it manages; the traffic monitoring, generates an hourly mobility forecast, tests the air pollution effects, and decides a general strategy for the following period in order to achieve and maintain user equilibrium, compatible with the environment protection constraints. The subsystems co-operate to the general strategy taking the Supervisor decisions into their specific operating strategies.

- **The Public Transport Management** subsystem manages through SIS (the operation aid system of ATM, operating since 1994 on the whole fleet of 1350 vehicles) the public transport commercial speed and regularity by taking advantage of the position monitoring and traffic lights priority, within the Supervisor strategies. It co-operates the information to the citizens. It manages 200 waiting time information displays at stops, 100 on board equipment announcing next stop, 100 passengers weighting-counting equipment. (Statistics are related to 2000)

- **The Urban Traffic Control** subsystem manages the traffic lights by a traffic-responsive regulation according to the online local measurements and the area policy suggested by the Supervisor, and contextually provides the traffic light priority to public transport. It manages 150 crossings in the urban area, with about 700 traffic sensors (Up to year 2000). "Utopia" has been used as an adaptive control traffic system in this subsystem.

- **The Environment Monitoring and Control** subsystem, using the weather forecast, the data coming from 11 pollution detection stations and the traffic data, foresees at short term the environment conditions and make them available to the Supervisor so that this can adopt the mobility policies compatible with the safeguard of the environment. Taken collectively, the stations detect the following pollutant data: Sulphur dioxide, nitrogen dioxide, nitrogen monoxide, carbon monoxide, hydrocarbons, ozone, and suspended particulates .

- **The Parking Control and Management** subsystem, in connection with 8 automatic parking, supplies forecasts on the places availability and enables the telematics booking by Videotel to clients provided with smart cards (Mizar atomization, 2012).

- **The Variable Message Signs** subsystem provides collective dynamic guidance to the different city districts, and supply real time info on the available places at the automatic parking lots. It operates with 26 routing panels and 23 parking panels.(Up to year 2000)

- **The Information Media Control** subsystem supplies, by Internet to access to real time information on the state of public transport, traffic, parking and environment. It helps people with online information to make their pre-trip planning on the best mode and the best route through 10 PIA (automatic information kiosks) installed in different points of the city.

- **The Fares and debiting** subsystem ensures that payments can be made without stopping at automatic parking to the drivers provided with smart cards of 150 equipped cars. It also enables, through smart card use, the purchasing of public transport tickets at the parking. This option would avoid numerous traffic congestions especially in highways because of stopping in the middle of the highway to pay tolls.

- **The Maximum Priority** subsystem assists the ambulances navigation trough the urban network and allows clearing the traffic lights intersections along the chosen route. It operates over 15 ambulances of the regional emergency call number "118".

- **The Route Guidance** subsystem helps the driver of a specifically equipped car in navigating through the route network, in order to optimize the trip time within the real traffic conditions. It operates over 5 intersections and 50 equipped cars (Up to year 2000).

5.4. Turin Case Study and results

Statistics which had been collected till March 2000 declare that; Urban Traffic Control manages on about 20% of the city traffic lights, located on several main avenues of the city and 3 street car lines, where waiting time has been displayed at stops. Variable Message Signs (VMS) for routing have been applied at the external ring of the city, while a number of VMS for parking at the downtown border, and information kiosks in 9 central locations.

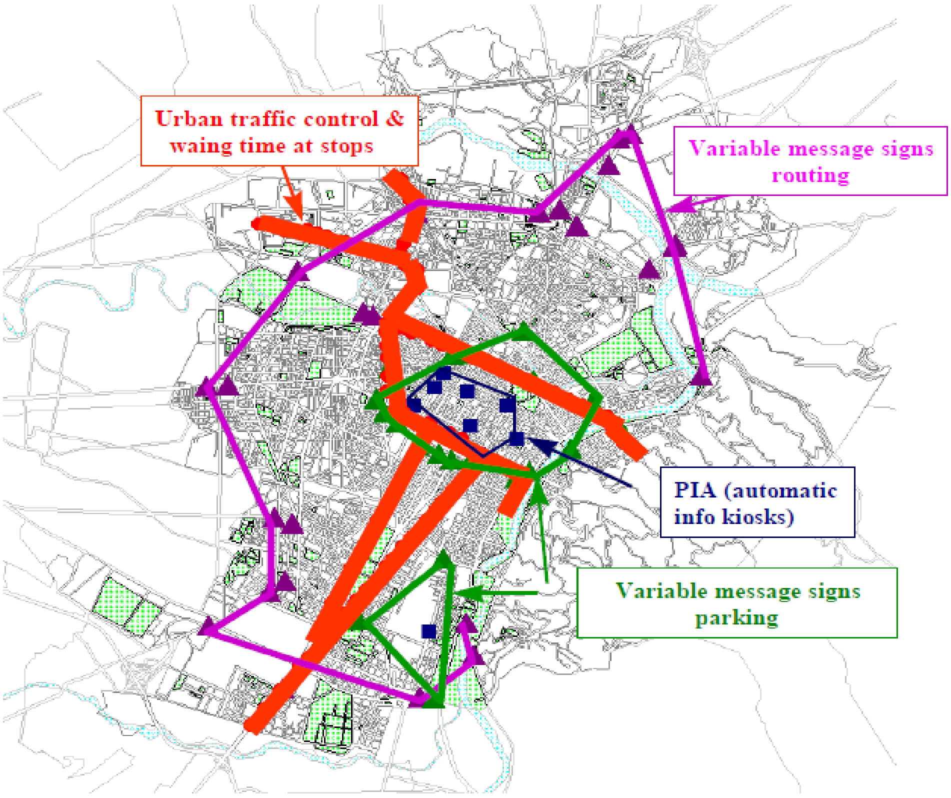


Figure 68: Turin Case Study

The 5T application area, where the System effects are more intensive, counts for about 30% of the city residents. But these results are for year 2000. Recently statistics declare that "Utopia" adaptive traffic control system is controlling around a half of all the signalized intersections in town. This increasing trend has a direct relation to the increasing urge for taking more advantage of applying utopia in Turin day by day.

The Project was tested during a two years experimentation phase, ended in 1997, with a cost of 1.8 billion Lire (something more than 0.9 million Euros). The experimentation has been released by subsystems observations and evaluations at the center, by extensive on the field campaigns of time measurements and on site interviews, and by a telephone survey on a panel of 500 citizens resident in the area of application of the system.

5.4.1. Traffic and Public Transportation Management Improvements

5.4.1.1. 5T System Benefits measured in 2000

The trials of 5T system have been carried out on 2 fixed routes:

- The whole tramway line 3 and part of line 4.
- 360 trips have been made both by car and by public transport.
- 2 scenarios have been chosen: in scenario 1 (5T "Off" that is 5T strategies not operating) and in scenario 2 (traffic control "on").

In the following table the benefits of applying 5T project in Turin is measured. These results are related to 2000.

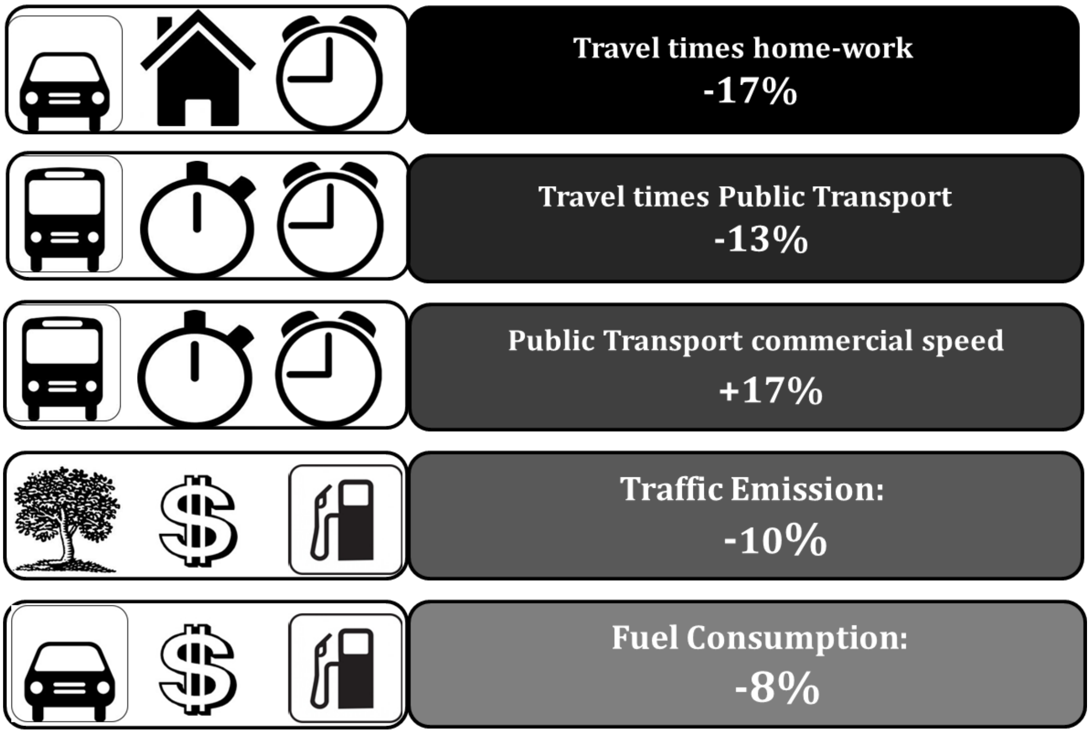


Table 30: 5T System benefits measured in 2000[28].

[28] Results based on European Project Quartet performance indicators

5.4.1.2. 5T System Benefits measured in 2012

In the recent traffic measurements which have been done in Turin, two specific paths were selected and applied by two different scenarios to check the upcoming results. In the following map these two paths are determined

- Two paths:
  - Siracusa – Potenza (6,9 Km), Which in the map is shown by red color.
  - Unione Sovietica – Sacchi (7,0 Km), Which in the violet is shown by red color.
- Two Time slots:
  - 7:00 ->9:00 (rush hour)
  - 12:00 ->14:00 (low traffic hour)
- Two Scenarios:
  - System on
  - System off (5T strategies not operating)

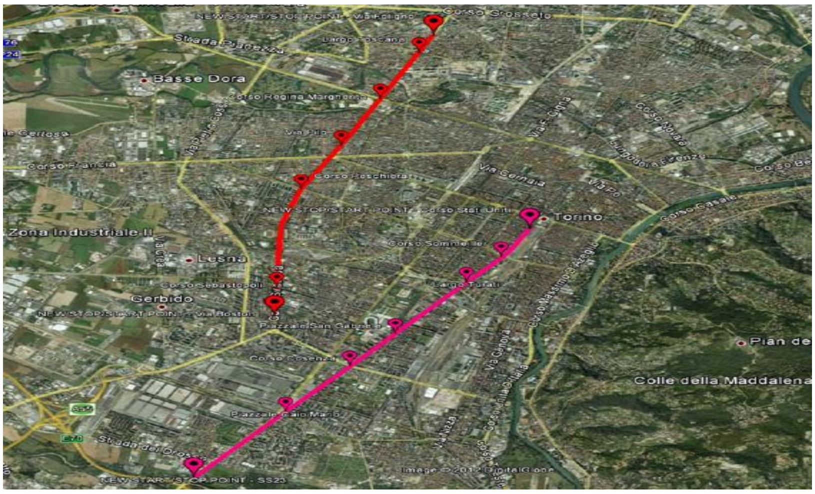


Figure 69: Siracusa – Potenza, Unione Sovietica – Sacchi

In the following table the benefits of applying 5T project in Turin is measured. These results are related to 2012.

Table 31: 5T System benefits measured in 2012

5.4.2. Management System Improvements, Routing and Citizens Information:

Trials have regarded 9 Origin/Destination pairs.

- 1020 trips have been made by public transport and 920 trips by car.
- Scenario 1 (5T "Off") and scenario 2 (5T "On", that is with all the supervision, management, routing and information strategies operating).
    - About 30% of the trips carried out in scenario 1 had the destination assigned in advance, simulating the "occasional trips". It declares the trips which occurred in 5T "off" scenario but they just use information of the destination before the departure was started.
- The results have been separately computed for the O/D pairs mainly out of the area controlled by 5T, and O/D pairs mainly within the 5T area, and for these last expanded by the degree of influence of 5T to represent the "full coverage".

Usual Trips				
Equipment average	Out of the 5T area	In the 5T area	Reduction in Travel time of O/D	Reduction in O/D Travel time (Mean)
(%)			(%)	(%)
17	✓		0.3	-20
67		✓	-12.4	
100			-19	
Occasional Trips			-25	

Table 32: O/D decrease in Travel Time for Private Car

Usual Trips				
Equipment average	Out of the 5T area	In the 5T area	Reduction in Travel time of O/D	Reduction in O/D Travel time (Mean)
(%)			(%)	(%)
14	✓		-2.4	-22
57		✓	-11.1	
100			-21	
Occasional Trips			-26	

Table 33: O/D decrease in Travel Time for Public Transport

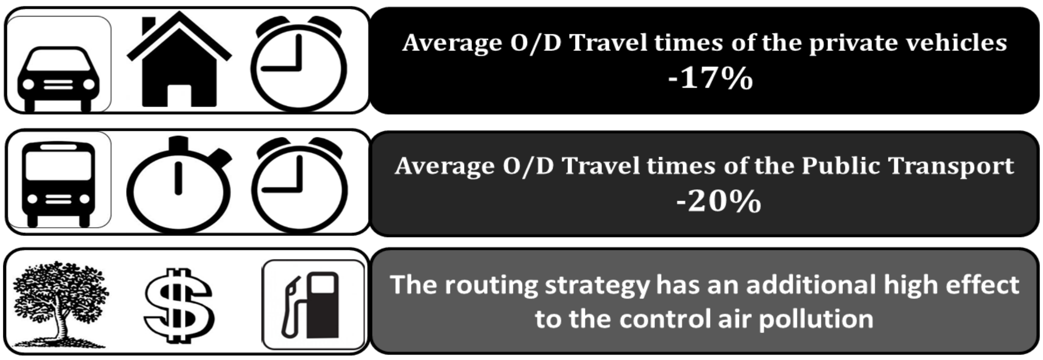


Table 34: O/D Travel Time by routing and information strategies operating

5.4.3. Telematics Technologies Impact (5T)

An area of 500 citizens located in Turin has been interviewed. Their trips show an increase of 3% of modal split in favor of the public transport. (Data are related to 2000).

On the basis of this figure and of the previous reported effects, the general impact of the 5T system can be stated as:

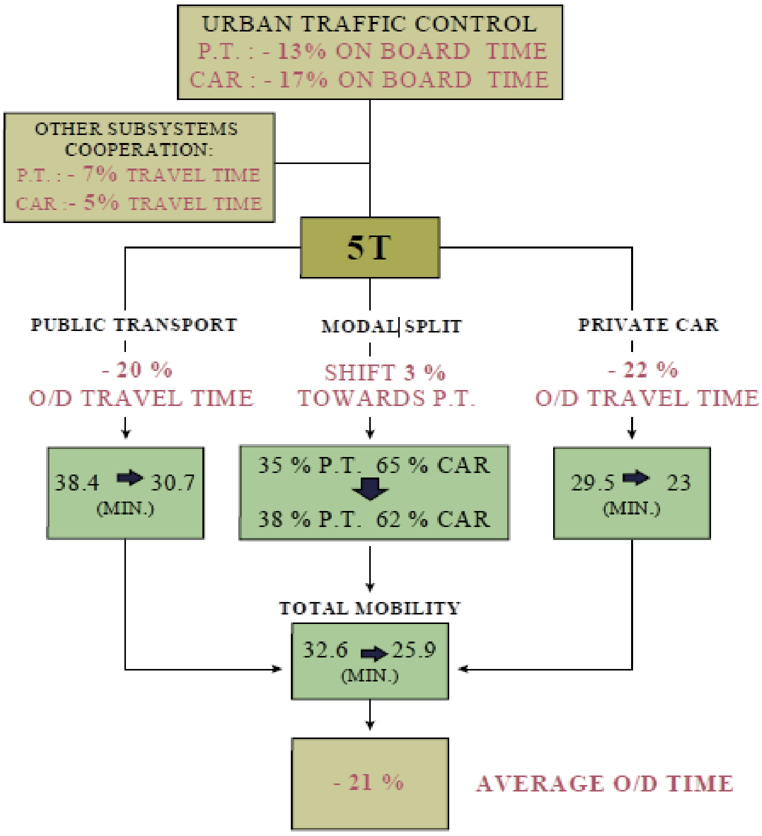
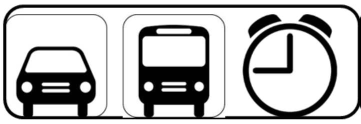


Figure 70: Telematics Technologies Impacts Chart



	Average O/D Travel times **-21%=7min per trip**
The mentioned area has perceived the public transport service quality improvement and has judged with particular favor the passenger information subsystem.	
The general impact of 5T at the city level on the environment	
	Modal Split effect on pollutant emissions **-10% to -11%**

Table 35: Telematics Technologies Impacts and Improvements in General

5.5. Project of 5T in recent age

5T project has been experiencing an increasing trend during its application on the Turin city, which make it a big reputable monitoring center in recent years. 5T became a private company owned by local public institutions, whose focus is on ITS (Intelligent Transport Systems) design, development and management, at the service of individual and collective mobility, both at urban and at regional level

5T manages the Traffic Operation Centre (TOC) in the metropolitan area of Torino, integrated with the public transport real-time monitoring system, to get smoother traffic and to improve the performance of public transport

5T is now working on the extent of the TOC[29] to the whole Piemonte regional area and on the implementation of the Regional Electronic Ticketing System (BIP Project), aiming to integrate in a unique contactless smartcard the entire mobility network in Piemonte.

5T Company is consist of four shareholders with different percentage collaboration. In the following figure the percentages of these shareholders is presenting.[30]

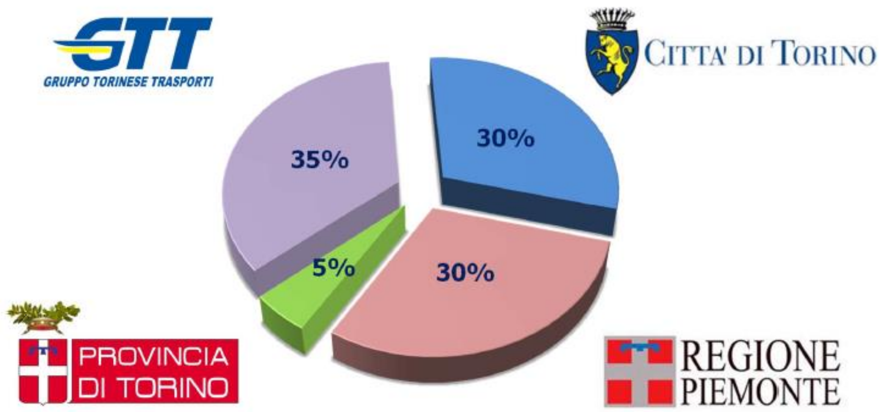


Figure 71: Shareholders Which Collaborate in 5T Project

[29] Traffic Operation Center

[30] ICT Emissions, Stakeholder workshop, Thursday 9th May 2013, Madrid

5.5.1. 5T Architecture

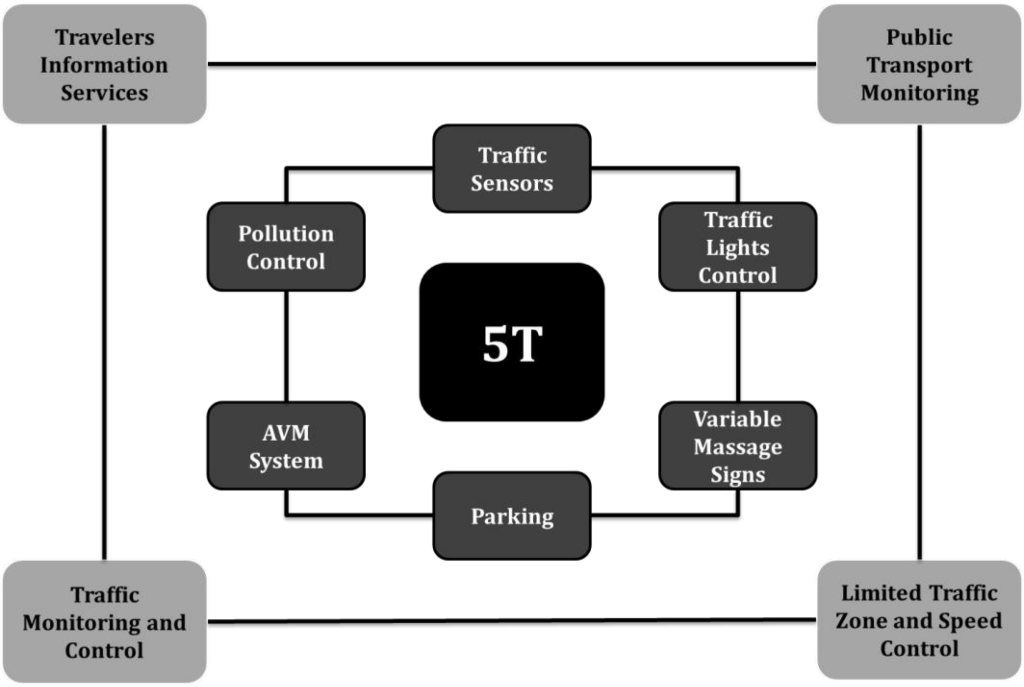


Figure 72: 5T Metropolitan System 2012

5.5.2. Urban Traffic Control - Utopia

The Urban Traffic Control subsystem is consisting of "Utopia" adaptive traffic control system. Utopia has provided an actual innovation in traffic control. The efforts of this UTC[31] is both in minimizing the private traffic overall trip time, and selective and absolute priority to public transport vehicles.

5.5.2.1. Utopia Deployment

The deployment would be discussed in the following in three scales. First the deployment of Utopia UTC in Europe scale, after that in Italy scale, and at the end the deployment in Turin scale since this city is the case study of this chapter.

[31] UTC: Urban Traffic Control

UTOPIA in Europe (Deployment)

- Sweden (Goteborg, Uppsala)
- Norway (Oslo, Trondheim)
- Denmark (Copenhagen, Aalborg)
- The Netherlands (Eindhoven, Den Haag, Den Bosch, Helmond, Rhenen)
- Belgium (Brussels)
- Poland (Lodz, Gdansk, Malbork)
- Romania (Bucharest)
- Ukraine (Kiev)
- Russia (Moscow, Kazan)
- Ireland (Galway)
- … for more than 30 cities

UTOPIA in Italy (Deployment)

In large cities:

- Roma
- Milano
- Torino
- Bologna
- …

In small cities:

- La Spezia
- Bergamo
- Cremona
- Verona
- Trento
- Udine
- Perugia
- …

Utopia in Turin (Deployment)

- 330 (out of 600) controlled intersections with dynamic regulation of traffic-light cycles
- Over 3,000 inductive loops
- 25 above-ground sensors
- 71 cameras on 23 intersections
- 2 speed control systems

5.5.2.2. Utopia Architecture

Most of the Urban Traffic Control systems are based on similar factors. The basic principle of UTOPIA is to perform a real-time optimization of the signal settings in order to minimize the total socio-economic cost of the traffic system, in terms of the avoidance of congestion and decrease the amount of emissions, and the reduction of travel time both for private traffic and for priority vehicles.

UTOPIA has a hierarchical and distributed architecture. This architecture is consisting 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.

The architecture is consisting of three system components:

First, Central system

- LAN architecture[32]
- Modularity[33]

Second, Communication Network

- Flexible
- WAN architecture[34]
- Support for TCP/IP protocol
- Support for proprietary protocol

Third, Roadside Units

- Intelligent controllers
- Can connect other devices

---

[32] LAN is a computer network covering a small geographic area, but with higher speed and data transfer rate rather than WAN network.

[33] Modularity means the system is consisting of separate parts or units which can be put together to form a new higher level system.

[34] WAN is a computer network that covers a broad area (e.g., any network whose communications links cross metropolitan, regional, or national.

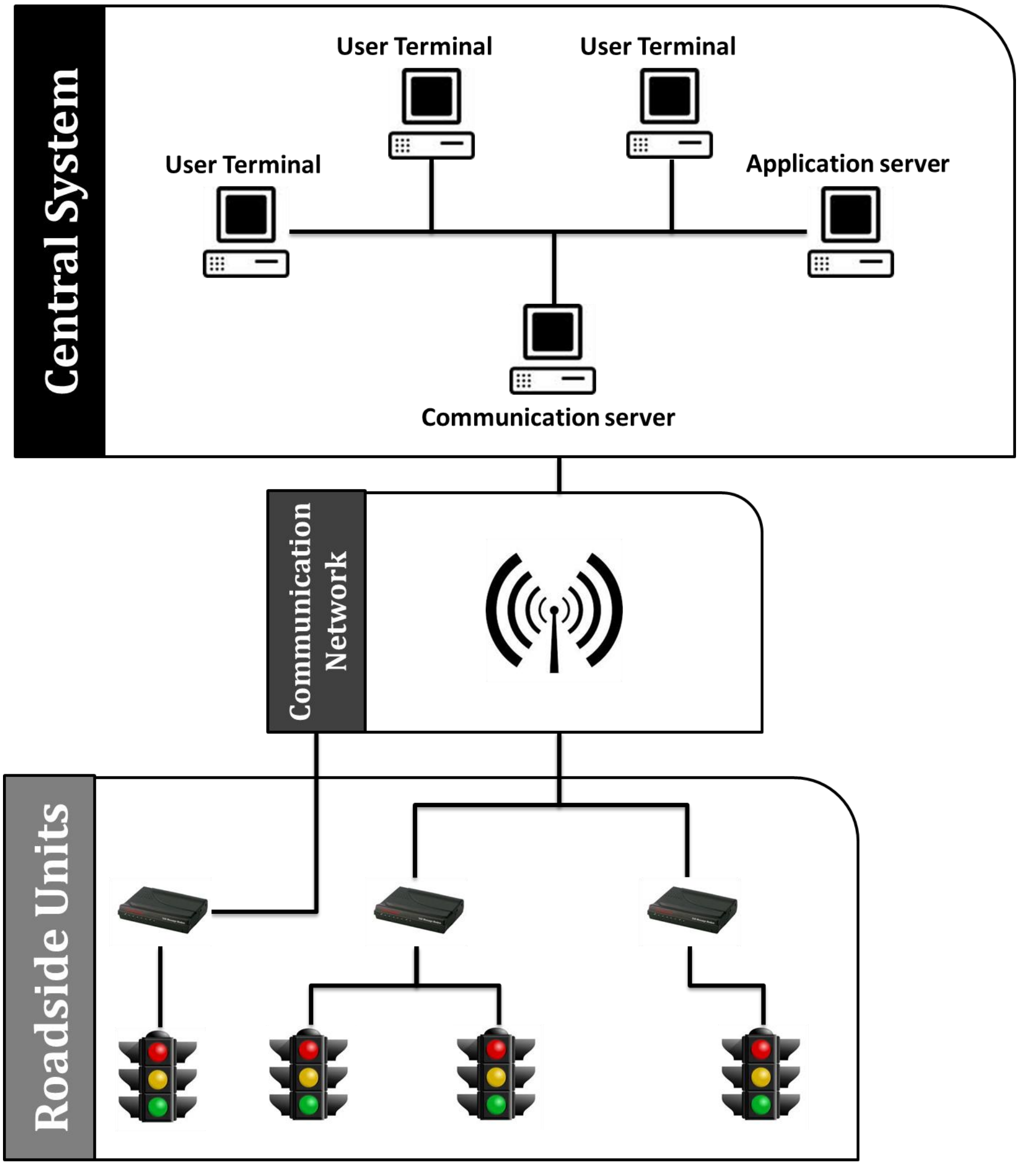


Figure 73: Utopia Architecture

- **Central System:**

Central system of Utopia, which is higher level compare to the other two parts, would calculate the network-wide optimization strategy and reference control strategies. Based on a LAN of standard computers (servers and workstations), it provides for scale-ability and modularity of all the functions: control, diagnostic, PT priority, monitoring and user interface. In the following functions that carried out by central level software are mentioned:

- Traffic network monitoring
- System diagnostic
- Traffic control and public transport priority
- Co-operative monitoring and control
- Graphical and interactive user interface

- **Roadside Unit**

The second level in the Utopia, which has lower level compare to the central system part, is based on a network of Roadside Units. This part is equipped by industrial computers which are running the "SPOT" software, intersection by intersection to control the traffic, calculating the demand and etc. In the following the basic functions carried out by intersection level software "SPOT" are mentioned:

- Traffic light controller interface (Actuation)
- Intersection control (Adaptive traffic control and plan selection)
- Intersection status estimation
- Public transport priority
- Local level diagnostic

- **Communication**

After introducing the two major parts of Utopia, one last important part remains, which is necessary for connecting these two parts together. In order to operate properly, the Roadside Unit needs data from the Central System and data from the adjacent Roadside units. On the other hand, each Roadside Unit locally data (traffic volume and planned control strategy) must be distributed to the adjacent Roadside Unit and to the Control Center. In the following different types of communication that happen in the system would be mentioned:

✓ Center ----- Local:

- Configuration data (including public transport priority data)
- Control parameters (weighting factors, reference plan, co-ordination criteria)
- Public transport priority forecast
- Center Operator direct commands

✓ Local ----- Center:

- Actuated control strategy data (Cycle length and offset, stage length)
- Traffic Measures (traffic volumes, detectors occupancies)
- Traffic estimates (clearance capacity, turning proportions, queues estimation…)
- Diagnostic data and fault in the system

✓ Local ----- Local:

- Traffic counts and traffic forecasts
- Planned control strategy

Communication can also take place between the software "SPOT", which is used in Roadside Unit, and the controllers which are installed at the intersections. In the following this type of communication also would be demonstrated:

Communication of "Spot" roadside unit with the controllers is divided in to categories:

- ✓ Spot ----- controller
  - Second by second signal command
- ✓ Controller ----- Spot
  - Second by second detector data

Spot runs normally on industrial pc, Linux environment, but it is also available for tests running on Windows. All the communications are TCP/IP[35], allowing physical network independence.

Dynasim supports Utopia protocol and connects to the Spot units as it was a set of controllers. This is a TCP/IP socket communication; allow running on different Windows machines, if necessary. Everything can run on a Windows pc, up to 10 intersections.

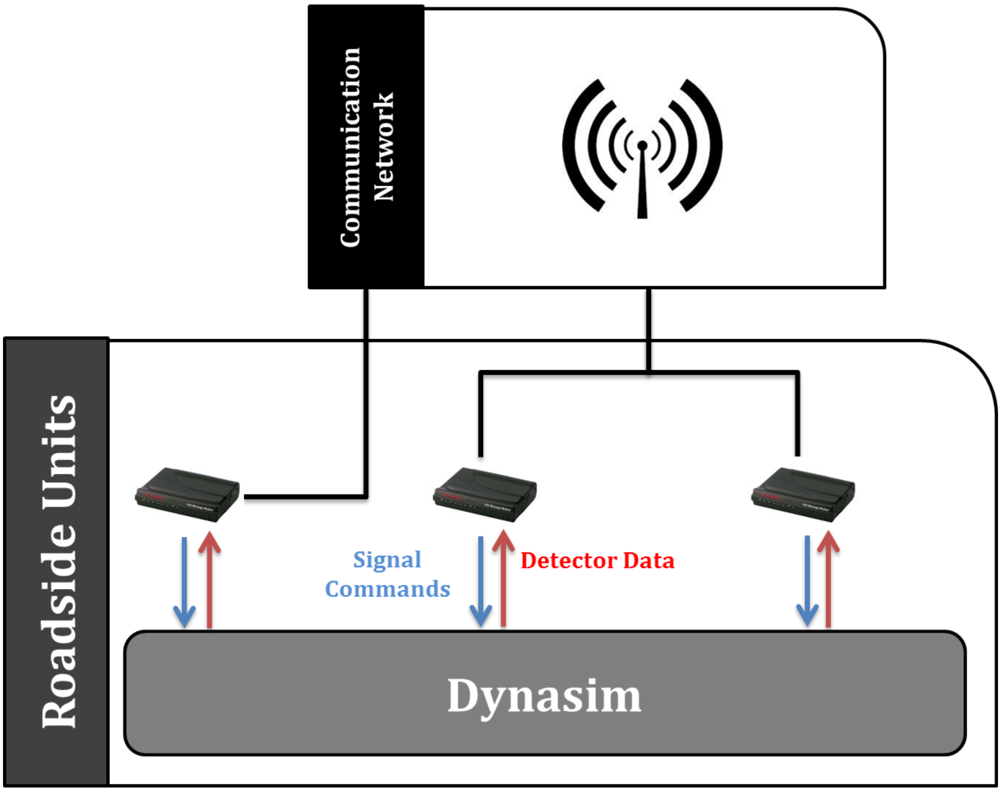


Figure 74: Communication between Spot roadside unit and controllers

[35] The Internet protocol suite is the networking model and a set of communications protocols used for the Internet and similar networks. It is commonly known as TCP/IP, because its most important protocols, the Transmission Control Protocol (TCP) and the Internet Protocol (IP) were the first networking protocols defined in this standard.

5.5.2.3. Advantage of Simulating

One of the advantages of applying Utopia as an adaptive traffic control system on cities is the ability of simulating the system. Simulations allow comparing and calibrating solutions before to implement them on street. Simulations allow evaluating travel times on all the routes, for private cars as well as for buses, and also pedestrian waiting time. Moreover the video of a simulation itself provides a visual impression of traffic control performance. Usually simulating is used for two main reasons:

- Simulations for new installations:

A new area where Utopia is proposed can be simulated, in order to calibrate Utopia and to compare the control efficiency respect to other control systems, in terms of travel time reduction.

- Simulations for road works or topology changes:

Utopia operators can simulate road changes and see effects in advance. This ability would help to have a prediction close enough to real results before applying the system, consequently would make decision making easier.

5.5.2.4. Benefits and improved results

Regarding improvements to priority, the UTOPIA concept was tested in Gothenburg and Turin. Junction waiting times for public transport improved by 52% in Gothenburg for vehicles with absolute priority, while travel times for both buses with weighted priority and private vehicles were reduced by as much as 15%. Moreover in Turin, reductions in public transport travel times as high as 14.4% were achieved. Travel times for private cars in Turin were measured in parallel with those made for public transport. An overall reduction of 17% was registered. In the following the improvements of applying of Utopia on two case studies of Gothenburg and Turin would be shown graphically:

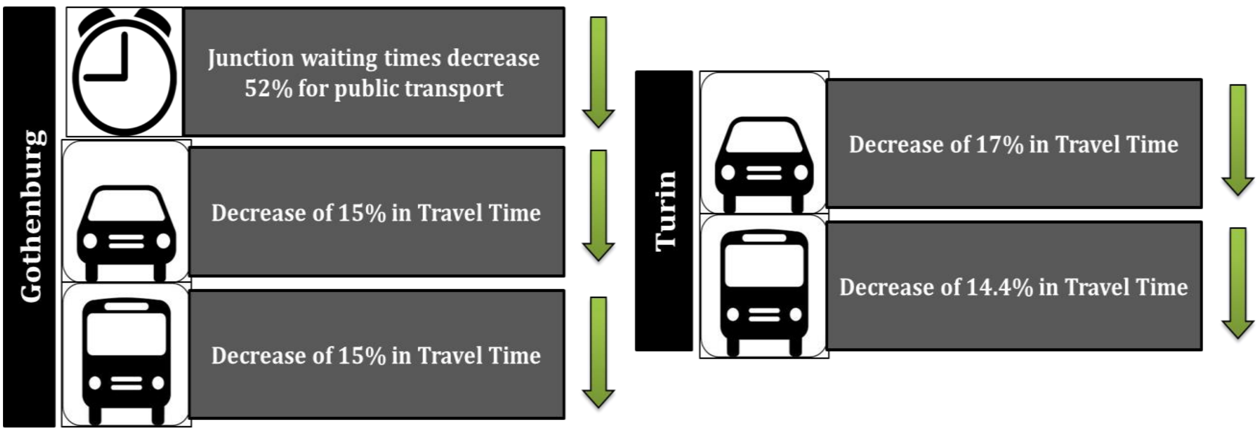


Table 36: Improved results on Gothenburg and Turin

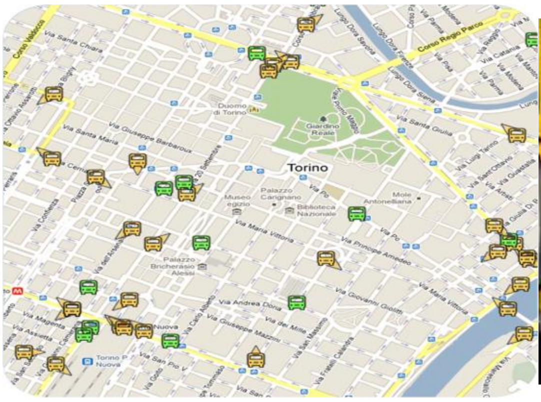
5.5.3. Access Control and Limited Traffic Area



The recent statistics of access control and limited traffic area:

- 35 limited traffic area gates
- 15,000 transits/day
- 6% average non-authorized transits

5.5.4. Public Transport Monitoring



The recent statistics of public transport monitoring:

- 1,400 urban + 300 extra-urban vehicles with real-time positioning
- 8 tram lines with priority at intersections
- 101 bus lines
- 3,300 bus stops with real-time arrival information

5.5.5. Information on the Road

The recent statistics of information on the road:

- 26 above-road VMS[36]
- 8 movable VMS
- 20 parking info VMS for 26 parking lots structures
- 18 extra-urban displays
- 36 limited traffic area displays

5.5.6. Public Transport Information Services

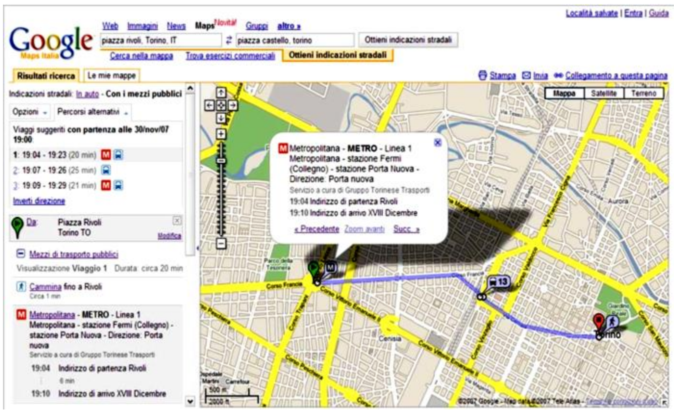
The recent statistics of public transport information services:

- Travel planning service via web or app:
  - 230,000 travel planning/month
  - over 50,000 downloads of GTT[37] Mobile app
- Bus stop arrival information: 160,000 SMS/month
- Real-time information:
  - 350 bus stop displays
  - 1,060 on-board displays

36 VMS: Variable Massage Signs

37 Gruppo Torinese Transporti, (http://gttweb.5t.torino.it/gtt/en/percorsi/percorsi-ricerca.jsp)

5.5.7. GOOGLE Transit



Since 2007 Google Transit integrates GTT public transport information provided by 5T. In June 2011 Google Live Transit was launched: a new service providing real-time public transport information. Google Live Transit is currently available in 6 towns worldwide, Torino and Madrid in Europe.

5.6. Virtues and Vices of 5T Project

5.6.1. Virtues

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

- 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, able to perform dynamic traffic-responsive regulation, are powerful tools in reducing congestion and pollution and improving convenience for the travelers;
- Demand itself must be included in generating and keeping the best equilibrium solution by allowing travelers the necessary information, made available by mobility telematics.

5.6.2. Vices

Several problems have been raised during the 5T experience:

- Longer times
- Some developments below the expectations,
- Early termination of some applications
- Two systems stopped right after the experimentation. Two subsystems (Route Guidance and Maximum Priority) and few functions (Videotel, parking payments without stopping) have been stopped.
- The main cause of delays, misunderstandings, low profile participation by some parts can be found in the incorrect interpretation of the user needs and in the under estimation of the level of agreement necessary to reach the goals.

5.6.3. Lesson to learn

The first lesson is that complex systems, like the mobility telematics ones, cannot be developed against the will of anyone of the actors. A common understanding is as necessary as the financial resources to generate integrated systems.

As anywhere, in some part of the project the interest for the technology has taken the leadership, and it has become clear that this approach can be a wasteful exercise of very little practical use for the city.

A third lesson learned in this 5T is: do not make application at too small scale, because they have a high probability to fail and to present justification to the failure in their "laboratory size"; and if they do not fail they have anyway difficulties in being kept alive; and if they are kept alive they will in any case be hardly significant.

Steering and coordinating the Consortium 5T toward its objectives has been quite a difficult experience, from which comes out that the organization to realize mobility telematics must be as simple and clear as possible avoiding the splitting of responsibility for single tasks, and conferring real decision power and effectiveness where needed.

Complex systems must be continuously monitored to understand if they fulfill their promises in terms of availability and performances. Even if this concept was stated since the beginning, a large effort has been necessary to implement it in the 5T subsystems.

Finally each system must foresee a maintenance phase after the realization a period in which the manufacturer is called to maintain systems and equipment up to their specified availability and performances levels. After such a phase somebody predefined should emerge as in charge of the maintenance and development of the system, otherwise all the efforts to develop it will be in short time wasted.

As a final remark the work done in Europe on IRTE[38] effect has cleared that mobility telematics applications are a new effective tool to generate additional transport capacity. This tool can, and must, be carefully adapted to the needs of the users and the strategies of the operators. Telematics technologies must be integrated in appropriate planning framework and used together space allocation and fares system to fit the strategies and calibrated to reach the objectives set for the mobility and the city life.[39]

[38] Integrated Road Transport Environment

[39] *P. Gentile: An Integrated Approach to Urban Traffic Management Conference on Smart CO2 Reductions, Turin, 2-3 March 2000*

5.7. Results Interpretation and Conclusion

After the tests and trials which had done and by considering the results, the 5T Project has been consolidated into a configuration capable to maintain the results achieved at reduced costs. Two subsystems (Route Guidance and Maximum Priority) and few functions (Videotel[40], parking payments without stopping) have been stopped.

The enhancement of SIS[41], the public transport operation aid system, by a new release and a further expansion of 5T in order to grant the priority and the information on the whole city tramways network can generate a sizeable decrease of the unit cost for the public transport operation together with perceivable improvements of trip time and service quality for the citizen.

In the year 2000, the expansion of the system has been proposed by a specific project presented to the Italian Ministry of Environment for financial support. The project calls for a new investment of 21 billion Lire (almost 11 million Euros) to extend UTC to 50% of the city traffic lights, install 100 more VMS. Further extension of 5T, estimated of the order of 30 billion Lire (more than 15 million Euros) will allow the expansion of the Supervisor and the Environment Control over the metropolitan area, further increase of traffic light controlled by UTC, the integration of the peripheral highway for VMS traffic routing and the development of smart card mobility payment system.

A prerequisite of all these developments, by considering financial capability a part, is the incorporation of a new 5T company. The city has started in 1999 the process of the transformation of 5T Consortium into a new body which will be in charge of the management, integration and development of the mobility telematics in the area of Turin. The new company, with the participation of ATM, AEM, FIAT CSST, and MIZAR, has been incorporated at the beginning of 2000. In 2008, 5T becomes a company totally owned by local public bodies and almost all of the developments which were predicted in the year 2000 satisfied and right now the Urban Traffic Control of this system, "Utopia", extended to 50% of the city traffic lights.

40 The videotel was, globally, the first example of a network for the dissemination of data and messaging. In the late seventies until the mid-eighties, this system was developed that allowed to transmit the information (usually text pages) to be usually displayed on the TV. (http://it.wikipedia.org/wiki/Videotel)

41 SIS; The operation aid system of ATM

In the following graph the summarization of Telematics Technologies for Transport and Traffic in Turin (5T) project benefits and improvement that cause to the city is shown:

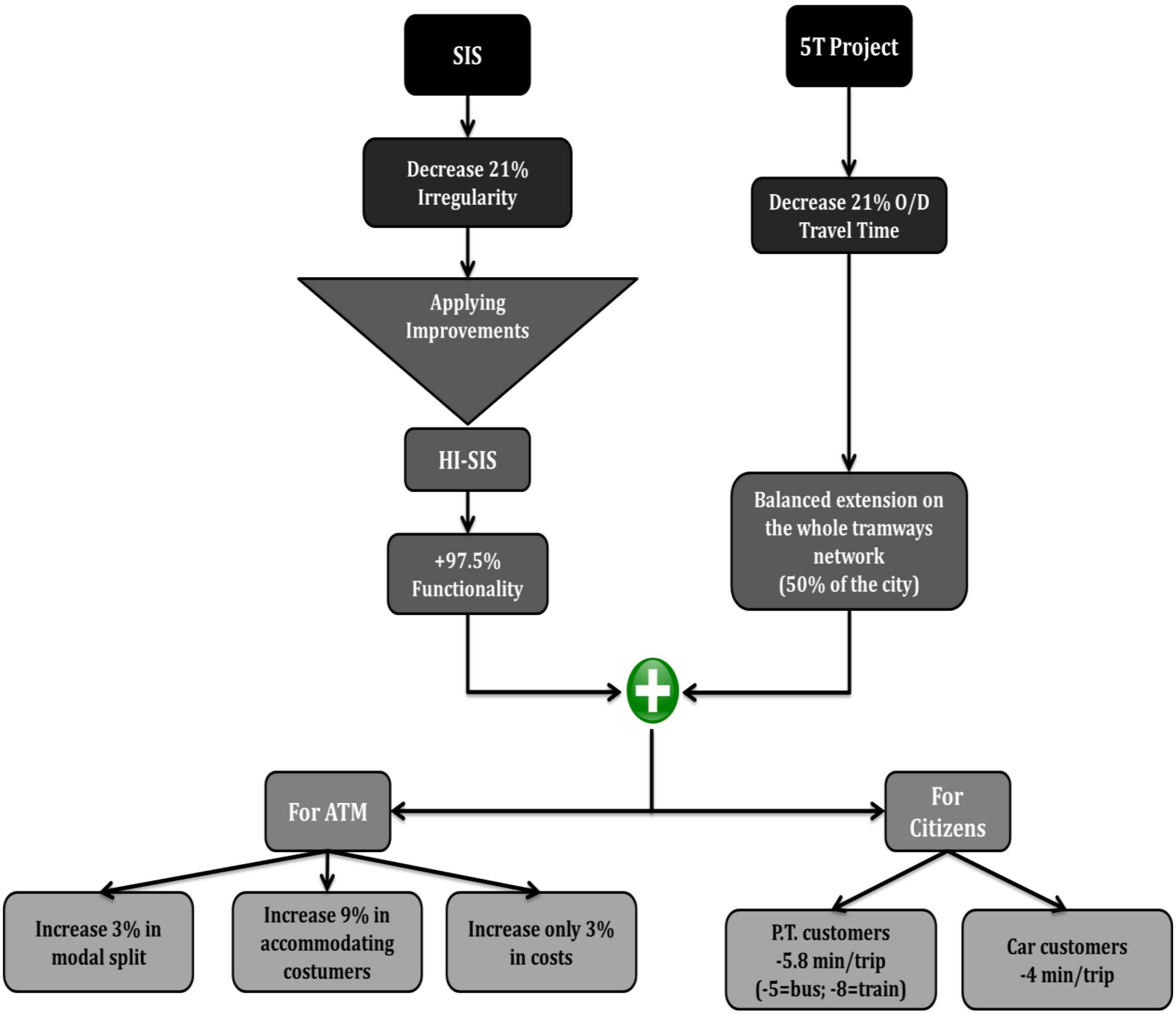


Figure 75: Summarization of 5T project benefits

5.7.1. Ongoing 5T Project in Regional Scale

5T project have been explored with an improving trend from 1992 which started as a large-scale project till now which became one reputable company which owned by local public bodies. There are two important ongoing projects for 5T in regional scale right now:

✓ The first one is developing the TOC, Traffic Operation Center, in metropolitan scale. Day by day more area of the metropolitan would go under the control of 5T project. The Regional Traffic Operation Centre is consisting of:

- Traffic monitoring and supervision
- Real-time information services
- Support to PA for transport planning

The long-term vision of this ongoing project is achieving to this result that over 33,000 km roads will be monitored, which 7,600 km of these roads would be the main roads.

✓ The second one is BIP Regional transport ticketing. Coordinating the BIP project that will introduce a single contactless ticket for the purchase of any mobility service in Piemonte.

- BIP - Biglietto Integrato Piemonte (Piemonte Integrated Ticket):
  - 100 public transport companies are involved in this project
  - 3,400 buses
  - 15,000 bus stops
  - 300 railway stations
- BIP Card integration with:
  - Pyou Card which is involving in many topics like sports, museums…
  - University smartcards
  - bike-sharing and car-sharing
  - Regional museum card

Figure 76: BIP Card Interoperability

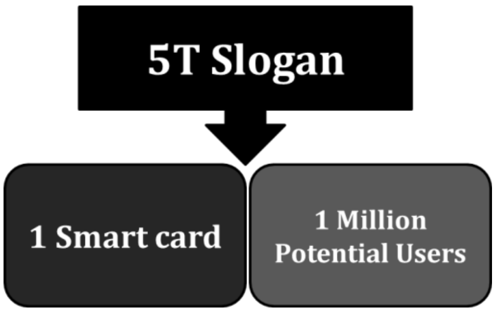


Figure 77: 5T Slogan

COMPARISON

6. Comparison between Adaptive Traffic Control Systems

In this chapter all the four adaptive traffic control systems of this study research, which are consisting of "SCATS", "SCOOT", "INSYNC", and "UTOPIA - 5T Project", would be compared. Initially a brief summary of each of them would be provided with their advantages and weak points and at the end, the main table of comparison would be revealed.

6.1. SCATS (Sydney Coordinated Adaptive Traffic System)

6.1.1. A Brief Summery

SCATS which is the acronym of The "Sydney Coordinated Adaptive Traffic System", is an intelligent transportation system and innovative computerized traffic management system. This system was developed in Sydney, Australia by former constituents of the Roads and Maritime Services in the 1970s, used in Melbourne since 1982 and Western Australia since 1983. After releasing initial proper outcomes of the system other countries also got interested in SCATS and applied it to the cities with the problem of traffic control system. Tehran, New Zealand, Shanghai, Amman, Dublin, Oakland County, Minneapolis, and Michigan are just a few examples of it.

In the SCATS method, traffic network subdivided into Regions. Each region has homogenous flow characteristics and subdivided into links and nodes. For each region, some factors should be calculated:

- Degree of saturation for all nodes
- Ratio of detected flow to saturation flow
- The most critical nodes for each region should be identified
- The highest degree of saturation which is not always the same node should be calculated

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 help to Minimize Stops(light traffic), delay (heavy traffic) and travel time By selecting the most appropriate; Cycle Length, Splits (that is the phase, or green, splits), and Links (or Offsets).

- Detects traffic volume by movement
- Converts data to flow rate
- Calculates optimal cycle length
- Calculates optimal splits by phase
- Determines phase combinations

6.1.2. SCATS Benefits and Advantages

The SCATS system can be selected for different project and cities to be applied because of the following key reasons:

- One of the benefits of this system is its small system architecture size
- The system could be customized to fit in the existing 170NEMA dual-ring[42] configuration without extensively modifying the field equipment.
- There is this possibility to use either the existing 170E or the new 16-bit 2070 could be used as the local controller. Therefore this system would be matched with previous system and do not need much cost to settle new devices.
- Although the telecommunication circuits are consisting of both hardwire[43] inter-connect and 'point-to-point' circuits, but it could be utilized with only minor modifications.
- One of the results of applying this system is increasing public Health Savings by reducing the amount of emissions because of decreasing traffic congestion.
- Improved operations for all users, especially for transit bus routes. Enhanced public transport time and reliability.
- SCATS showed great ability to handle unpredictable change of traffic volumes and patterns on special day and special times. Demonstrated the ability to provide response to traffic demand dynamically.
- It has the potential to handle the traffic patterns and volumes adequately.
- It would handle long pedestrian clearance time[44]
- Responsive to day-to-day and time-of-day fluctuations in demand
- Responds well to traffic congestion resulting from crashes, clears backups quickly
- During low volume traffic demand the traffic signal timing will adjust reducing overall delay
- Provides an effective maintenance alarm system that reduces traffic delays due to equipment malfunction
- Eliminates the need (and associated costs) for signal retiming typically performed every three to five years.

---

[42] Dual Ring typology: A network topology in which two concentric rings connect each node on a network instead of one network ring that is used in a ring topology. Typically, the secondary ring in a dual-ring topology is redundant. It is used as a backup in case the primary ring fails. In these configurations, data moves in opposite directions around the rings. Each ring is independent of the other until the primary ring fails and the two rings are connected to continue the flow of data traffic.

[43] Hardwire: Refers to elements of a program or device that cannot be changed. Originally, the term was used to describe functionality that was built into the circuitry of a device.

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

- Reduction in Collisions
- Reduced air pollution
- Reduced fuel consumption
- Reduced delays

6.1.3. SCATS Weak Points

The SCATS Philosophy is based on optimizes in real time by using many distributed computers as processors. The point is although it has libraries of offsets, phase split plans, but there is no comprehensive plan which is determinable which trustable completely. But different plans should check and be voted to be used for advanced cycles. SCATS is not model based. It relies on incremental feedbacks. Intersections can be grouped as sub-systems and by accumulation of more sub-systems it converts to a system. Consequently in the other word, there is no traffic model in SCATS, the "adaptive" process is completed by the local actual control, which limits the use of an optimization methodology.

The other point is changing the phase plans are done manually not automatically which cost time and personnel. This point can cause problem when the system want to answer to dynamic traffic demand.

Another important disadvantage of this system is that, with the stop line detection philosophy, it is impossible to provide currently feedback information about the performance of signal progression.

6.1.4. Case Study Results

Site: Oakland County 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 37: SCATS Case Study Results

6.2. SCOOT (Split Cycle Offset Optimization Technique)

6.2.1. A Brief Summery

The Transport Research Laboratory (TRL) in collaboration with UK traffic systems suppliers developed the SCOOT (Split Cycle Offset Optimization Technique) urban traffic control system. SCOOT is now co-owned by Peek Traffic Ltd, TRL Ltd and Siemens Traffic Controls Ltd. Early systems were tested in the late 1970's in Glasgow. The development of SCOOT for general use was carried out in Coventry with the first commercial system being installed in Maidstone (England) in 1980. SCOOT is now used in over 190 towns and cities in the UK and overseas.

SCOOT is a fully adaptive traffic control system which uses data from vehicle detectors and optimizes traffic signal settings to reduce vehicle delays and stops. There are a number of basic philosophies which lead to the development of SCOOT. One of these was to provide a fast response to changes in traffic conditions to enable SCOOT to respond to variations in traffic demand on a cycle-by-cycle basis. SCOOT responds rapidly to changes in traffic, but not so rapidly that it is unstable; it avoids large fluctuations in control behavior as a result of temporary changes in traffic patterns.

SCOOT not only reduces delay and congestion but also contains other traffic management facilities. For example, in 1995 a new facility was introduced to integrate active priority to buses (link with bus priority) with the common SCOOT UTC system. The system is designed to allow buses to be detected either by selective vehicle detectors or by an automatic vehicle location (AVL) system.

Many benefits are obtained from the installation of an effective Urban Traffic Control system utilizing SCOOT, both reducing congestion and maximizing efficiency which in turn is beneficial to the local environment and economy. In the other word the characteristics of SCOOT can be summarized as below:

- Customized congestion management
- Reductions in delay of over 20%
- Maximize network efficiency
- Flexible communications architecture
- Public transport priority
- Traffic management
- Incident detection
- Vehicle emissions estimation
- Comprehensive traffic information

6.2.2. SCOOT Benefits and Advantages

- **Impacts on demand**

SCOOT is in use worldwide and has been shown to give significant benefits over the best fixed time operation. The effectiveness of the SCOOT strategy has been assessed by major trials in five cities. The results from the trials are summarized in the table below.

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
Worcester	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 38: SCOOT Impacts on Demand

Comparisons of the benefits of SCOOT, against good fixed time plans, showed reductions in delays to vehicles of average 27% at Foleshill Road in Coventry - a radial network in Coventry with long link lengths. In Worcester the use of SCOOT rather than fixed time UTC showed considerable saving which was estimated to be 83,000 vehicle hours or 357,000 per annum at 1985 prices. The replacement of isolated signal control in Worcester by SCOOT was also estimated to save 180,000 vehicle hours per annum or 750,000 per annum. In Southampton, economic benefit, excluding accident and fire damage savings, amounted to approximately 140,000 per annum at 1984 prices for the Portswood/St. Denys area alone.

Research by Bell (1986) suggests that SCOOT is likely to achieve an extra 3% reduction in delay for every year that a fixed-time plan "ages". Further, the effects of incidents have been excluded from many of the survey results to ensure statistical validity. Since SCOOT is designed to adapt automatically to compensate for ageing and incident effects, it is reasonable to expect that, in many practical situations, SCOOT will achieve savings in delay of 20% or more.

In 1993 a SCOOT demonstration project in Toronto showed an average reduction in journey time of 8% and vehicle delays of 17% over the existing fixed time plans. During weekday evenings and Saturdays, vehicle delays were reduced by 21% and 34%. In unusual conditions following a baseball game, delays were reduced by 61%, demonstrating SCOOT's ability to react to unusual events. (Siemens Automotive, 1995)

- **Impacts on supply**

Field trials of bus priority using SCOOT survey were carried out in areas of Camden Town and Edgeware Road in London in 1996. The Camden network consisted of 11 nodes and 28 links. The Edgeware Road site was a linear network consisting of 8 nodes and 2 pelican crossings. The bus routes were surveyed for the periods 7:00 - 12:00 and 14:00 - 19:00. The results show that greater benefits can be obtained where there is lower saturation level. (Bretherton et al, 1996)

Efficiency		Vehicle time saving and economic benefit were very significant in both Worcester and Southampton.
Protection of the environment		Reduction in delay and stops decreases fuel consumption. In the Toronto project, there was an average reduction in fuel consumption of 5.7%, emission in hydrocarbons of 3.7% and emission in carbon monoxide of 5% over the existing fixed time plans.
Equity and Social Inclusion		The facility of priority for public transport vehicles has made the transport environment more equitable and reduced the potential for social exclusion through lack of access to car.
Safety		There are no specific safety features of SCOOT, although standard techniques to ensure such measures as sufficient inter-greens, minimum green times and no conflicting signal setting are implemented in controllers and are part of the UTC system.
Economic Growth	£ £ £ £	No analysis has been conducted.
Finance	£	Installation of SCOOT costs 20,000 to 25,000 $ per junction

Table 39: SCOOT Impacts on Supply

6.2.3. SCOOT Weak Points

Maintaining a good offset on a short link can be a problem. Because it is a short link with little storage capacity, the queue in the 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 as well on critical short links as on longer ones.

But recently the congestion offset facility has been provided to ensure good control and avoid loss of throughput on such links. In addition, users can set a fixed / biased offset on the link to permanently constrain the offset towards the desired value for congested conditions.

Another weak point of SCOOT urban traffic control system is it needs large installation base. In most of the cases there would be a problem with free space for installation.

Detectors of SCOOT:

- Detector dependent (as are all adaptive traffic control systems)
- Detector Failure, up to 15% detector failure accommodated. (Performance degrades back to a fixed time plan if faults not rectified)
- Lane detection

Scope of SCOOT:

- SCOOT adaptive traffic control system is still essentially tactical.
- It has regional boundaries.
- Unable to accommodate oversaturation.
- It is just applied to urban, (Freeway interaction is unknown for this system)

6.3. INSYNC

6.3.1. A Brief Summery

The InSync adaptive traffic control system is an intelligent transportation system that enables traffic signals to adapt to actual traffic demand. INSYNC was developed in 2005. As of March 2012, traffic agencies in 18 U.S. states have 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 field of transportation and mostly in United State 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, respectively. Mounted video cameras determine the number of vehicles present 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. InSync's dynamic phasing and dynamic green splits enable the traffic signals to use green time efficiently.

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.

6.3.2. INSYNC Benefits and Advantages

- Digitize Way of Thinking

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 appreciate what conditions will exist in the next few minutes.

This is a substantial departure from other traffic management systems. Nearly all traffic control systems today use digital hardware but remain constrained by analog thinking such as common cycle lengths, set sequences, fixed offsets and standardized allotment of green time, or splits. The InSync Processor is instead a modern state machine, meaning it can dynamically choose which phases to serve and instantly adjust and coordinate service and green time. By adapting to actual traffic demand, InSync is superior to predetermined signal timing plans that, at best, estimate traffic demand based on a small historical sampling and generalize those results across years of traffic signalization. InSync's ability to constantly see and flexibly serve actual demand in the best way possible is what enables it to produce such astounding before-and-after results.

Even the latest traffic controllers still conform to the operational concepts of analog electromechanical controllers from the early twentieth century. Modern controllers are constrained in their sequencing, green splits, offsets, cycle lengths and relative cycle lengths, all of which reduce a system's ability to serve actual traffic demand.

In contrast to this, InSync uses a digital state machine. It can flexibly adapt to actual traffic conditions based on real-time inputs and algorithmic decisions.

There is a big difference in Insync compare to SCATS and SCOOT adaptive control traffic systems that is caused by 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 actual traffic conditions. (Using standard sequences, InSync maintains all safety considerations while not being constrained by the ring-and-barrier.)

- System Integration

InSync integrates effortlessly with existing traffic operations software such as central systems, advanced traffic management systems (ATMS) and other infrastructure used to manage networks of intersections.

While central systems deliver many benefits, they also have certain limitations. Although InSync has the benefit of a central system but meanwhile by adding InSync' real-time adaptive traffic controls, increases its capabilities. With InSync's universal compatibility, integration with a central system is seamless and causes no disruptions. The two operate in parallel without interfering with each other.

- Integrated INSYNC with Centralized Center

At intersections outfitted with InSync, the local traffic controller operates in free mode. If desired, the traffic practitioner can use the central system to switch from InSync's adaptive control to a traditional timing plan; InSync then functions in detector mode to pass calls directly to the controller. The operator can reengage InSync's adaptive functionality just as easily.

InSync adds to the central system's monitoring and reporting functionality with live camera views and traffic data that can be easily accessed, exported and archived in real-time. If the central system's vehicle and system detection inputs are independently submitted for each phase, the central system can continue to monitor and report on intersection conditions and operations. Adding InSync improves centralized visibility and control rather than diminishing it.

- Save Agency Time and Resources

Most of the adaptive systems that come packaged with central systems rely on timing plans. This requires the agency to create and maintain coordinated timing plans. InSync requires no such outlay of agency resources because it does not use timing plans.

- Mitigation of the Risk Regard to Central Center

The InSync model is based on a fully distributed intelligence network. For every intersection that is enhanced with InSync, an InSync Processor is installed in the traffic cabinet for that intersection. By contrast, central system-based adaptive solutions rely on intelligence residing on a central server. If that central server or communications between the central server and intersections fail, the system is rendered useless, potentially causing chaos on the roadways and in the offices of the traffic agency and IT department. InSync's distributed design eliminates the loss of functionality caused by disruption to centralized intelligence.

- Failure Mitigation (Detection, Communication, and Hardware Failure)

InSync is designed with robust failure mitigation capabilities that allow it to control traffic even when the system experiences some form of failure. In any failure scenario, InSync attempts to send email and SMS notifications to designated staff so they are immediately alerted of potential problems. Local staff can review the situation by looking at camera views and other settings through a standard web browser, rather than having to make an emergency trip to the troubled traffic signal or the traffic management center.

6.3.3. INSYNC Weak Points

- Detector dependent:

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

- Oversaturation

The second weak point of this system is this fact that INSYNC like most of other ATCS is unable to accommodate oversaturation.

- No Central System

Another point in this regard is that, there is no Central system for this adaptive traffic control system. INSYNC cannot manage more than a limited intersection because the problem of not having the central system. They are applied for each intersection, not big system.

6.3.4. Case Studies Results

Performance measurement						
In 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 40: INSYNC Case Study Results (Reduction)

Performance Measurement			
Safety Results			
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 41: INSYNC Case Study Results (Safety)

6.4. UTOPIA – 5T Turin

6.4.1. A Brief Summery

UTOPIA (Urban Traffic Optimization by Integrated Automation) / SPOT (System for Priority and Optimization of Traffic) is designed and developed by FIAT Research Centre, ITAL TEL and MIZAR Automazione in Turin, Italy. The objective of the system is to improve both private and public transport efficiency. The system has been fully operational since 1985 on a network of about forty signalized junctions in the central area of Turin. The area also contains a tram line and control of the trams is integrated within UTOPIA/SPOT (Wood, 1993). UTOPIA/SPOT is now used in several cities in Italy and also in the Netherlands, USA, Norway, Finland and Denmark.

The system uses a hierarchical-decentralized control strategy, involving intelligent local controllers to communicate with other signal controllers as well as with a central computer. Central to the philosophy of the UTOPIA/SPOT system is the provision of priority to selected public transport vehicles at signalized junctions and improvements in mobility for private vehicles, subject to any delays necessary to accommodate priority vehicles (Wood, 1993). The French PRODYN system and the German MOTION system have some similarities to SPOT, but have not been used outside their counties (Kronborg and Davidsson, 2000).

6.4.2. UTOPIA Benefits and Advantages

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

- 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, able to perform dynamic traffic-responsive regulation, are powerful tools in reducing congestion and pollution and improving convenience for the travelers;
- Demand itself must be included in generating and keeping the best equilibrium solution by allowing travelers the necessary information, made available by mobility telematics.

- **Impacts on demand**

The improvements attributed to UTOPIA in Turin have been calculated a previous traffic responsive control strategy rather than against a fixed time system. Benefits of implementing UTOPIA were shown to give an increase in private traffic speed of 9.5% in 1985 and 15.9% in 1986, following system tuning. In peak times the speed increases were 35%. Public transport vehicles, which were given absolute priority, showed a speed increase of 19.9% in 1985 (Wood, 1993).

- **Impacts on supply**

UTOPIA/SPOT has been explicitly designed with public transport vehicle priority in mind (Wood, 1993). Buses and LRT[45] vehicles are given absolutely priority at junctions, subject to the accuracy in forecasting their arrival time. In Turin LRT are given higher priority than buses because they have more passengers but extra priority can be assigned on a vehicle by vehicle basis if required.

Efficiency		The Speed of both private and public transport was increased.
Protection of the environment		No estimation has been made, but reduction in delay and stops decreases fuel consumption and emission of pollutants.
Equity and Social Inclusion		Public Transport vehicle priority has made the transport environment more equitable.
Safety		No specific safety features of UTOPIA are known.
Economic Growth	£ £ £ £	No analysis has been conducted.
Finance	£	No evidences regarding costs, but installation and maintenance would have been significant.

Table 42: UTOPIA Impacts of Supply

45 LRT: Light Rail Transport

6.4.3. UTOPIA Weak Points

Several problems have been raised during the 5T experience:

- Longer waiting times for vehicles because of giving priority to buses and preemption.
- Some developments below the expectations,
- Early termination of some applications
- Two systems stopped right after the experimentation.
- The main cause of delays, misunderstandings, low profile participation by some parts can be found in the incorrect interpretation of the user needs and in the under estimation of the level of agreement necessary to reach the goals.

Many papers or reports on UTC systems evaluated only the impact on efficiency such as reduction in journey time, delay and stops compared with previous types of system. However, reducing travel times can increase road capacity, and increasing capacity over a significant area may cause a shift in demand towards car use and increase car traffic volume. The potential for the benefits of UTC systems to be eroded by induced traffic needs to be borne in mind. Relatively little information is available on environmental or safety benefits.

6.4.4. Case Study Results

Performance measurement					
In Terms of Reduction & Increase					
Turin (Italy)					
Survey		Travel Time	Fuel	Emissions	Commercial speed
(year)		(%)	(%)	(%)	(%)
2000	Private vehicle	-17	-8	-10	N/A
	Public transport	-14,4			17
2012	Private vehicle	-17	-10	-11	N/A
	Public transport	-20			N/A

Table 43: UTOPIA Case Study Results

6.4.5. 5T Turin Summarization

5T srl is a limited company totally owned by Local Government Bodies (Municipality of Torino, Province of Torino, Piemonte Region and GTT, the Public Transport Company of Torino). 5T srl designs, develops, implements and manages ITS solutions and Traffic information services, aimed at achieving the following goals:

- Improve traffic conditions and reduce congestions in the urban areas
- Reduce air pollution caused by traffic
- Improve quality and efficiency of the public transport service
- Provide real-time traffic and travel information services

In Torino metropolitan area, the company manages the following systems:

- Traffic Operation Centre and variable message signs panels (VMS) providing information regarding traffic conditions and parking availability in the metropolitan area.
- Urban traffic control thanks to 300 controlled intersections improving traffic conditions and providing priority green light to public transport in the city of Torino.
- Limited traffic zone (LTZ) control in the city of Torino.
- Transit control in lanes reserved for public transport in Torino.
- Video surveillance on GTT buses and at bus stops in Torino.
- Information services to citizens about travel planning, traffic conditions, travel times, arrival times of public vehicles at bus stops, free places at parking lots (www.5t.torino.it).
- Public transport information services (bus stops displays, on-board displays, SMS, voice).

5T srl also provides assistance and support for the following systems:

- Fleet management of GTT public transport vehicles.
- Speed excess control systems of Torino Local Police.

At a regional level, 5T srl is developing:

- The extension of the Traffic Operation Centre (TOC) for traffic monitoring and supervision on the whole Piemonte.
- The Regional Electronic Ticketing System (BIP Project), aiming to seamless integrate in a unique contactless smartcard the entire mobility network in Piemonte.

6.5. Differences between Fixed-Time Plan and Adaptive Control System

Many traffic control systems manage the signals on a fixed-time basis, where a series of signal timing plans are scheduled by day of week and time of day. The time relationship between signals is pre-calculated; based on previously surveyed traffic conditions. Such fixed-time systems cannot be expected to cope with traffic conditions that differ from those prevailing when the intersection was surveyed.

Furthermore, as traffic patterns change with the passage of time, fixed time plans become outdated. This requires the area to be resurveyed, and new signal timing plans calculated every few years. Experience has shown this procedure to be expensive, and to require 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 the plans and timetables; either case results in 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 SCATS 6 Fixed Time Plan system. This is a great improvement on other fixed time systems because it has the benefit of improved decision making capabilities built-in.

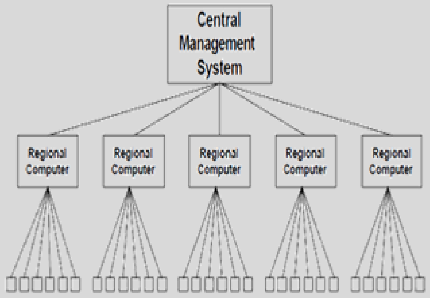
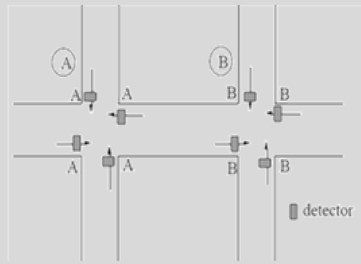
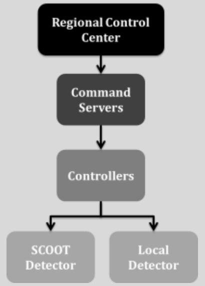
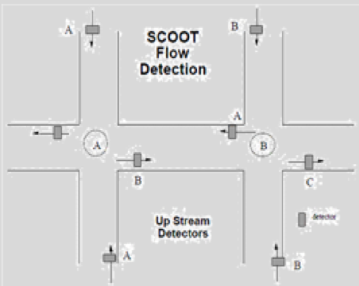
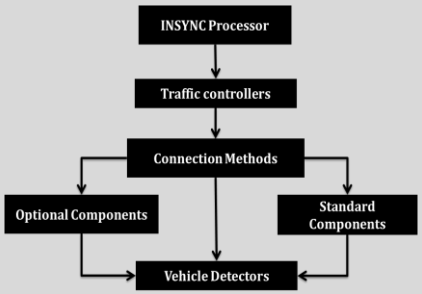
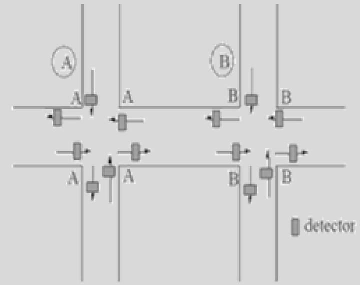
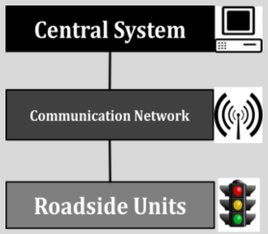
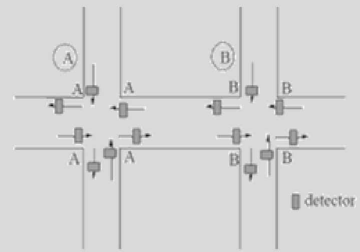
The implementation of a fully responsive system does not, however, mean that the careful design of each intersection can be avoided. The present state of technology only allows for the real-time variation of signal timings at intersections which have known or anticipated traffic requirements.

TRANSYT, developed by TRL, is probably the best known example. TRANSYT can be used to compile a series of fixed time signal plans for different times of day or for special recurring traffic conditions.

In the following comprehensive comparison tables between these mentions adaptive traffic control systems would be brought:

Table 44: Comparison tables between four ATCS

ATCS	Age of Birth	Initially Designed to	Place of First Implementation	Number of Intersections	Number of Cities	Number of Countries	Developed by	Funded by
SCATS	1970s . It has been used in Melbourne since 1982 and Western Australia since 1983	Faced with the need to implement a large area traffic control system in Sydney and the problems of "fixed-time" systems.	Sydney (Australia)	More than 36,000	263	27	Former constituents of the Roads and Maritime Services	The NSW (New South Wales) Department of Main Roads (now it becomes Roads and Maritime Services)
SCOOT	**1975** research version Glasgow (Scotland) **1979** 1st installation Coventry (England) **1991** version 2.4 released First US installation	It was originally designed to control dense urban networks, such as large towns and cities at first, but It is also successful in small networks, especially for areas where traffic patterns are unpredictable.	Glasgow, Scotland, (United Kingdom)	More than 40,000	200	14	TRL (Transport Research Laboratory) in collaboration with UK traffic systems suppliers	Department for Transport (DfT) and the SCOOT suppliers
INSYNC	2005	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 appreciate what conditions will exist in the next few minutes.	United State of America	More than 900	75	18 U.S States	Rhythm Engineering Company	Rhythm Engineering Company
UTOPIA (5T Turin)	5T Project (1992) UTOPIA (1985)	Develops ITS solutions to improve individual and collective mobility on a regional scale. Reducing environmental pollution caused by traffic. Improving efficiency and quality of public transport. Providing real-time information services to travelers. Development of a strategic supervisory system for all Transport Telematics sub-systems.	Turin, Italy	In Turin 330 out of 600 Intersections	More than 30	More than 12	FIAT Research Centre, ITALTEL and MIZAR Automazione	Municipality of Torino, Province of Torino, Piemonte Region and GTT, the Public Transport Company of Torino

ATCS	Configuration	Architecture	Detectors	Detector Architecture	Model Optimizer
SCATS	• Detects traffic volume by movement • Converts data to flow rate • Calculates optimal cycle length • Calculates optimal splitsand offset by phase • Determines phase combinations • Checks timing alteration thresholds • Sets up implementation		The major detector in the SCATS adaptive traffic control system is "Inductive Loops". Controller collects number of spaces and total space time during green of each cycle. The detectors are installed at the downstream of the intersections.		....
SCOOT	The data from the model is then used by SCOOT in three optimizers which are continuously adapting three key traffic control parameters - the amount of green for each approach (Split), the time between adjacent signals (Offset) and the time allowed for all approaches to a signaled intersection (Cycle time).		Detectors are normally required on every link. They are usually positioned at the upstream end of the approach link. inductive loops are normally used. Detectors are positioned where they will detect queues that are in danger of blocking upstream junctions and causing congestion to spread through the network.		Cycle Optimizer Split Optimizer Offset Optimizer
INSYNC	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, respectively. Mounted video cameras determine the number of vehicles present and how long the vehicles have been waiting (delay).		Three different detector options. Depends on the vulnerability of the intersection and the level of the exposure of the area, operating agents should make a comparison between “InSync”, “InSync Tesla” and “InSync Fusion” to see which is the right solution for the concerned traffic. Detectors are installed both Upstream and Downstream of junction.		Digitize Signal Operation Local Optimizer Global Optimizer
UTOPIA (5T Turin)	UTOPIA has a hierarchical and distributed architecture. This architecture is consisting 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. The architecture is consisting of three system components: Central system, Communication Network, and Roadside Units.		This part is equipped by industrial computers which are running the “SPOT” software, intersection by intersection to control the traffic, calculating the demand and etc. - Public transport priority - Local level diagnostic. Detectors are installed both Upstream and Downstream of junction.		....

ATCS	Local Controllers	Connectors and Cables	Software	Additional software	History (Problems Before Applying this System)
SCATS	Operate under the strategic umbrella, Keep local flexibility to meet cyclic variation in demand at each intersection, and Base on detector information. • 170 E Controllers Thru Interface Card • 2070s Thru Controller Software • Adaptive Traffic Control Controllers	• Point-to-Point or Multi-drop. • Once per second communication with each intersection. • Messages are normally 1 to 5 bytes, average 3 bytes. • Optional digital communications port (RS232) for direct network connection. • Requires 300 Baud Full duplex channel with addressing/routing by network.	Central software Regional software	....	Problems of Fixed-Time Plans
SCOOT	Use existing controller Controller firmware upgrades (EPAC) Addition of dedicated command unit Replace Controller EPAC 2070. 2070L. 2070N	Leased line, copper cable, fiber optic, or combinations	The Kernel and TRANSYT	the "knitting" or UTC software	VA, vehicle Actuation, none coordinated. Fix Time Plan
INSYNC	Use existing controller Video processing for up to 5 networked InSync cameras 330s-STYLE NEMA-STYLE	Detector card Spade cable C1 Y-Cable ABC Y-Cable	CentralSync Software (Windows-Based)	The WEBUI (Web User Interface)	Fix Time Plan
UTOPIA (5T Turin)	Spot runs normally on industrial pc, Linux environment, but it is also available for tests running on Windows. All the communications are TCP/IP , allowing physical network independence. Dynasim supports Utopia protocol and connects to the Spot units as it was a set of controllers. This is a TCP/IP socket communication; allow running on different Windows machines, if necessary. Everything can run on a Windows pc, up to 10 intersections.	In order to operate properly, the Roadside Unit needs data from the Central System and data from the adjacent Roadside units. On the other hand, each Roadside Unit locally data (traffic volume and planned control strategy) must be distributed to the adjacent Roadside Unit and to the Control Center.Communication can also take place between the software "SPOT", which is used in Roadside Unit, and the controllers which are installed at the intersections.	SPOT Software	Dynasim, GTT (Web User of public transport information), GOOGLE transit	The improvements attributed to UTOPIA in Turin have been calculated a previous traffic responsive control strategy rather than against a fixed time system.

ATCS	Model Based	Trend of Distribution (Grow rate)	Additional Traffic Management Fascilities	Benefits	Weak Points
SCATS	SCATS is not "model-based". It relies on incremental feedbacks. is although it has libraries of offsets, phase split plans, but there is no comprehensive plan which is determinable which trustable completely. But different plans should check and be voted to be used for advanced cycles.	Constant - Increasing slowly	Five priority inputs are provided, one railroad and four vehicles. Vehicle priority inputs accept steady or pulsed signal for different preemption display. Preemption display (signal groups), ending overlaps and return stage can be selected. Preemption is a function of the controller, SCATS knows preemption is active. SCATS Route Preemption Control (RPC) System provides automatic emergency route control from a single input (e.g. fire station pushbutton).	• Demonstrated the ability to provide response to traffic demand dynamically. • Can handle long pedestrian clearance time . • Responsive to day-to-day and time-of-day fluctuations in demand. • Responds well to traffic congestion resulting from crashes, clears backups quickly. • During low volume traffic demand the traffic signal timing will adjust reducing overall delay • Provides an effective maintenance alarm system that reduces traffic delays due to equipment malfunction. • Enhanced public transport time and reliability. • Reduced fuel consumption. • Reduced air pollution. • Reduced delays.	• With the stop-line detection philosophy, it is impossible to provide currently feedback information about the performance of signal progression. • There is no traffic model in SCATS, the "adaptive" process is completed by the local actual control, which limits the use of an optimization methodology. Consequently each plan should be checked to get vote. • Detector Dependent
SCOOT	SCOOT is a "model-Based" urban adaptive traffic control system which uses TRANSYT software to compile a series of fixed time signal plans for different times of day or for special recurring traffic condition. This system need an online computer which continuously monitored traffic flows over the whole network, and fed the flows into an online model "the Kernel software" and used the output from the model as the input to its signal timing optimizers.	Increasing gently	• Bus priority (Active and Passive priority by applying phase extension, Recall, or stage skipping) • Gating techniques. • Pedestrian facilities (Puffin and Pelican crossing). • Special Events	• Installation advantages (Installation in SCOOT needs minimal local knowledge, It does not require intimate knowledge of the network, Day by day it is becoming more self-validating). • Flexible and controllable (Double cycling, Plan weighting factors, Operates with most types of controller). • The SCOOT Personality (Not as highly personnel dependent as some other adaptive traffic control systems. Non hysterical, it copes with large flow change gently. Sophisticated, it has so many facilities and options which make it outstanding system). • Coping with unpredictable variations, Complex flow patterns, and Heavy flows close to saturation).	• It needs large installation base. • Detector dependent. Detector Failure, up to 15% detector failure accommodated. (Performance degrades back to a fixed time plan if faults not rectified). • Lane detection. • Unable to accommodate oversaturation. • It has regional boundaries. It is just applied to urban, (Freeway interaction is unknown for this system).
INSYNC	INSYNC is not "Model-Based" Adaptive Traffic Control System	Highly Increasing	• System integration with centralized control, • Arterial Corridors, • Intersecting arterial, • freeway interchange, • Saturation, • and Special Events	• Digitize Way of Thinking • System Integration • Integrated INSYNC with Centralized Center • Save Agency Time and Resources • Mitigation of the Risk Regard to Central Center • Failure Mitigation (Detection, Communication, and Hardware Failure)	• Detector dependent. • Unable to accommodate oversaturation. • There is no Central system for this adaptive traffic control system. Cannot manage more than a limited intersection because the problem of not having the central system. They are applied for each intersection, not big system.
UTOPIA (5T Turin)	INSYNC is not "Model-Based" Adaptive Traffic Control System	Highly Increasing	• The City Supervisor • The Public Transport Management • The Environment Monitoring and Control • The Parking Control and Management • The Variable Message Signs • The Information Media Control • The Fares and debiting • The Maximum Priority (Preemption)	• Develops and manages ITS solutions improving individual and collective mobility on a regional scale. • Improve traffic flows and safety. • Reducing environmental pollution caused by traffic. • Improving efficiency and quality of public transport. • Providing real-time information services to travelers. • Development of a strategic supervisory system for all Transport Telematics sub-systems. • Ability of simulating the system. Simulations allow comparing and calibrating solutions before to implement them on street. Simulations allow evaluating travel times on all the routes, for private cars as well as for buses, and also pedestrian waiting time. • The shift of mobility toward public transport. • Telematics management systems, able to perform dynamic traffic-responsive regulation.	• Longer waiting times for vehicles because of giving priority to buses and preemption. • Some developments below the expectations, • Early termination of some applications • Two systems stopped right after the experimentation. • The main cause of delays, misunderstandings, low profile participation by some parts can be found in the incorrect interpretation of the user needs and in the under estimation of the level of agreement necessary to reach the goals. • Detector Dependent

ATCS	Mostly Applied to	Applied to	Case Studies	Installation (Cost)	Differences Regard to Other ATCS	Additional Comments
SCATS	Australia	Tehran, New Zealand, Shanghai, Amman, Dublin, Rzeszów, Hong Kong, Gdynia, Oakland County, Minneapolis, and Michigan .	• Minneapolis (MN), • Oakland Country (MI), • and Arlington County (VA),	SCATS Installation Cost Ranges for 64 Intersection System: • Central Hardware approx. $ 30,000 • Central Software approx. $40K to $70K • Regional Hardware approx $20K • Regional Software approx $70K • Local Controllers approx. $3.5K to 5.5K • Communication Network - Included above • Detection Sensors approx. $230K	The SCATS Philosophy is based on optimizes in real time by using many distributed computers as processors. The point is although it has libraries of offsets, phase split plans, but there is no comprehensive plan which is determinable which trustable completely. But different plans should check and be voted to be used for advanced cycles. SCATS is not model based. It relies on incremental feedbacks. Another difference of this ATCS regards to modern adaptive conrtol system is the "Analogue" way of thinking.	SCATS gathers data on traffic flows in real-time at each intersection. Data is fed via the traffic controller to a central computer. The computer makes incremental adjustments to traffic signal timings based on minute by minute changes in traffic flow at each intersection. This adaptive traffic control system help to Minimize Stops(light traffic), delay (heavy traffic) and travel time By selecting the most appropriate; Cycle Length, Splits (that is the phase, or green, splits), and Links (or Offsets).
SCOOT	United Kingdom	United Kingdom 70+ locations (London to Aberdeen), Heathrow Airport Worldwide Bahrain, Beijing, Dalian, Cape Town,Karachi(Pakistan), Larnaca(Cyprus), Limassol(Cyprus), Madrid, Sao Paulo - Rio Branco, Nicosia, Santiago, Dubai North America Oxnard, Toronto, Red Deer, Minnesota,San Diego,Anaheim, Alexandria,Arlington VA, Orlando FL.	• SAO PAULO • NIJMEGEN • TORONTO • BEIJING • WORCESTER • LONDON • SOUTHAMPTON • COVENTRY	20,000 to 25,000 ($) per junction	One of the differences is having the optimizers. The operation of the optimizers provides the necessary combination of responsiveness to traffic fluctuations and the stability to maintain coordination. The split optimizer optimizes every stage change, the offset is optimized each signal cycle for every node and the cycle time for each region is optimized once every five minutes or once every two and a half minutes when required to respond to rapid flow changes. Another difference is that this system in "Model-Based".	The split optimizer optimizes every stage change, the offset is optimized each signal cycle for every node and the cycle time for each region is optimized once every five minutes or once every two and a half minutes when required to respond to rapid flow changes. SCOOT signal timings evolve as the traffic situation changes without any of the harmful disruption caused by changing fixed time plans on more traditional urban traffic control systems. By the combination of relatively small changes to traffic signal timings, SCOOT responds to short term local peaks in traffic demand, as well as following trends over time and maintaining constant coordination of the signal
INSYNC	United State of America	Arizona, Arkansas, California, Colorado, Florida, Georgia, Illinois, Iowa, Kansas, Kentucky, Michigan, Missouri, New Jersey, New Mexico, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Vermont, Virginia, West Virginia, and Wisconsin	• Lee's Summit, Missouri • Columbia, MO • Evan, GA • Grapevine, TX • Salinas, CA • San Ramon, CA • Springdale, AR • Topeka, KS • Wichita, KS • Upper Merion, PA	Average 20,000 to 27,000 (US $) per junction	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 appreciate what conditions will exist in the next few minutes. This is a substantial departure from other traffic management systems. Nearly all traffic control systems today use digital hardware but remain constrained by analog thinking such as common cycle lengths, set sequences, fixed offsets and standardized allotment of green time, or splits. The InSync Processor is instead a modern state machine, meaning it can dynamically choose which phases to serve and instantly adjust and coordinate service and green time. By adapting to actual traffic demand, InSync is superior to predetermined signal timing plans that estimate traffic demand based on a small historical sampling and generalize those results across years of traffic signalization.	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. InSync's dynamic phasing and dynamic green splits enable the traffic signals to use green time efficiently. 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.
UTOPIA (5T Turin)	Turin (Italy)	• Sweden (Goteborg, Uppsala) • Norway (Oslo, Trondheim) • Denmark (Copenhagen, Aalborg) • The Netherlands (Eindhoven, Den Haag, Den Bosch, Helmond, Rhenen) • Belgium (Brussels) • Poland (Lodz, Gdansk, Malbork) • Romania (Bucharest) • Ukraine (Kiev) • Russia (Moscow, Kazan) • Ireland (Galway) • Italy (Roma, Milano, Torino, Bologna, La Spezia, Bergamo, Verona, udine, Trento, Cremona)	• Turin (Italy)	....	One of the advantages of applying Utopia as an adaptive traffic control system on cities is the ability of simulating the system. Simulations allow comparing and calibrating solutions before to implement them on street (Simulation for new installations, and simulation for road works or topology changes).	Most of the Urban Traffic Control systems are based on similar factors. The basic principle of UTOPIA is to perform a real-time optimization of the signal settings in order to minimize the total socio-economic cost of the traffic system, in terms of the avoidance of congestion and decrease the amount of emissions, and the reduction of travel time both for private traffic and for priority vehicles. . UTOPIA is taking advantage of having City Supervisor to assist for making decision in strategic circumstances .

7 CONCLUSION

7. Conclusion

In this thesis four different adaptive traffic control system have been studied. Each of them has unique characteristics which make them worthy to compare. By making comparison tables which were provided in the chapter six, all the aspects and feathers of these systems were studied. In the following by provided tables the functionality of each of these systems are discussed. And in few words if want to explain functionally it would be:

- ✓ SCATS: is a traffic control system which can cover one big metropolitan. The architecture is consisting of central, regional, and local computers. The installation cost is between "7500" to "12000" euro per intersection. The expected reduction in travel time would be averagely between "15%" to "30%".
- ✓ SCOOT: is optimized version of SCATS which is some steps ahead. It can cover just urban area, not freeway interchanges. The installation cost is between "15000" to "19000" euro per intersection. The architecture is the same as SCATS but without central computers. The expected reduction in travel time would be averagely between "10%" to "25%".
- ✓ INSYNC: is a plug and play system, which would locally add to the existing traffic control system to improve the network or separately as one traffic control system. There is not central monitoring for this system so it can apply just local by local. The installation cost is between "15000" to "22000" euro per intersection. The expected reduction in travel time would be averagely between "20%" to "40%".
- ✓ UTOPIA: is a traffic control system which can cover one big metropolitan. The architecture is consisting of central and local computers. The installation cost is between "15000" to "18000" euro per intersection. The expected reduction in travel time would be averagely between "10%" to "25%".

ATCS	N. of countries	N. of cities	N. of Intersections	Mostly applied to	Instalation costs per intersection Euro (£)
SCATS	27	263	More than 36000	Sydney (Australia)	7500 - 12000
SCOOT	14	200	More than 40000	Glasgow(UK)	15000 - 19000
INSYNC	18	75	More than 900	USA	15000 - 22000
UTOPIA	12	30	330 (Turin)	Turin (Italy)	15000 - 18000

Table 45: Conclusion table 1

ATCS	Architecture	Detectors
SCATS	Central management system - Regional computer - Local computer	Downstream
SCOOT	Regional central center - Command server - Local controller	Upstream
INSYNC	Local controllers with central processor - Detector	Downstream + Upstream
UTOPIA	Central system - Roadside unit	Downstream + Upstream

Table 46: Conclusion Table 2

ATCS	Applying Strategic Supervisor	Central System	Just Urban Cotrolling System (Regional Boundaries)	Large Installation Base	Unable to Accommodate oversaturation
SCATS		✓		✓	
SCOOT	✓		✓	✓	✓
INSYNC					
UTOPIA	✓	✓			

Table 47: Conclusion Table 3

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	-	-	-	-

Table 48: Conclusion Table 4

This research would be an appropriate database for government and authorities of countries which deal with traffic problems, high pollution and emission level, and high fuel consumption. By the comparisons tables which presented in the last chapters, authorities can make a reasonable decision to choose an appropriate adaptive traffic control system which fit best with the demands of the city and apply, to improve their intercity networks.


DSS

8. Proposal for New ATCS Decision Support System

8.1. DSS Definition

A Decision Support System (DSS) is a computer-based information system that supports business or organizational decision-making activities. DSSs serve the management, operations, and planning levels of an organization and help to make decisions, which may be rapidly changing and not easily specified in advance. Decision support systems can be either fully computerized, human or a combination of both.

DSSs include knowledge-based systems. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, and personal knowledge, or business models to identify and solve problems and make decisions

8.2. Existing DSS in regards to Transportation management

Road traffic management has long been a complex issue and seems likely to continue to be so. Road traffic laws and policies depend on a large number of factors. Making a correct decision for traffic management can be difficult because decision-makers need to analyze and absorb a large quantity of information. This information can be vague and sometime conflicting in nature. Therefore, there is a need for a better control and a reliable and consistent system to help simplify the traffic decision making process. By incorporating the variables involved in traffic management such as the numbers of accidents, traffic violations, and traffic policemen on duty into an artificial intelligence technique, it is possible to build a traffic decision making system to help decision makers for analysis of traffic laws and policies.

The other responsibility of the traffic manager is development and implementation of automated transportation decision support models for the scheduling and routing of cargo and passenger movements internationally. The decision support models can be used for planning operations or scheduling actual movements.

Applying a comprehensive decision support system in traffic and transportation management can be categorized in many branches. For instance members in charge can represent a DSS in the field of intelligent transport system, adaptive traffic control system, and many other subjects which related to transportation management.

In the following one of the existing decision support system which is used in Europe scale is going to be introduced.

8.2.1. 2DECIDE ITS Toolkit

The 2DECIDE ITS Toolkit aims to provide a single point of access to European ITS experience. It is a decision-support tool to assist transport organizations in the selection and deployment of Intelligent Transport Systems to help them solved traffic transport problems and to address policy objectives.

The Toolkit builds on an extensive knowledge base of expert opinion on a wide range of ITS services, case studies and evaluation reports to outline the ITS measures and likely impacts for these measures relevant to user needs giving an insight into ITS deployments in Europe.

The ITS Toolkit is a starting point for establishing a central point to access ITS evaluation in Europe and shall further grow in content and quality of information and be continuously improved over the coming years.

- Why

The ITS Toolkit has its roots in the European ITS Action Plan, adopted in December 2008, which provided a policy framework to guide the development and deployment of Intelligent Transport Systems (ITS) for road transport, including interfaces with other transport modes. One of the measures proposed under Action Area 6 of this plan – "European ITS cooperation and coordination" – was the creation of an online decision support system aimed principally at helping public authorities, infrastructure operators and transport providers make more effective and informed decisions on investing in ITS to solve transport problems and meet policy objectives. This policy goal was realized by the 2DECIDE project, funded under the EU's Seventh Framework Program for Research and Development (FP7), which has created this ITS Toolkit.

This two-year project collected and assessed existing evaluation results from local, national and EU-wide ITS deployment activities, as well as good practice case studies. Secondly the actual ITS Toolkit and its underlying search and match mechanisms were developed. The ITS Toolkit is a starting point for establishing a central point of access for ITS evaluation in Europe and shall further grow in content and quality of information and be continuously improved over the coming years.

- What

The ITS Toolkit aims to help its users to find and learn about suitable ITS service applications and technologies for a given situation and context. The ITS Toolkit contains a general description of each ITS service, functionality and technology to outline the typical requirements for each ITS solution. Besides the matching of context, e.g. road type, geographical extent and/or problems and goals, the ITS Toolkit aims to provide likely values of impacts experienced in comparable conditions. At the end of each user request the actual evaluation reports of relevant studies (if freely available) are part of the output of the ITS Toolkit, giving user the possibility to study the experiences of others in greater depth.

In the first stage of the ITS Toolkit a basic set of information on ITS solutions for road and public transport modes has been included. The content of the toolkit – the actual evaluation reports – have been collected from a range of European projects, actual deployments at national and local level, and from other sources like journals. The content of the studies are in some cases not available for free to the public. In these cases the ITS Toolkit contains a summary and the link to the source.

The ITS Toolkit aims at a wide audience involved in all areas of transport planning and operation as well as related areas such as environmental issues, safety, security, accessibility, etc. Therefore it is aimed not only at ITS experts but also at those with little or no knowledge of ITS.

- How

The ITS Toolkit aims to provide a single point of access to European ITS experience and its user interfaces are therefore available in four languages (English, French, German and Italian). The ITS Services and technologies have been grouped into a classification system similar to well established international classification schemes.

In technical terms the ITS Toolkit consists of the "knowledge base" – a database where all information about ITS services and the actual evaluation reports are stored. The knowledge base is assessed by the inference engine which matches the user input (context, problem/goal, ITS service) with the data stored in the knowledge base through an advanced search mechanism and an inference algorithm. The two elements of the inference engine allow to not only identify ITS services (and their descriptions) which are relevant to the user's query, but also give an indication of the impacts – expressed as values or grades – that can be expected in the specified context. In addition, the ITS Toolkit contains information on feasibility aspects (technical, legal organizational) and the experienced user acceptance. Except for the general parts of the ITS Toolkit's output, all information has been extracted from the existing evaluation reports.

The evaluation reports digested in the ITS Toolkit have been carefully selected under aspects of quality and the coverage of all aspects of road and public transport. In this sense the ITS Toolkit gives an insight into the past and current evaluation practices throughout Europe. The usability of the ITS Toolkit is enhanced with the creation of a user profile. This allows users to choose and remember their preferred language, store past queries, export the toolkit's output and submit their own evaluation reports.

In the following one example of this ITS toolkit is depicted; the ITS Toolkit aims to help you find and learn about suitable ITS service applications and deployments for a given situation and context.

The procedure would be started by choosing one or more search criteria from the lists below. In some cases, you can select multiple levels of detail.

Fields that must be selected are both Geographical Coverage and Area of Transport. In addition, one of the following needs to be selected:

- ITS Service or
- A Problem or
- An Objective.

The Toolkit will return the following information

Step 1: Data entry for user input

Step 2: ITS services ranked by relevance to the criteria provide

Step 3: Information on selected ITS services and case studies

Step 4: Information on selected studies

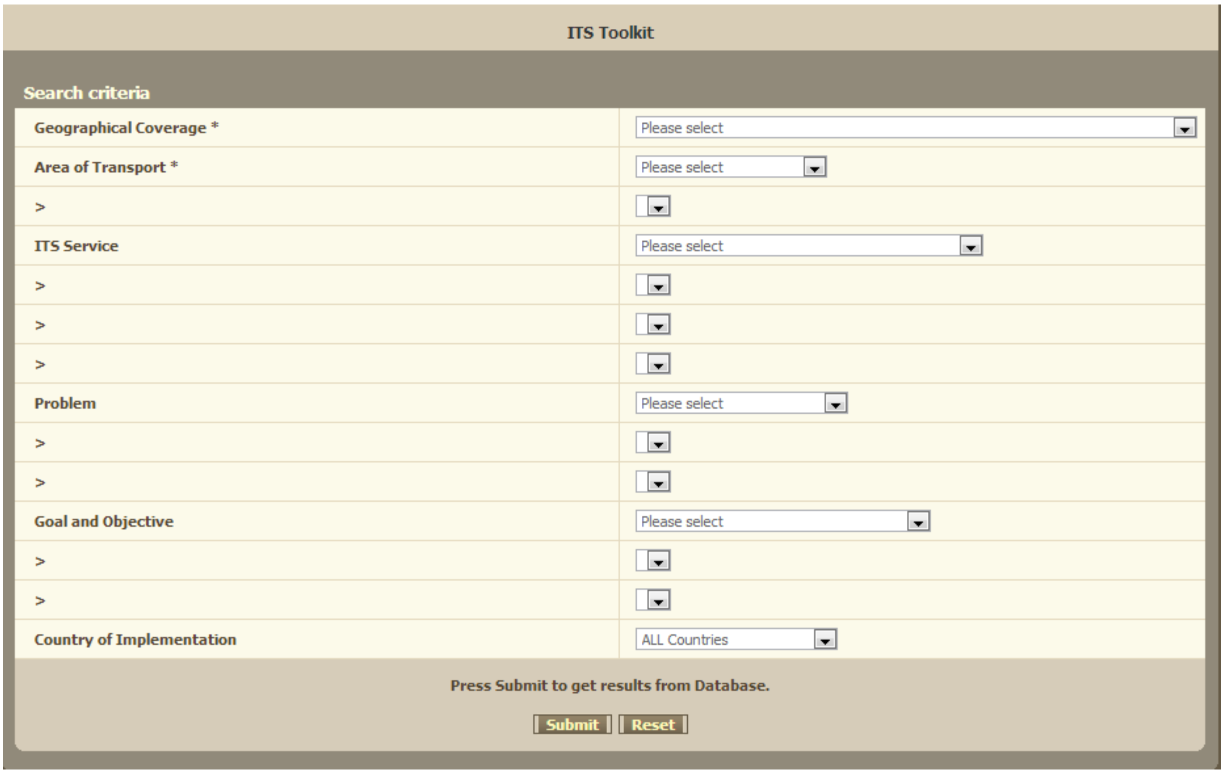


Figure 78: 2DECIDE ITS Toolkit

8.3. Proposal for New DSS in the Regards to ATCS

In this chapter new decision support system is going to be proposed in the regards to choosing possible adaptive traffic control system which more relate to the demands and more fits with the existing site problem. This decision system would be helpful to the governments and authorities that by giving some criteria in different levels as an input, to find out about the possibilities of different adaptive traffic control systems which fit more to their cases.

The procedure would be started by choosing one or more search criteria from the lists below. In some cases, multiple levels of detail can be selected.

Fields that must be selected are both Geographical Coverage and Area of Transport. In addition, initial problem, architecture, type of the detectors, model-based, installation cost, goals and objectives, and some other detailed criteria also should be chosen.

In the following the related decision support system would be simulated as a toolkit webpage. When users, who are in this case government and authorities that want to choose most related adaptive traffic control system to apply to their regions, achieve to this website, by selecting some criteria as an input, can get appropriate results. As a matter of fact the website would be very applicable because of being user friendly for the users.

The outcome and results of the toolkit would be ATC system ranked by relevance to the criteria provide. Besides ranking of ATCS, the users would find also the relevance case studies and the statistics in regards to the improvement and efficiency of the systems after getting applied.

In the following the simulation of this DSS would be depicted. This simulation webpage is consists of four steps which are brought here respectively.

This new toolkit will return the following information;

- ✓ *Step1:* Data entry for user input; Geographical coverage, area of transport, country of implementation, existing traffic control system, architecture, and the problem.

ATCS Toolkit	
STEP 1	
Search criteria	**Detailed option**
Geographical Coverage	Please select
	District Scale
	Metropolitan Scale
	Regional (Intra-urban)
Type of Transport	Please select
	Public Transport
	Road Transport
Country of Implementation	Please select
	Asia
	Europe
	USA
	Australia
	United Kingdom
Existing traffic control system	Please select
	Fixed-time plan
	Previous ATCS method
Architecture	Please select
	Central management system - Regional computer - Local computer
	Regional central center - Command server - Local controller
	Local controllers with central processor - Detector
	Central system - Roadside unit
Problem	Please select
	Accident
	Congestion
	Noise and air pollution
	Parking issues
	Traveller transport servise

Figure 79: ATCS Toolkit, STEP 1

In the STEP 1, each of the search criteria should be filled, by selecting one of the detailed options next to them. This is how DSS works. Taking input from users to limit its database step by step to achieve to final results which catch more with the users demand.

Geographical coverage would be categories to the three scales. This is one of the most important factors. Because one of the major factors that makes difference between ATCS is the scale of the implementation zone, and how much they can cover. Another important criterion is the existing traffic control system on the field. In the other hand, since the architecture of the systems are different, it is really necessary for the government to know about their problem to choose the correct and appropriate system model and architecture for their demand. The last but not the least is choosing your problem on the network that would need to be solved.

- ✓ *Step2:* Other search criteria would be gathered by the webpage but these data are more in detail. Knowing about type of the detectors is one of the detailed factors. This factor would be selected depends on the options that traffic managers need to access. For instance if predicting the arrival time of upstream flow with cruise speed is important detectors should installed in upstream (after the previous intersection). Another important detailed factor is that if users need model-based system or not. In addition in almost all the cases additional traffic management facilities are important or even more important than initial effects of ATCS. Therefore the ability of choosing these facilities is an outstanding option of this toolkit. The last but not the least is the installation cost of these systems which is one of the most important factors for decision making, to see if the government can afford for the selected system or if the benefits of applying the system worth its cost.

ATCS Toolkit	
STEP 2	
Search criteria	**Detailed option**
Type of Detectors	Please select
	Downstream
	Upstream
	Upstream + Downstream
Model based	Please select
	yes + "Fixed-time plan"
	No
Additional Traffic Management Facilities	Please select
	Bus priority
	Railroad priority
	Preemption
	Pedestrian
	Gating technique
	Freeway interchange
	Arterial corridors
	City supervisor
	public transport management
	Environmetal monitoring & control
	Fares & debiting
	VMS
Installation Costs	Please select
	5000 - 15000 (US%)
	20000 - 25000 (US%)
	25000 - 30000 (US%)

Figure 80: ATCS Toolkit, STEP 2

- *Step3:* In this step the final input for the simulated DSS system would be taken. The final but the most important one; "Goals & Objectives". This is what transportation management companies and governments want exactly from this website. In this step they can choose exactly want kind of results and improvement they need for their zones. These results can be improvement in road safety, any reduction in emission, air pollution, congestions, and other improvements which are brought in the following;

ATCS Toolkit	
STEP 3	
Search criteria	**Detailed option**
Goal & Objectives	Please select
	Improve road safety
	Decrease traffic violation
	Enhance security
	Improve public transport service
	Reduce environmental impacts
	Telematic management sys
	Shift mobility toward public transport
	Pre-trip information service
	Reduce fuel consumption
	Increasing average speed
	minimizing the congestions

Figure 81: ATCS Toolkit, STEP 3

- *Step4:* In this step ATC systems would ranked by relevance to the criteria provide. In the following, by using one example of how this decision support system would work, the step4 would be explained more in detail. By selecting the search criteria in each step, in the step 4 the relevant adaptive traffic control systems which best fit with the input would be realized in the ranking order. The first rank is the best fitted one and as the ranks get higher the relevancy would be decrease.

ATCS Toolkit

STEP 1

Search criteria	Detailed option
Geographical Coverage	Please select
	District Scale
	Metropolitan Scale
	Regional (Intra-urban)
Type of Transport	Please select
	Public Transport
	Road Transport
Country of Implementation	Please select
	Asia
	Europe
	USA
	Australia
	United Kingdom
Existing traffic control system	Please select
	Fixed-time plan
	Previous ATCS method
Architecture	Please select
	Central management system - Regional computer - Local computer
	Regional central center - Command server - Local controller
	Local controllers with central processor - Detector
	Central system - Roadside unit
Problem	Please select
	Accident
	Congestion
	Noise and air pollution
	Parking issues
	Traveller transport servise

STEP 2

Search criteria	Detailed option
Type of Detectors	Please select
	Downstream
	Upstream
	Upstream + Downstream
Model based	Please select
	yes + "Fixed-time plan"
	No
Additional Traffic Management Facilities	Please select
	Bus priority
	Railroad priority
	Preemption
	Pedestrian
	Gating technique
	Freeway interchange
	Arterial corridors
	City supervisor
	public transport management
	Environmetal monitoring & control
	Fares & debiting
	VMS
Installation Costs	Please select
	5000 - 15000 (US%)
	20000 - 25000 (US%)
	25000 - 30000 (US%)

STEP 3

Search criteria	Detailed option
Goal & Objectives	Please select
	Improve road safety
	Decrease traffic violation
	Enhance security
	Improve public transport service
	Reduce environmental impacts
	Telematic management sys
	Shift mobility toward public transport
	Pre-trip information service
	Reduce fuel consumption
	Increasing average speed
	minimizing the congestions

Table 49: Example of how the ATCS decision support system would work

After selecting the inputs, like what that has done in the above table, and submit these input data, the decision support system starts processing and relates the input criterion to the adaptive traffic control system and would release a table like what is brought in the below. This table contains different ATC systems and put them into the order by considering the ranking of the relevance to the input requests. For this case and for these data inputs the ranking table of phase 4 would be depicted in below;

Ranking	ATC systems Ranked by Problem / Objective Relevance
1	SCOOT (Split Cycle Offset Optimization Technique)
2	UTOPIA
3	INSYNC
4	SCATS (Sydney Coordinated Adaptive Traffic Control)

Table 50: ATCS Toolkit, STEP 4

Now in this step when these results are released, by clicking on each of them, users can have access to detailed information about the ATC systems and can use the related case studies and the statistics in this regards. These information can be categorized in the next step which is the step 5.

- ✓ *Step5:* In this step by clicking on each ATC systems, the information on selected adaptive traffic control system and case studies would be released and would be really useful for government and authorities to make the decision. For instance the data and case studies that can be accessible would be shown by previous step example. Therefore in the step 4, by clicking on the first ranked ATC system, which in this example is SCOOT, following information would be released. Since inputs in the first three steps are mostly about public transportation and implementing in United Kingdom, the results are also in this regards. Although users can find lots of more detailed information about the whole framework of the selected ATC system.

The information about the system were brought in the content of the thesis in previous chapters of SCOOT "CHAPTER 3", and I did not bring them again here to avoid useless repetition. In the following just the case studies of United Kingdom which are related to public transportation were brought.

- **LONDON 1996**

The Transportation Research Group (TRG) carried bus priority field trials in areas of Camden Town and Edgeware Road in London as part of the PROMPT project. The Camden network consisted of 11 nodes and 28 links. The Edgeware Road site was a linear network consisting of 8 nodes and 2 pelican crossings. The bus routes were surveyed for the periods 07:00 - 12:00 and 14:00 - 19:00.

Site: Camden Town			
Strategy	Reduction in Bus Delay		Gain in Vehicle delay
	Sec/bus/link	(%)	Sec/veh/link
Central Extensions	0.2	1	1.7
C.E. + Recalls	3.7	17	5.3
Local Extensions	4.2	19	0.4
L.E. + Recalls	4.8	22	5

Table 51: London Bus Priority SCOOT System

Following results (50% saturation) show that greater benefits can be obtained where there is more spare capacity.

Site: Camden Town Low Saturation Level: Average 50%			
Strategy	Reduction in Bus Delay		Gain in Vehicle delay
	Sec/bus/link	(%)	Sec/veh/link
Central Extensions	4.8	44	-0.1
C.E. + Recalls	7.5	68	-1.6
Local Extensions	7.5	68	-1.2
L.E. + Recalls	7.8	71	-0.6

Table 52: London Bus Priority SCOOT System – Low saturation level

Site: Edgeware Road			
Strategy	Reduction in Bus Delay		Gain in Vehicle delay
	Sec/bus/link	(%)	Sec/veh/link
Local Extensions	2.8	33	-0.1
L.E. + Recalls	3.1	35	4

Table 53: London Bus Priority SCOOT System – Edgeware Road

- **SOUTHAMPTON (LANCES HILL) 1994/1995**

The trial for bus priority was carried out in the Bitterne area of Southampton at the junction of Lances Hill and Maybray King Way. The ROMANSE office of Hampshire County Council carried out the trial. Normal SCOOT operation (with no bus priority) was compared with SCOOT + Central Extensions and Recalls.

Site: Lances Hill - Southampton	
Time Period	Reduction in Journey time
	(%)
Morning Peak	60.7
Off Peak	3.6
Evening Peak	36.8
All Periods	41.7

Table 54: Southampton Bus Priority SCOOT System

SCOOT is in use worldwide and has been shown to give significant benefits over the best fixed time operation. The effectiveness of the SCOOT strategy has been assessed by major trials in five cities. The results from the trials are summarized in the table below;

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
Worcester	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 55: SCOOT Case Study Results in General

These results are one example of the application of the Proposed ATCS decision support system.

In the following the expected results after applying the adaptive traffic control system would be depicted. This table is in the terms of reduction. These results can be really helpful for the government to choose one related system to their network by considering the desired expected benefits.

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	-	-	-	-

Table 56: Expected results in terms of reduction

Table of Comparison														
Adaptive Traffic Control System	Benefits									Weak Points				
	In Terms of								Applying Strategic Supervisor	Central System	Detector Dependent	Just Urban Cotrolling System (Regional Boundaries)	Large Installation Base	Unable to Accommodate oversaturation
	Reduction and Safety						Savings	Increase						
	Stops	Delay	Travel Time	Fuel Usage	Emission	Annual Crash	Annual Crash related	Average Speed						
SCATS	✓	✓	✓	✓	✓			✓		✓	✓		✓	
SCOOT	✓	✓	✓	✓	✓				✓		✓	✓	✓	✓
INSYNC	✓	✓	✓	✓	✓	✓	✓	✓			✓			
UTOPIA (5T Turin)	✓	✓	✓	✓				✓	✓	✓	✓			

Table 57: Table of Comparison as an Output of Proposal DSS

Table of Comparison											
Adaptive Traffic Control System	Model-Based (Having Plan)	Additional Traffic Management Facilities									
		Bus Priority	Gating Technics	Pedestrian Facilities	Preemption (Emergency Vehicle)	Train	Fares and Debiting	Integrated Transportation Ticket	LTZ (Limited Traffic Zone)	Parking Control And Management	Providing Real-time Information to Travelers
SCATS				✓	✓	✓					
SCOOT	✓	✓	✓	✓							
INSYNC				✓	✓						
UTOPIA		✓			✓		✓	✓	✓	✓	✓

8.4. Proposal for Integrated ATC system for Milan – Italy

In this part of the thesis, by considering all four adaptive traffic control systems which introduced in different chapters and by going through their characteristics and vices and virtues, as an outcome one integrated ATC system would be proposed for the city of Milan – Italy. Since the city of Milan does not have one unique and homogenous adaptive traffic control system and different traffic control systems have been used for different parts of it, lots of inconsistency would found in the traffic network that cause lots of congestions, increasing in fuel consumption, air emissions, delays, travel time and decrease the average speed. In this regards it would be worth to put effort to have a new city-scale integrated system. Right now the city has different type of traffic control systems that one of them is UTOPIA, the one that has been used in Turin homogenously.

In continue the city of Turin would be compared with the city of Milan and at the end the one integrated ATC system would be proposed.

8.4.1. Milan VS Turin

8.4.1.1. The Population

Milan is the second-largest city in Italy and the capital of Lombardy. The city proper has a population of about 1.35 million, while its urban area is the 5th largest in the EU and the largest in Italy with an estimated population of about 5.2 million.

Turin is a city and an important business and cultural center in northern Italy, capital of the Piedmont region, located mainly on the left bank of the Po River, in front of Susa Valley and surrounded by the western Alpine arch. The population of the city proper is 911,823 (December 2012) while the population of the urban area is estimated by Eurostat to be 1.7 million inhabitants. The Turin metropolitan area is estimated by the OECD to have a population of 2.2 million.

8.4.1.2. The Urban Network Pattern

As it is understandable from the following Milano and Torino maps, the urban network pattern of these cities have little similarities but there is a big difference in them. The urban network pattern of the Milano is more arterially and radially, in contrast to the city of Turin that has intersecting network.

Figure 82: Milano Urban Network Pattern

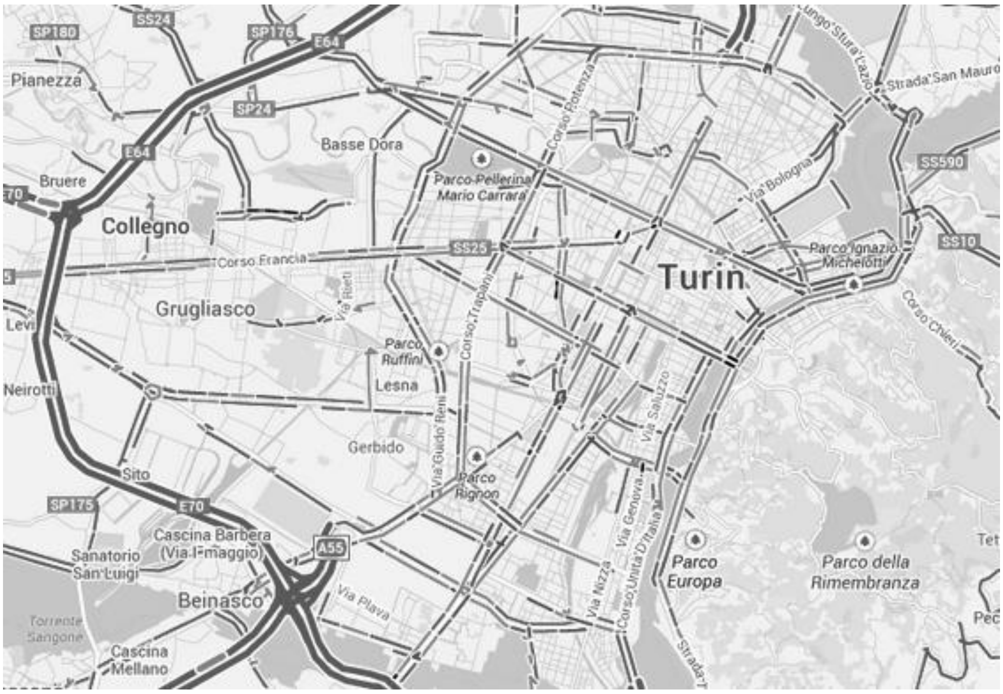


Figure 83: Torino Urban Network Pattern

8.4.2. Problem statement of city of Milan

There are two main problems that city of Milano faces, namely urban decay when parts of the city become run down and undesirable to live in, and traffic congestion. Traffic congestion is caused by

- Many people working in the C.B.D.[46] which may have narrow streets.
- Shortage of off-street parking which means people park on the roads and so increase congestion.
- People not using public transport - either because it is less convenient, too expensive or not available
- More people own and use cars

As well as causing aggravation stationary traffic causes severe air pollution from exhaust fumes. Various solutions to these problems have been tried.

- Ring roads and by-passes; these can be unpopular as countryside around towns and cities are lost when they are built
- Park and Ride - you park your car on the edge of the built up area and then ride a bus or train into the C.B.D.
- One way streets to speed up traffic flow
- Multi-storey car parks
- Banning cars from the C.B.D., either with pedestrianized streets or by stopping them coming into the city center at all. Cars are banned from the center of Milan on Sundays.
- Charging car drivers when they enter the city center

A complete solution to traffic congestion needs people to be able and willing to travel on public transport more.

8.4.3. Conclusion and Proposal

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

- 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, able to perform dynamic traffic-responsive regulation, are powerful tools in reducing congestion and pollution and improving convenience for the travelers;

[46] C.B.D: Central Business District

- Demand itself must be included in generating and keeping the best equilibrium solution by allowing travelers the necessary information, made available by mobility telematics.

The improvements attributed to UTOPIA in Turin have been calculated a previous traffic responsive control strategy rather than against a fixed time system. Benefits of implementing UTOPIA were shown to give an increase in private traffic speed of 9.5% in 1985 and 15.9% in 1986, following system tuning. In peak times the speed increases were 35%. Public transport vehicles, which were given absolute priority, showed a speed increase of 19.9% in 1985 (Wood, 1993).

Consequently by considering the benefits of the UTOPIA and also one the characteristics of Milano and its demands, implementing one integrated UTOPIA adaptive traffic control system on whole urban of the Milano city would be really beneficial. Since the UTOPIA architecture is consisting of central system as a higher decision making level, it would handle to manage adaptively the actual demands for whole urban of Milano.

Since the total area of Turin is 130 square km and the total area of Milan is 182 square km, and also since the population of the Milan metropolitan is almost twice the population of Turin metropolitan, it is better to add also one assistant adaptive control system to the UTOPIA, to manage the traffic lights signals local by local. In this regards one factor which would help to make a decision about choosing this assistant ATC system is the urban network pattern of the city. Milano has radial and arterial urban network pattern. By considering the four ATC systems which were discussed in previous chapters "INSYNC" adaptive traffic control system would be the best match for some local parts of the city that after applying UTOPIA to whole metropolitan, still have problems. Since "INSYNC" is a plug and play system and has this ability to cooperate with the UTOPIA central system, and also its capability in managing arterial corridors and arterial interchanges, they would build the best match to decrease the congestion.

In addition applying 5T project also on Milan would be very efficient because of all the benefits of this project and it would lead to the shift of mobility toward public transport.

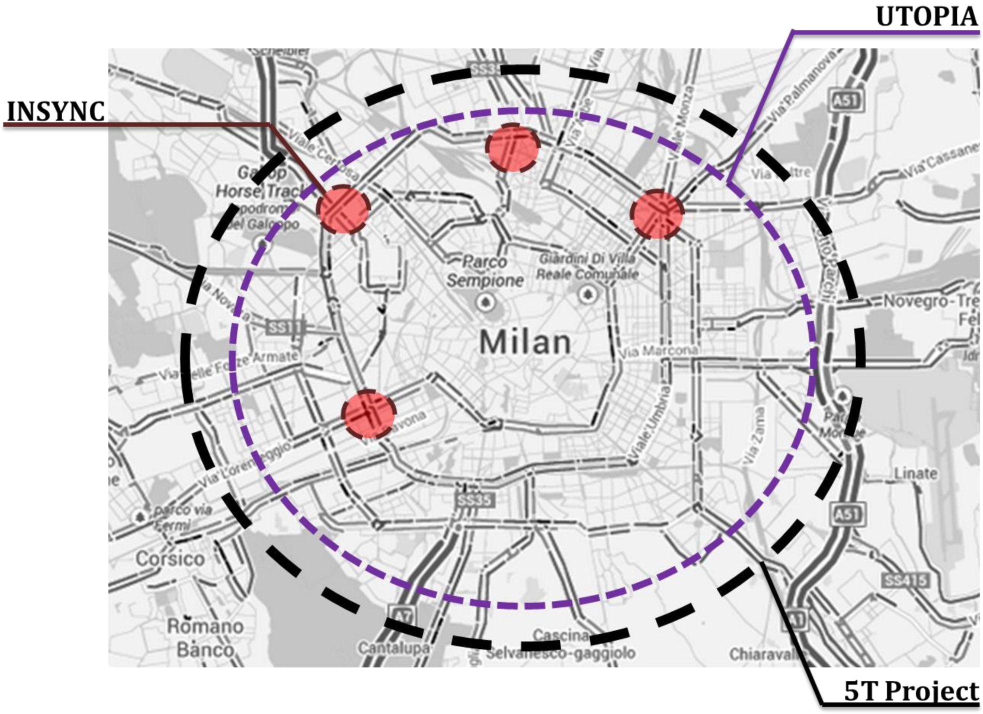


Figure 84: Proposal of Integrated ATC systems on Milano

After applying this proposal integrated system on Milano metropolitan, the efficiency and how much it made difference in the results is really important. The point is approaching to the expected results need metropolitan wide-scaled survey that cover reasonable amount of traffic lights intersections as case studies. Since this large scale survey on Milano is out of the efforts of this thesis, expected results would be estimated roughly in the following.

The latest survey that have been done by "A2A Electrical Networks" in the "31.12.2008", the existing number of intersections with traffic lights in Milano metropolitan are 710 traffic light intersections. By considering the average installation cost per each junction (intersection) between 15000 Euros to 18000 Euros, the expected cost of applying the Utopia to the whole metropolitan of Milano can be reached. In the following table the expected installation cost and the expected results of applying this system would be depicted.

Applying UTOPIA				
Case Study	Expected Results			
Milano Metropolitan	Installation Costs for whole Milano	Reduction in		
		Travel Time	Fuel	Emission
	(Euro)	(%)	(%)	(%)
	1065000 - 1278000	10 - 25	8 - 10	10 - 15

Table 58: Expected results after appying UTOPIA on Milano

8.5. Further Research Agenda

This proposed decision support system in regards to adaptive traffic control system from this research would be upload to the database of the 2DECIDE ITS toolkit website[47] in the near feature to assist government, authorities and transportation regular users to make the best decision. The outcome would be significant in the field of improvement in traffic and noticeable decrease in delay, stops, network congestions, fuel consumption, and emissions.

This research would be an appropriate database for government and authorities of countries which deal with traffic problems, high pollution and emission level, and high fuel consumption. By the comparisons tables which presented in the last chapters, authorities can make a reasonable decision to choose an appropriate adaptive traffic control system which fit best with the demands of the city and apply, to improve their intercity networks. Furthermore this research is a big step for the researcher in this field and would assist them for further studies and achieving to the desired results. Traffic problem is related directly to people health and fortune. Consequently we should never stop improving traffic networks.

[47] http://www.its-toolkit.eu/2decide

9 INDEX & TABLES

9. Index and Tables

9.1. Bibliography

Acott, Kent (6 January 2011). "Red lights that drive you made". The West Australian. Retrieved 18 January 2012

Antoniola. M. (2011). Traffic management in a metropolitan area: the experience of 5T in Torino

Bowen, G. T., & Bretherton, R. D. (1996). Latest developments in SCOOT-Version 3.1.

Bowers, D. J., Bretherton, R. D., & Bowen, G. T. (1995). The ASTRID/INGRID incident detection system for urban areas. In Steps Forward. Intelligent Transport Systems World Congress (Volume 1).

Bretherton, D., Bodger, M., & Cowling, J. (2005). SCOOT-Managing congestion, communications and control.

Bretherton, D., N. Hounsell, and B. Radia. "Public transport priority in SCOOT."Intelligent Transportation: Realizing the Future. Abstracts of the Third World Congress on Intelligent Transport Systems. 1996.

Bretherton, R. D., Wood, K., & Bowen, G. T. (1998, April). SCOOT version 4. InRoad Transport Information and Control, 1998. 9th International Conference on (Conf. Publ. No. 454) (pp. 104-108). IET.

Cheung, S. Y., Coleri, S., Dundar, B., Ganesh, S., Tan, C. W., & Varaiya, P. (2005). Traffic measurement and vehicle classification with single magnetic sensor. Transportation research record: journal of the transportation research board, 1917(1), 173-181.

Colyer, J. (1985). SCOOT FROM SCRATCH-EXPERIENCE IN WORCESTER. TRAFFIC OPERATION AND MANAGEMENT. PROCEEDINGS OF SEMINAR M HELD AT THE PTRC SUMMER ANNUAL MEETING, UNIVERSITY OF SUSSEX, ENGLAND, 15-18 JULY 1985, VOLUME P269. Publication of: PTRC Education and Research Services Limited.

Daniel, J. (1992). Signal Priority for Public Transit Vehicles Using Advanced Traffic Control Systems: A Comparative Evaluation of ATSAC, SCATS and SCOOT.

Dutta, U., McAvoy, D. S., Lynch, J., & Vandeputte, L. (2008). Evaluation of the SCATS Control System (No. MIOH UTC TS4 2008-Final).

Foti. G. (1998). Validation of IRTE supported Public Transport Management. TELEMATICS APPLICATIONS. PROGRAMME (DG XIII). TRANSPORT SECTOR. PROJECT NO: TR 1044

Foti. G. (2009). 5T SIDT 2009 International Conference

Gentile. P. (2000). An Integrated Approach to Urban Traffic Management Mobility Telematics Application in Turin - The 5T Project. SMART CO2 REDUCTIONS Non-product Measures for Reducing Emissions from Vehicles conference.

Gordon, R. L. (2003). Systems engineering processes for developing traffic signal systems (Vol. 307). Transportation Research Board.

Gross, N. R. (2000, January). SCATS Adaptive Traffic System. In TRB Adaptive Traffic Control Workshop.

Hounsell, N. B., and B. P. Shrestha. "AVL based bus priority at traffic signals: a review and case study of architectures." Eur J Transp Infrastruct Res 5.1 (2005): 13-29.

Hounsell, N. B., McLeod, F. N., Bretherton, R. D., & Bowen, G. T. (1996). PROMPT: field trial and simulation results of bus priority in SCOOT.

Hounsell, N., et al. "Intelligent Bus Priority in London: Towards Large Scale Implementation." Proceedings of 7: th World Congress on Intelligent Transport Systems, Turin. 2000.

Hounsell, Nick, and Birendra Shrestha. "A new approach for co-operative bus priority at traffic signals." Intelligent Transportation Systems, IEEE Transactions on 13.1 (2012): 6-14.

Hounsell, Nick. "Improving Bus Operations Using ITS." Traffic and Transportation Studies (2000). ASCE, 2000.

Hunt, P. B. Robertson,D. I. and Winton, R. I. (1981). SCOOT – a traffic responsive method of co-ordinating signals. TRL Laboratory Report 1014.

INSYNC Summery. (2012). From http://rhythmtraffic.com/

Leaflet, T. A. (2009). Integration of Pedestrian Traffic Signal Control within SCOOT-UTC Systems.

Mirchandani, P., & Head, L. (2001). A real-time traffic signal control system: architecture, algorithms, and analysis. Transportation Research Part C: Emerging Technologies, 9(6), 415-432.

Mizar atomization. (2012). UTOPIA, Urban Traffic Control System Architecture

Pietrowicz, G. P. (2001). SCATS operational experience at the road commission for Oakland County. Transportation Research Board.

Powell, R. J. (1985). SCOOT IN SOUTHAMPTON. TRAFFIC OPERATION AND MANAGEMENT. PROCEEDINGS OF SEMINAR M HELD AT THE PTRC SUMMER ANNUAL MEETING, UNIVERSITY OF SUSSEX, ENGLAND, 15-18 JULY 1985, VOLUME P269. Publication of: PTRC Education and Research Services Limited.

SCOOT Demonstration Project Report to Transportation Department. Municipality of Metropolitan Toronto. (November 1993).

Selinger, M., & Schmidt, L. (2009). Adaptive Traffic Control Systems in the United States. HDR Engineering White Paper.

The MOVA Signal Control System. Traffic Advisory Leaflet, 3/97, Department for Transport.

Traffic Advisory Leaflet, TAL 1/01, Puffin Pedestrian Crossings, DfT.

Waterson, B. J., Rajbhandari, B., & Hounsell, N. B. (2003). Simulating the impacts of strong bus priority measures. Journal of transportation engineering,129(6), 642-647.

Wilson, C. J., Millar, G., & Tudge, R. (2006). Microsimulation Evaluation of Benefits of SCATS-Coordinated Traffic Control Signals. In Transportation Research Board 85th Annual Meeting (No. 06-1984).

Wood, K., Bretherton, D., Maxwell, A., Smith, K., & Bowen, G. (2002). Improved Traffic Management and Bus Priority with SCOOT. TRL STAFF PAPER PA 3860/02.

World Health Organization. (2009). Country Profiles: United States of America. Global Status Report on Road Safety.

World Health Organization. (2009). The State of Road Safety around the World. Global Status Report on Road Safety.

Zhang, Y. (2001). An evaluation of transit signal priority and SCOOT adaptive signal control (Doctoral dissertation, Virginia Polytechnic Institute and State University).

9.2. List of Figures

9.3. List of Tables