

ADVANCED ARTERIAL TRAFFIC CONTROL (AATC) SYSTEMS

Signalized intersections play a major role in determining the overall performance of arterial networks and many other types of transportation facilities. They are the points where conflicting traffic streams meet and compete for the same physical space, creating many potential conflicts. For a long time, transportation practitioners have been thinking of ways to make signalized intersections more efficient, and a key tool that they have been trying to take advantage of in this regard is information technology (IT). To a large extent, improving the performance of signalized intersections through the use of IT has centered on two simple ideas,

The first idea attempts to make the traffic signal more intelligent and more responsive to actual traffic demands. The concept is to use traffic sensors or loop detectors, similar to those described in relation to FIMS, at the approaches to the intersection. These sensors would detect the presence or passage of vehicles and would communicate this information to the signal controller. Based on this information, the signal controller would attempt to optimize the signal plan so as to minimize the vehicle's delay at the intersection. These signals are commonly referred to as actuated traffic signals.

The second idea involves controlling a group of signals that lie along a major corridor in an integrated or, to use signal control terminology, in a coordinated way. This means that the signal plans of the individual intersections would be coordinated in such a fashion that a platoon of vehicles discharged from one intersection will not be stopped right away at a downstream intersection, but instead would proceed through a sequence of coordinated intersections without stopping. In addition to actuated and coordinated signals, AATC applications include adaptive traffic control and signal preemption to allow emergency vehicles to safely reach their destination as soon as possible. The following sections will describe these applications in more detail.

Actuated Traffic Signals

Actuated signal control could be regarded as one of the very first applications of IT to transportation problems, which predates the term *ITS* by several years. As opposed to pre timed signals, actuated signals have the capability to revise their timing plans based upon actual traffic demands obtained from traffic detectors. The idea behind the use of actuated controllers is to have an adaptive type of control that is responsive to the continuously changing traffic conditions. For pre timed controllers, the implemented signal plan is only optimal for the volumes assumed in developing the "offline" plan. These volumes could be very different from the actual volumes, particularly if signal plans are not updated regularly, which is often the case. Actuated controllers are capable of optimizing the allocation of time based upon real traffic volumes.

To understand the basic concept of operations for actuated controllers, we first need to define the following three parameters:

Minimum green. Each signal phase of an actuated controller is assigned a minimum green time. This time is typically taken to be equal to the time it takes a queue of vehicles potentially stored between the stop line and the approach detector location to enter the intersection.

Passage time interval. The passage time interval is the time it takes a vehicle to travel from the detector location to the stop line. The passage time also defines the maximum gap, which is the maximum time period allowed between vehicles' arrivals at the detector for the approach to retain the green. If a time period equal to the passage time interval elapses without vehicle actuations at the detector, the green for that approach is terminated, and another approach, with a call for service waiting, gets the green. In such a case, the terminating phase is said to have "gapped out."

Maximum green time. In addition to assigning each phase a minimum green, each phase is assigned a maximum green. If the demand on one approach is sufficient to retain the green until this limit (i.e., vehicles keep arriving before the maximum gap expires), the phase is terminated after the maximum green time is exceeded. In this case, the terminating phase is said to have "maxed out."

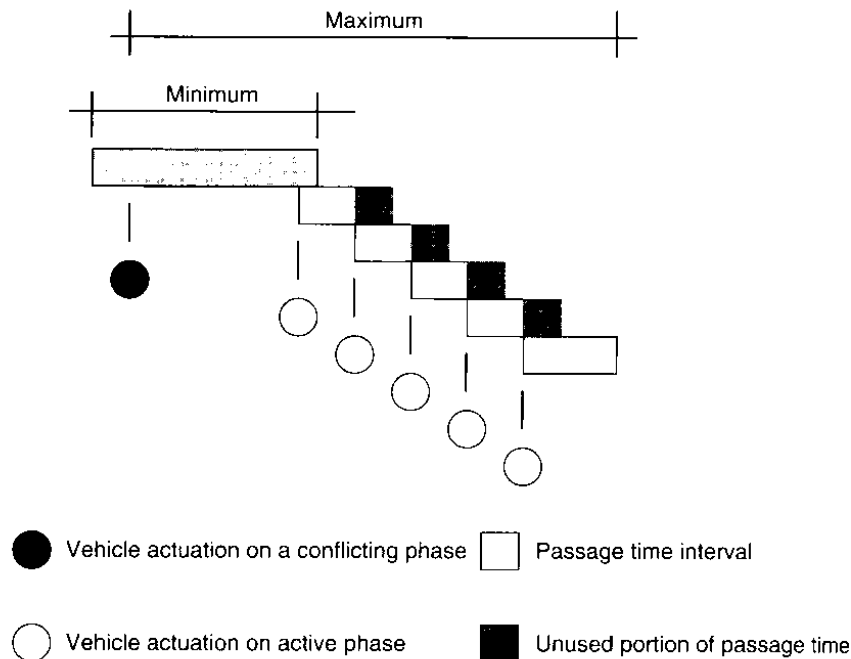
Figure 9.21 shows the operational concept of an actuated controller. When a certain phase becomes active, the minimum green is displayed first. Following this, the green is extended by the vehicle passage time. Depending upon vehicle actuations, the minimum green is extended by the passage time interval for each vehicle actuation. If a subsequent actuation occurs within one passage time interval, another passage time interval is added (measured from the time of the new actuation, and not from the end of the previous passage time interval). Finally, the green is terminated according to one of two mechanisms: A passage time elapses without a vehicle actuation (the phase gaps out); or the maximum green time for that phase is exceeded (the phase gaps out).

Readers interested in learning the details of actuated signal controller design are referred to appropriate references in traffic and highway engineering, including *Traffic and Highway Engineering* by Garber and Hoel.

Signal Coordination

When a number of traffic signals are located close to one another along a major corridor, one simple idea to improve the efficiency of the transportation system is to coordinate the start of the green for those signals. By carefully setting the time difference between the start of green at successive intersections (i.e., this difference is commonly referred to as the signal offset, as will be explained later), it may be possible to create a "green wave" along the corridor that would allow drivers to go through those signals without having to stop at each and every intersection.

FIGURE 9.21 Actuated control operational concept.



A key requirement for coordinating signals is that successive signals are close enough to one another, thereby allowing vehicles to arrive at intersections in the form of platoons (i.e., a group of vehicles closely spaced to one another). Intersections that are far apart from one another are not good candidates for coordination because vehicles, after traveling for long distances in between intersections, tend to disperse, and the platoonlike structure of the traffic stream is destroyed. In these cases, intersections can be regarded as if they were isolated intersections, and vehicles' arrival patterns at those intersections tend to become random.

To allow for coordination, all signals along a coordinated system have to have the same cycle length (in some cases, however, an intersection with exceptionally high volumes may be allowed to have double the cycle length). A common cycle length is needed so that the start of the green would occur at the same time relative to the nearby intersections. While the cycle length has to be the same, the length of the green at different intersections can vary. Given the requirement for common cycle lengths, most signals along coordinated systems are set to operate on a pre-timed basis. It is still possible to coordinate traffic-actuated signals, but they would have to have a common background cycle length.

Coordinated actuated controllers are therefore often of the semiactuated type, which allow for varying the green given to the side streets from one cycle to the next.

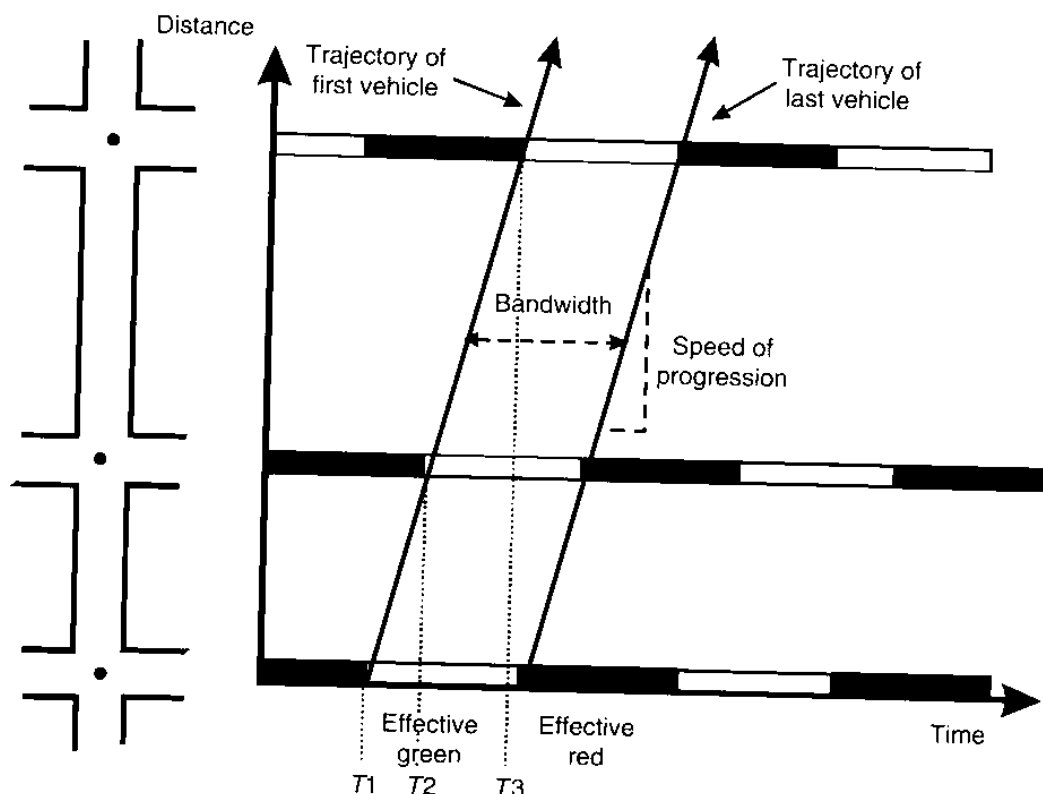
For signal coordination, individual controllers need to be interconnected in order to achieve the necessary synchronization. Typically, in a coordinated system, a master controller would send coordination pulses to all other controllers within the coordinated system (these are typically referred to as local controllers). Direct communication could be established using hard-wired cable, telephone lines, coaxial cable, fiber optic cable, or radio communications. In addition, indirect communication could be established using time-based coordinators.

Time-Space Diagram and Signal Coordination

A powerful tool that has historically been used to design coordinated signal systems is the time-space diagram introduced earlier in Chapter 2. At the present time, the use of the time-space diagram for the design of coordinated signal plans has largely been replaced by more powerful traffic simulation software and optimization algorithms. Nevertheless, the diagram is still quite useful in illustrating the concepts, factors, and challenges of signal coordination.

Figure 9.22 shows a typical time-space diagram for a signal coordination problem. To the left of the *x*-axis of the diagram, which represents the distance, we draw to scale a plan of the corridor or street along which the signals are to be coordinated,

FIGURE 9.22
Signal coordination on a time-space diagram.



We then focus on a given direction (say the NB direction in this example), and at the location of each intersection and along the .r-axis. we draw a schematic representation of the phase sequences for the selected direction at that particular intersection. To make things simpler, we typically only plot the duration of the effective green (i.e., the green + the yellow) as a blank line, and the effective red as a solid line. When representing the signal plan for each intersection, it is important to correctly record the beginning of the green for each signal. Vehicles' trajectories could then be drawn and their interactions with the signal plan studied.

As can be seen from Figure 9.22, the first signal turns green at time, T_1 , followed by the second signal at time, T_2 , and the third at time T_3 . The difference between the time when an upstream signal turns green and when the downstream turns green is referred to as the signal offset. Typically the offset is defined as $(T_2 - T_1)$ or $(T_3 - T_2)$ and therefore is usually a positive number between 0 and the common cycle length for the coordinated system of signals. Also shown in Figure 9.22 is the concept of bandwidth. This is the amount of green that can be used by a platoon of vehicles moving through a series of intersections without having to stop at any of these intersections.

Determining "Ideal" Offsets

If we focus on one direction (such as the NB direction in Figure 9.22), determining the values for the "ideal" offsets is straightforward. If the offset for a given signal is to be related to the signal directly upstream from that signal, the ideal offset can be easily computed as follows:

$$O_{\text{ideal}} = L/S \quad (9.9)$$

where

L = distance between signalized intersections

S = average vehicle speed

The calculations are illustrated by the following example.

EXAMPLE 9.14

Calculating Ideal Offsets for Signal Coordination

It is required to coordinate signals along the one-way corridor shown in Figure 9.23. All signals shown have a common cycle length of 80 sec, and the effective green for the direction to be coordinated for all signals is about 60% of the cycle length. Given that the average vehicle speed along the corridor is 35 mph and the distances between intersections are shown in Figure 9.23, calculate the ideal offsets for the signals.

FIGURE 9.23
Calculation of ideal
offsets for one-way
progression.

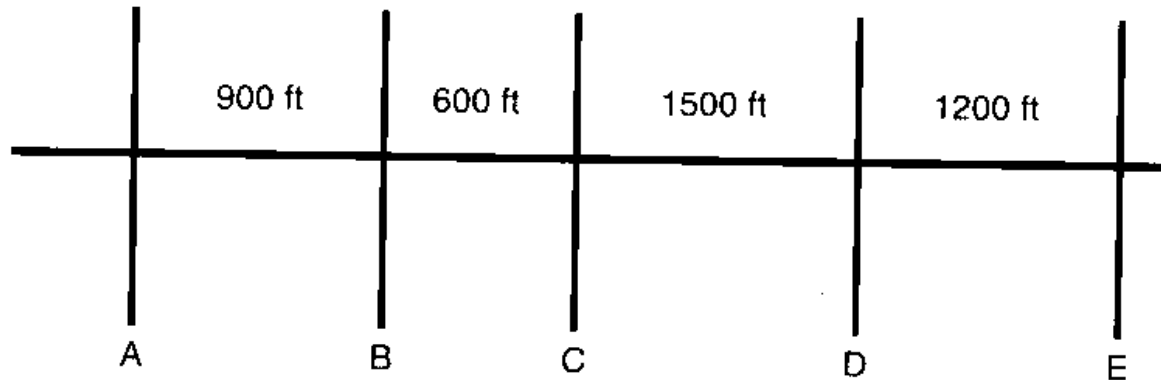


TABLE 9.12 Calculating the Ideal Offsets for the Corridor of Figure 9.23

Signal	offset Calculated Relative to Signal	Ideal offset (sec)
B	A	$900/51.33 = 17.5 \text{ sec}$
C	B	$600/51.33 = 11.7 \text{ sec}$
D	C	$1500/51.33 = 29.2 \text{ sec}$
E	D	$1200/51.33 = 23.4 \text{ sec}$

Solution

We first convert the speed given in miles/hr into the equivalent value in ft/sec as follows:

$$\text{Average speed} = 35 \text{ mph} \approx 35 \times 5280/3600 = 51.33 \text{ ft/sec}$$

We then apply Equation 9.9 to calculate the offsets as shown in Table 9.12.

The offset for a given signal is calculated relative to the one right upstream of that signal.

Bandwidth Concept

As previously mentioned with reference to Figure 9.22, the bandwidth can be defined as the time difference, in seconds, between the trajectories of the first and last vehicle in a platoon of vehicles capable of moving through a series of intersections without having to stop at any of these intersections. *Bandwidth efficiency* gives an indication of the efficiency of the coordination scheme. It is generally defined as the ratio of the bandwidth to the cycle length, as given by Equation 9.19.

$$\text{Bandwidth efficiency} = (\text{BW}/C) \times 100 \quad (9.10)$$

where

BW = band width, sec C = cycle length, sec

In general, a bandwidth around 50% is regarded as an indication for good coordination.

Bandwidth capacity gives the number of veh/hr that can go through the coordinated system without stopping. The bandwidth capacity can be easily computed by first determining the number of vehicles per traffic lane that go without stopping in each traffic signal cycle. This can be done by dividing the bandwidth in seconds by the discharge or saturation headway, which is typically around 2 sec/veh (see Chapter 4). This number is then multiplied by the number of signal cycles/hr. and by the number of traffic lanes, as shown in Equation 9.11.

$$\text{Bandwidth Capacity (veh/hr)} = \frac{3600 \times BW \times N}{C \times h} \quad (9.11)$$

where :

BW = bandwidth, sec

N = number of through lanes in the indicated direction

C = cycle length, sec

h = discharge or saturation headway, sec

Determining the bandwidth for a given coordinated system can be estimated graphically from a time-space diagram similar to the one shown in Figure 9.22. Once this is determined, the efficiency and capacity of the bandwidth can be calculated. The following example illustrates the procedure.

EXAMPLE 9.15

Calculating Bandwidth, Bandwidth Efficiency and Bandwidth Capacity

Figure 9.24 shows a set of three traffic signals along an arterial with two lanes in each direction. The signals are coordinated primarily for the NB direction. The cycle length, the duration of the green for the N-S phase, and the offset for each of the three signals (A, B, and C) are as shown in Table 9.13.

FIGURE 9.24 Roadway sketch for Example 9.15.

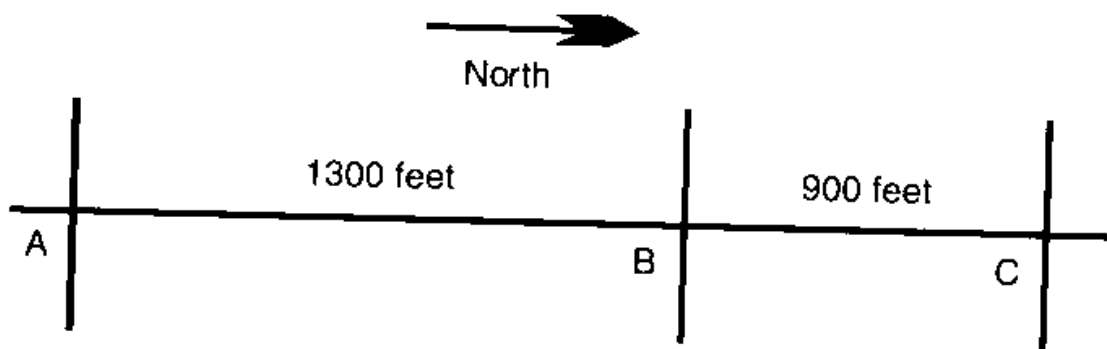


TABLE 9.13 Signal Data for Example 9.15

Signal	Cycle Length	Green for N-S Phase	Offset relative to upstream signal
Signal A	80 sec	35 sec	0 sec
Signal B	80 sec	45 sec	20 sec
Signal C	80 sec	40 sec	15 sec

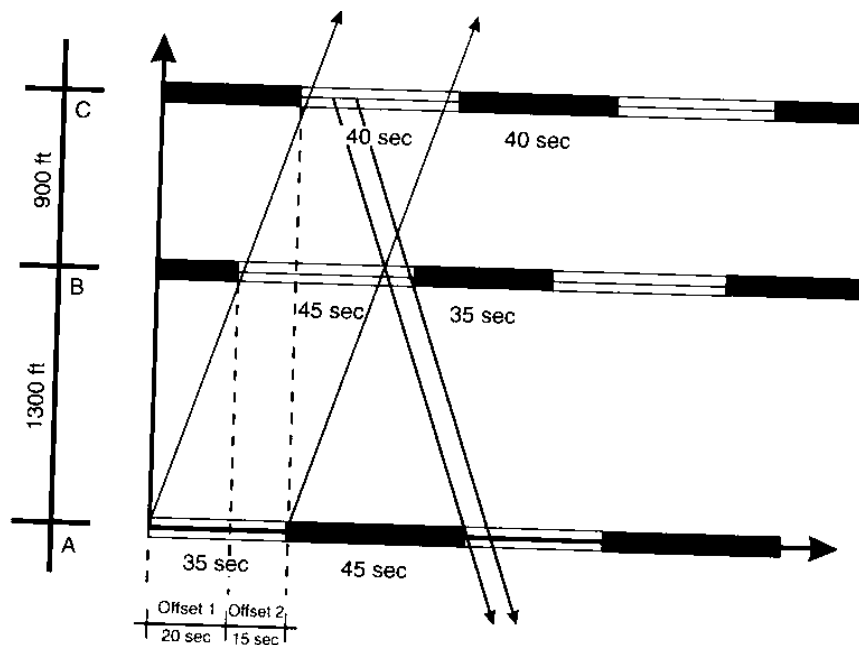
Given that the average vehicle speed along the corridor is 41 mph.

1. Draw a time-space diagram for the coordinated system.
2. Determine the bandwidth efficiency and the bandwidth capacity for the NB direction.
3. Determine the bandwidth efficiency and capacity for the SB direction.

Solution

- (I) The first step in solving this problem is to draw the time-space diagram for the coordinated system as shown in Figure 9.25.

FIGURE 9.25 Time-space diagram for the northbound direction.



The road with the three signals was first drawn to scale along the y-axis of the time-space diagram. Next, the signal timings for each of the three signals A, B, and C were sketched along the x-axis. For signal A and for the N-S direction, we have 35

sec of green followed by 45 sec of red (to make the 80 sec cycle). Signal B has 45 sec of green followed by 35 sec of red. Since the offset for signal 8 is 20 sec, the green of signal B is drawn so as to start 20 sec after *the* start of the green for signal A, Finally, signal C gets 40 sec of green and 40 sec of red. The green for signal C starts 15 sec after the green for signal 8.

We then draw the vehicle trajectories. The average vehicle speed along the corridor is 41 mph. which is equivalent to $41 \times 5280/3600 = 60$ ft/sec. Vehicle trajectories are therefore represented by straight lines having a slope of 60 ft/sec, as shown in Figure 9.25, for both *the* NB and SB directions.

(2) As can be seen from Figure 9.25, for the NB direction. the bandwidth is equal to 35 sec. Given this, the bandwidth efficiency can be easily calculated from Equation 9.10 as follows:

$$\text{Bandwidth efficiency} = \left(\frac{\text{BW}}{C} \right) \times 100 = \frac{35}{80} \times 100 = 43.75\%$$

Bandwidth capacity can be calculated from Equation 9.11 as

$$\text{Bandwidth capacity} = \frac{3600 \times \text{BW} \times N}{C \times h} = \frac{3600 \times 35 \times 2}{80 \times 2} = 1575 \text{ veh/hr}$$

(3) For the SB direction. as can be clearly seen for Figure 9.25. the bandwidth is much smaller. only about 6 sec. With the bandwidth determined. the bandwidth efficiency and safety can be easily calculated from Equations 9.10 and 9.11 as follows:

$$\text{Bandwidth efficiency} = \left(\frac{\text{BW}}{C} \right) \times 100 = \frac{6}{80} \times 100 = 7.5\%$$

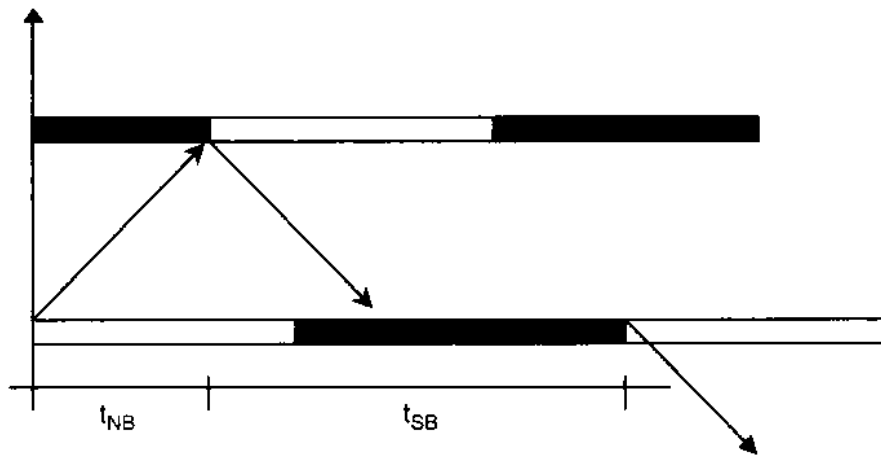
Bandwidth capacity can be calculated from Equation 9.11 as :

$$\text{Bandwidth capacity} = \frac{3600 \times \text{BW} \times N}{C \times h} = \frac{3600 \times 6 \times 2}{80 \times 2} = 270 \text{ veh/hr}$$

Challenges in Coordinating Signals

While signal coordination on one-way streets is straightforward. this is not the case for two-way streets and grid networks. The complexity arises from the fact that. for a two-way street. once the offsets are determined for a given direction (based upon the needs of that direction). the offsets for the other direction are fixed (see Figure 9.26). These offsets (for the other direction) may be inappropriate for the needs of that other direction. as Figure 9.26 and Example 9.15 illustrate.

FIGURE 9.26
Relationship between offsets on two-way streets



Determining the offsets for a two-way street starts with the realization that the offsets in the two directions add to one cycle length, or to an integer multiple of cycle lengths for longer block lengths (see Figure 9.26). Therefore, with reference to Figure 9.26, we could say that

$$I_{NB} + I_{SB} = C$$

where

I_{NB} ~ offset in the northbound direction

I_{SB} = offset in the southbound direction

C = cycle length

The actual offset, which has to satisfy Equation 9.12, can then be expressed as

$$t_{\text{actual}} = t_{\text{ideal}} + e \quad (9.13)$$

The goal of most signal optimization programs is to minimize the weighted sum of the difference between the actual and ideal offsets.

A number of computer programs are currently available to help in the design of optimal signal timing plans for coordinated systems. The idea behind these programs is to find a set of timing parameters (such as offsets, cycle lengths, and phase intervals) that would minimize a given performance measure (such as total delay or total number of stops) while satisfying the different constraints (such as the constraint defined in Equation 9.12). Among the most famous of these computer programs are TRANSYT-7F and SYNCHRO.

TRANSYT (TRAffic Network StudY Tool) was first developed by the U.K.'s Transport Road Research Laboratories in the late 1960s and has undergone several revisions since then. TRANSYT Version 7 was Americanized for the Federal Highway Administration (FHWA) in the late 1970s and early 1980s; hence the name

TRANSYT-7F. Currently, TRANSYT-7F is one of the most widely used computer programs for developing optimal timing plans for corridors and networks. To develop optimal coordinated signal plans, TRANSYT varies the cycle length, the phase lengths, and the signal offsets until the plan that optimizes a user-defined objective function is identified,

SYNCHRO is another signal timing software that could be used to generate optimal signal plans (cycle length, phase lengths, and offsets). For optimization, SYNCHRO uses an objective function that attempts to minimize a combination of delay, number of stops, and number of vehicles in queue. A unique advantage of SYNCHRO is its ability to accurately model the operation of actuated controllers within a coordinated system.

Adaptive Traffic Control Systems

Adaptive or computer traffic control refers to the use of a digital computer to control the operation of a group or system of signals. Adaptive traffic control systems combine the concept of actuated or computer control with the concept of signal coordination. These systems can therefore be regarded as the next step in the evolution of traffic signal control systems. The idea behind adaptive or computer traffic control systems is to take advantage of the power of digital computers to control many signals, along an arterial or in a network, from one central location. Computer traffic control systems predate ITS by several decades: the first installation of these systems took place in the early 1960s. These systems, however, have undergone continuous refinement since that time. In the following paragraphs, we give some historical perspective on the development of these systems.

The most basic type of computer signal control system first appeared in the 1960s. The idea was for a computer to control a series of controllers, but with no "feedback" of information from the field detectors to the computers. In such a system, the traffic plans implemented are not responsive to the actual traffic demand. Instead, the plans are developed "offline" from historical traffic counts and implemented based upon the time of day and day of the week. While this system appears rather simplistic, it offers several advantages, including the ability to update signal plans from a central location, the ability to store a large number of signal plans, and the automatic detection of malfunctioning equipment.

The next development was to have signal control systems in which information from the field traffic detectors is fed back into the central computer. The computer would then use this information to select the signal plan to be implemented. Plan selection is conducted according to one of the following methods.

Select plan from a library of predeveloped plans. In this method, the system has

access to a database (library) that stores a large number of different traffic patterns along with the "optimal" signal plans for each pattern (these plans are developed offline). Based upon information from the traffic detector, the computer matches the observed traffic pattern against the patterns stored in the library and identifies the closest one. The plan associated with the identified pattern is then implemented. This type of adaptive traffic control system is often referred to as a first-generation system. The distinguishing feature of these systems is that the plans, while responsive to traffic conditions, are still developed offline. Typically, the frequency of signal update is every 15 min. First-generation systems do not generally have traffic prediction capabilities.

Develop plan online. In this method, the "optimal" signal plan is computed and implemented in real time. This requires enough computational power to do the necessary computations online. Systems that develop plans online are classified as either second-generation or third-generation systems. These systems typically have a much shorter plan update frequency compared to first-generation systems. In addition, signal plans are computed in real time based on forecasts of traffic conditions obtained from feeding the detector's information into a short-term traffic-forecasting algorithm.

For second-generation systems, the plan update frequency is every 5 min, whereas third-generation systems have an update interval ranging from 3 to 5 min. The next section will describe some examples of these systems that are in use throughout the world,

Adaptive Traffic Control Algorithms

A number of adaptive traffic control algorithms are currently available. Among the most widely accepted of these are SCOOT, and SCATS. SCOOT (Split, Cycle, Offset Optimization Technique) is an adaptive traffic control system developed by the U.K.'s Transport Research Laboratory (TRL) in the early 1980s. In 1996, the system was in operation in more than 130 towns and cities around the world. SCOOT operates by attempting to minimize a performance index (PI), which is typically taken as the sum of the average queue length and the number of stops at all approaches in the network. In order to do this, SCOOT modifies the cycle lengths, offsets, and splits at each signal in real time in response to the information provided by the vehicle detectors.

The operation of SCOOT is based upon cyclic flow profiles (CFPs), which are histograms of traffic flow variation over a cycle, measured by loops and detectors, placed midblock on every significant link in the network. Using CFPs, the offset optimizer calculates the queues at the stop line. The optimal splits and cycle length

are then computed. In recent years, a number of additional features have been added to SCOOT to improve its effectiveness and flexibility. These include the ability to provide preferential treatment or signal priority for transit vehicles: the ability to automatically detect the occurrence of incidents: and the addition of an automatic traffic information database that feeds historical data into SCOOT, allowing the model to run even if there are faulty detectors.

The Sydney Co-ordinated Adaptive Traffic System (SCATS) was developed in the late 1970s by the Roads and Traffic Authority of New South Wales in Australia. For operation, SCATS requires only stop line traffic detectors, and not midblock traffic detection as does SCOOT. This is definitely an advantage since the majority of existing signal systems are equipped with sensors only at stop lines. SCATS is a distributed intelligence, hierarchical system that optimizes cycle length, phase intervals (splits), and offsets in response to detected volumes. For control, the whole signal system is divided into a large number of smaller subsystems ranging from 1 to 10 intersections each. The subsystems run individually unless traffic conditions require the "marriage" or integration of the individual subsystems.

In developing real-time signal plans, SCATS' objective is generally to equalize the saturation flow ratio of the conflicting approaches. Consequently, the system in many cases does not minimize delays on major arterials, which may actually exhibit deterioration in their level of service particularly during peak periods. This was evident in the FAST-TRAC ITS field test in Oakland County, Michigan. In that project, video detection was used to feed a SCATS system, which then developed timing plans in real time.

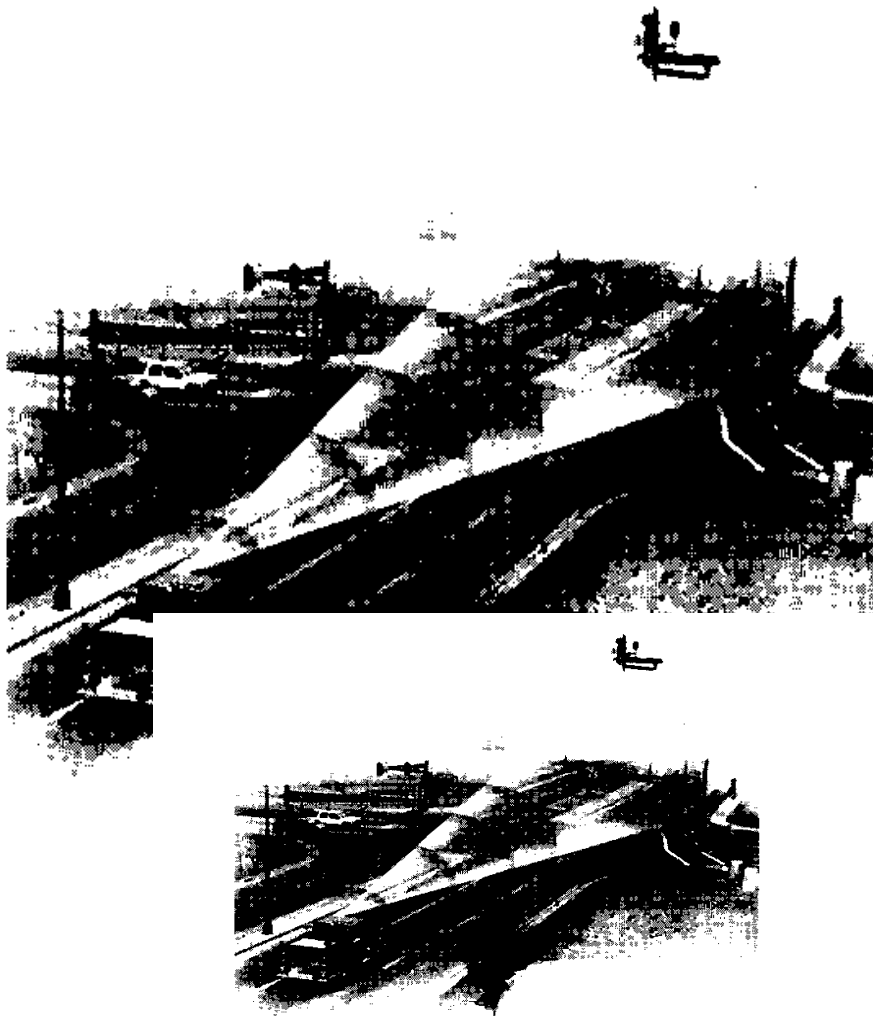
Signal Preemption and Priority

Advanced arterial traffic control (AATC) systems often include signal preemption and priority capabilities. These capabilities allow controllers to detect vehicles approaching signalized intersections and to provide them with some type of preferential treatment. There are several instances where such systems could be used. For example, signal preemption could be used to provide an approaching emergency vehicle with the green light, an act that could save the lives of those in an emergency situation. Signal preemption could be used at highway-rail grade crossings to prevent a vehicle from being trapped on the railway track. They could also be used to provide transit vehicles with some preferential treatment that may involve extending the green at an intersection for an approaching bus in order to allow buses to stay on their schedule.

Historically, the term *signal preemption* has been used to refer to highway rail grade crossing systems, emergency vehicles systems, and transit systems. More

recently, the use of the term *signal priority* is preferred to reflect the fact that there is a need to assign different priorities to different requests. For example, a highway-rail crossing typically is assigned the highest priority, which would typically involve instantaneous response from the controller to avoid trapping vehicles on the railway track. Emergency vehicles are typically assigned a slightly lower priority to allow a signal from a highway-rail grade crossing to override the emergency vehicle request, if a need arises to do so. Finally, transit vehicles are assigned an even lower priority. Such requests received from transit vehicles typically do not cause major disruptions of the phase sequence but may extend a green split by a prescribed amount, allowing the bus to pass the signal.

There are several control strategies that could be used to grant transit vehicles preferential treatment at signalized intersections. In this section, however, we focus primarily on emergency vehicle systems. In our discussion, we will use the term *preemption* since this is the term that is most often used today to refer to emergency



The right-of-way The approach allows for the development of more sophisticated signal coordination strategies compared to the local signal preemption approach, strategies that would anticipate the vehicle's turning movements and would minimize overall system disruption. However, it is much more complex and more expensive than the local signal preemption approach.

Advanced Arterial Traffic Control Systems Benefits

The benefits to be expected from advanced arterial traffic control systems include travel time reduction benefits; environmental benefits resulting from improved traffic flow conditions, lower emission rates, and less fuel consumption; and safety-related benefits resulting from lower accident rates under improved travel conditions. Following is a brief discussion of each of these benefits.

Travel Time Reduction Benefits

Evaluation studies conducted throughout the United States indicate that advanced signal control systems could result in travel time reduction in the range of 8 to 25%. The exact value of time reduction will depend upon a number of factors, including the variability of travel demand; the overall level of congestion; the time interval between signal timing plan modifications; and the density of traffic signals.

Environmental Benefits

Studies show that advanced signal control systems could result in a reduction in air pollutants (such as hydrocarbons and carbon monoxide) that range between 10 and 19%. They could also result in a 4 to 12% reduction in fuel consumption.

Safety Benefits

Some studies show that advanced signal control systems could also result in a reduction in the frequency of injury-related accidents ranging from 6 to 27%.

As an example of how the benefits of an advanced arterial traffic control system may be calculated, consider a segment on an arterial carrying an average annual daily traffic (AADT) of about 20,000 veh/day. Assuming that the average trip length for this segment is about 10 min, and using the conservative estimate of a 10% reduction in trip travel time (as discussed, studies show a reduction in the range 8 to 25%), the time savings resulting from deploying the ITS system could be estimated at

(0.10 X 10 ~ 1.0 min/veh/day). Assuming that the value of time is equal to \$8.90/hr. the benefits could be computed as follows:

$$\text{Benefits} \sim (\# \text{ of vehicles}) \times (\text{time saved}) \times (\text{time value}) \times 365 \sim 20,000 \times (1.0/60) \times (\$8.90) \times 365 = \$1,082.833/\text{year}$$

ADVANCED PUBLIC TRANSPORTATION SYSTEMS

Advanced public transportation systems attempt to improve the efficiency, productivity, and safety of transit systems. They also strive to increase ridership levels and customer satisfaction. In this section, we describe some examples of advanced public transportation systems. The examples described can be categorized under the following four categories: automatic vehicle location (AVL) systems; transit operations software; transit information; and electronic fare payment systems.

Automatic Vehicle Location (AVL) Systems

AVL systems are designed to allow for tracking the location of transit systems in real time. These systems work by measuring the actual real-time position of each vehicle and communicating the information to a central location. This information can then be used to increase dispatching and operating efficiency; allow for quicker response to service disruptions; provide input to transit information systems; and increase driver and passenger safety and security.

While a number of technologies are available for AVL systems, including dead reckoning, ground-based radio, signpost and odometer, and GPS, most agencies now are choosing GPS-based systems. GPS is a navigational and positioning system that relies upon signals transmitted from satellites for its operation. In 1996, there were 86 transit agencies across the country operating, implementing, or planning AVL systems; over 50% of these were using GPS technologies. The following section describes some real-world implementations of AVL systems.

Real-World Examples of Transit AVL Systems

In Atlanta, Georgia, about 250 buses of the Metropolitan Atlanta Rapid Transit Authority (MARTA)'s 750-vehicle fleet are equipped with AVL. The system is linked to the Georgia Department of Transportation traffic management center. There are also electronic signs at a few bus stops for displaying information to passengers waiting at these stops. The system was shown to yield concrete benefits, including improved on-time performance as well as increased safety.

The Tri-County Metropolitan Transportation District of Oregon (Tri-Met) has recently completed the implementation of a GPS AVL system for 640 fixed-route vehicles and 140 paratransit vehicles. The AVL is being employed as part of a regional ITS system, whereby the buses will be used as probes for traffic monitoring,

as discussed previously.

The Milwaukee Transit System (MTS) completed the installation of a GPS AVL on 543 buses and 60 support vehicles. Preliminary results indicate a 28% decrease in the number of buses more than one minute behind schedule.

Transit Operations Software

Transit operations software allow for automating, streamlining, and integrating many transit functions. This includes applications such as computer-aided dispatching (CAD), service monitoring, supervisory control, and data acquisition. The use of operations software can improve the effectiveness of operations dispatching, scheduling, planning, customer service, and other agency functions. Operations software is available for fixed-route bus operations as well as for paratransit or demand-responsive operations.

Operations software for demand response transit implement new scheduling and dispatching software for improved performance and increased passenger-carrying capability of the vehicles. Systems vary widely in their capabilities; the high-end systems have integrated automated scheduling and dispatching software with AVL, geographic information systems, and advanced communications systems. These systems provide dispatchers with the capability to view maps of the service area with the locations of all the vehicles in real time. Drivers have mobile data terminals displaying the next hour's pickups and dropoffs.

Real-World Examples of Transit Operations Software Implementations

Kansas City, Missouri, was able to reduce up to 10% of the equipment required for bus routes using an AVL/CAD system. This allowed Kansas City to recover its investment in the system within two years. On-time performance was improved by 12% in the first year of operating the AVL system. In *Ann Arbor, Michigan*, the city's paratransit service (A-Ride) has implemented computer-aided dispatch, automated scheduling, and advanced communications for eight AVL-equipped paratransit vehicles. This system is able to provide service 24 hours a day, with the services of a dispatcher needed only to take reservations and cancellations from callers and to confirm rides.

Transit Information Systems

Transit information systems implement traveler information systems that provide travelers with transit-related information. Three types of such systems can be identified: pretrip systems; in-terminal/wayside systems; and in-vehicle transit information systems.

Pretrip information systems provide travelers with accurate and timely infor-

mation before starting their trips to allow them to make informed decisions about modes as well as routes and departure times. The information provided can cover a wide range of categories, including transit routes, maps, schedules, fares, park-and-ride locations, points of interest, and weather. In addition, these systems often support itinerary planning. Methods of obtaining pretrip information include touch-tone phones, pagers, kiosks, the Internet, fax machines, and cable TV.

In-terminal/wayside systems provide information to transit riders who are already en route. This information is typically communicated using electronic signs, interactive information kiosks, and CCTV monitors. The overall goal is to provide real time bus and train arrival and departure times, reduce waiting anxiety, and increase customer satisfaction. In-vehicle information systems provide en route information for travelers on board the vehicle. The major impetus behind such systems is to comply with the applicable provisions of the American Disabilities Act of 1991.

Real-World Examples of Transit Information Systems

A good example of pretrip transit information systems can be found in Seattle, Washington, where a key product of Seattle Metro's transit information system is a Web site whereby travelers can obtain information on transit schedules and fares, van and carpooling, ferries, and park-and-ride facilities. This site also provides assistance to transit users in planning their trips. In addition, the University of Washington has developed a Java applet to allow users to view the locations of all buses traveling throughout the Metro System. The University has also developed Web pages to help travelers predict the time of arrival of buses at different bus stops.

Examples of in-terminal and in-vehicle information systems can be found in Ann Arbor, Michigan, where a pair of 31" video monitors is used to display real time data generated by the AVL system to inform passengers at the downtown transit center (in-terminal) about arrival status, delays, and departure times. The Ann Arbor system also includes in-vehicle annunciators and displays from which passengers will receive next -stop and transfer information. The latter will take the form of announcements that identify valid bus transfers at upcoming stops.

Electronic Fare Payment Systems

The idea behind electronic fare payment systems is to facilitate the collection and management of transit fare payments by using electronic media rather than cash or paper transfers. These systems consist of two main components: a card and a card reader. Cards could be of the magnetic-strip type, where the reader does most of the data processing. They could also be equipped with a microprocessor (smart cards), and, in this case, data processing could occur on the card itself. Electronic fare

payment systems offer a number of advantages: they offer convenience to vehicle operators by eliminating the need for any actions to be taken on their part; they eliminate the need for a passenger to worry about having exact change for the bus fare; they facilitate the collection and processing of fares; and they allow for adopting more complex and effective fare structures.

There are two types of electronic fare payment systems: (a) closed systems, and (b) open systems. Closed systems are limited to one main purpose (i.e., paying transit fares) or to a few other applications, such as paying parking fees. However, the value stored on the card cannot be used outside the defined set of activities; hence the name *closed system*. Open systems can be used outside the transit system. A prime example of an open system is a credit card, which naturally can be used with multiple merchants.

Transit AVL and Operations Software Benefits

Studies show that the deployment of transit AVL and operations software could result in both capital as well as operating cost savings to the operating agency. The default values are a reduction between 1 and 2% in fleet size and a reduction in the range of 5 to 8% in operating costs. To illustrate how the benefits from deploying such systems could be estimated, consider the case of a transit agency whose annual capital and operating costs are \$2,000,000 and \$1,500,000, respectively. Assuming a cost saving of 1.5% for capital costs and 6% saving for operating costs, the annual savings are equal to

$$2,000,000 \times 1.5/100 + 1,500,000 \times 6/100 \sim \$120,000/\text{yr}$$

MULTIMODAL TRAVELER INFORMATION SYSTEMS

Multimodal traveler information systems are designed to provide static, as well as real-time, travel information over a variety of transportation modes (e.g., highways, transit, ferries, etc.). In essence, these systems integrate the traffic information dissemination functions of freeway and incident management systems with the functions of transit information systems. They then add more information from sources such as Yellow Pages, tourist organizations, and weather services. Traveler information can be provided before or during a trip (pretrip and en route traveler information). Table 9.14 shows an extensive list of data of potential interest to the traveler that could be part of the traveler information system. Information is classified as either static or real-time information.

Following the collection and processing of data, telecommunications technologies, including voice, data, and video transmission over wire-line and wireless

channels, are then used to disseminate the information to the public. Among ---

TABLE 9.14

Potential Contents of a Multimodal Traveler information System

Static information:

Known in advance, changes infrequently

Planned construction and maintenance activities Special events, such as state fairs and sporting events Transit fares, schedules, and routes

Intermodal connections (e.g., ferry schedules along Lake Champlain)

Commercial vehicle regulations (such as Hazmat (hazardous material) and height and weight restrictions) Parking locations and costs

Business listings, such as hotels and gas stations Tourist destinations
Navigational instructions

Roadway conditions, including congestion and incident information

Alternate routes

Road weather conditions, such as snow and fog Transit schedule adherence

Travel time

Real-time information:

Changes frequently

the means of information dissemination are the Internet, cable TV, radio, phone systems, kiosks, pagers, personal digital assistants (PDAs), and in-vehicle display devices. In addition, efforts are currently underway to implement a national number, 511, which would provide travelers in the United States with real-time multimodal travel information.

Benefits of Multimodal Traveler Information Systems

Multimodal traveler information services allow users to make more informed decisions regarding time of departure, routes, and mode of travel. They have been shown to increase transit usage and reduce congestion when travelers choose to defer or postpone trips or select alternate routes. A good example of a regional multimodal traveler information system is given by the Smart Trek Model Deployment Initiative in Seattle, Washington. At the center of this system is a set of protocols and paradigms designed to collect and fuse data from a variety of sources; process the data to derive useful information; disseminate the information derived to independent information service providers; and warehouse the data for the purposes of long-range planning.

Challenges Facing Multimodal Traveler Information Systems

Although multimodal traveler information systems have the potential to yield significant benefits for both travelers and system operators, the demand for products has been slow to materialize. The size of the market for traveler information systems has been modest to date. Several reasons could be provided

نظم متطورة لمراقبة حركة المرور الرئيسية (aatc) signalized التداخلات دورا رئيسيا في تحديد مجمل - المرفق الأول (من أنواع أخرى كثيرة الرئيسية وشبكات النقل والمرافق. وهي نقطة الالتقاء streams المرور متناقضة حيث تتنافس على نفس الحيز المادي وإنشاء العديد نزاعات محتملة. لزم من طويل. ترانس - practitioners portation قد يفكر في طرق أبواب - أمورا أكثر كفاءة signalized تجعل. الأداة الأساسية التي ما فتئت تحاول الاستفادة من تكنولوجيا المعلومات في هذا المجال (it). الى حد كبير - ظل تحسين تقاطعات الطرق باستخدام signalized الأداء وقد تتمحور حول مجرد أفكار وهما أول إشارة المرور فكرة المحاولات الهادفة إلى جعل وأن يكون أكثر استجابة ذكية أكثر مطالب الحركة الفعلية. إذ إن هذا المفهوم في استخدام أجهزة استشعار الحركة أو loop مكاشيف مماثلة لتلك الدول الموصوفة في ما يتعلق نظام إدارة المعلومات المالية في نقطة تقاطع نهج. وهذه أجهزة استشعار سوف يكتشف وجود أو المرور والتي - سماح، وسوف ينقل هذه المعلومات إلى أن يشكل إشارة المراقب. واستنادا الى هذه المعلومات على الوجه الأمثل إشارة المراقب سيحاول بحيث تقلل الخطة علامة السيارة عند نقطة التقاء التأخير. وهذه الاشارات هي com - monly المشار إليها على أنها تعمل إشارات المرور.

والفكرة الثانية تتعلق بضبط مجموعة من إشارات الثاني جيم طول الممر الرئيسي بشكل متكامل أو، إذا استخدمنا مصطلحات الاشارات والتحكم في Coor - dinated الطريق. وهذا يعني ان اشارة لخطط سيتم تنسيق كل على حدة التداخلات في هذه الموجة من فصيلة المركبات التي تقاطع discharged لن تتوقف عن حقه في أسفل بعيدا جملة - الفرع، بل سيتم الشروع خلال سلسلة من الفروع تنسيقها - دون توقف. اضافة الى اشارات تعمل منسقة. وتشمل التطبيقات aatc تكييفية مراقبة حركة المرور والمنع للسماح سيارات الطوارئ الاشارات سالمين تصل إلى وجهتها بأسرع وقت ممكن. وستتضمن الفروع التالية لوصف هذه الطلبات بمزيد من التفاصيل.

تعمل إشارات المرور الإشارات تعمل مراقبة يمكن اعتبار واحد من أول تطبيقات لها مشاكل المواصلات التي تسبق فترة ما قبل عدة سنوات. على النقيض من توقيت سابق اشارات-اشارات تعمل لديها القدرة على مراجعة توقيتها خططا تقوم عند السير الفعلي لمطالب الحركة المستمدة من كاشفات. وأوضح أن الفكرة في استخدام تعمل المراقبين الجويين أن يكون له المركز - وجهها ونوع والسيطرة التي يتغير باستمرار الحركة تستجيب ditions - con. عن توقيت سابق المراقبين الجويين، وتنفذ فقط ما يعتبر مؤشرا مثالية بالنسبة لخطة المفترضة في أحجام بوضع "الإلكترونية" الخطة. هذه الكميات يمكن أن يختلف كثيرا عن الأحجام الفعلية، خاصة إذا كان إشارة البدء من الخطط لا تحديثها بانتظام، والتي غالبا ما تكون هذه القضية. تعمل المراقبين الجويين قادرون على الاستغلال الأمثل للوقت مبنية على التوزيع الحقيقي أحجام الحركة. فهم من عمليات تعمل المراقبين الجويين المفهوم الأساسي نحتاج أولا من تحديد المعايير الثلاثة التالية:

الدنيا الخضراء. إشارة إلى كل مرحلة المراقب يكلف تعمل بالحد الأدنى الخضراء حينها. هذه المرة هو أن يكون متساويا في العادة تؤخذ الوقت الذي تستغرقه السيارات من الصف محتملة بين الممنوعين من السفر المخزنة مكشاف موقع الخط والنهج لدخول التقاطع.

مرور فترة زمنية فاصلة. مرور الفترة الزمنية هي - والتي هي من الوقت الذي يستغرقه السفر من مكان الى توقف خط مكشاف. مرور يحدد كذلك أقصى اتساع الفجوة الزمنية، وهي المهلة القصوى المسموح به بين الوافدين والسيارات في هذا النهج من الحفاظ على المكشاف الخضراء. وإذا ما يساوي الفترة الزمنية والفترة الزمنية تنقضي دون المرور في السيارة actuations مكشاف الخضراء عن هذا النهج هو nated - termi، والأخرى نهجا يطالبون خدمة الانتظار، وتحصل الأخضر. وفي ظل هذه السهولة، ويقال إن تنتهي مرحلة "gapped". أقصى الخضراء حينها. بالإضافة الى تخصيص كل مرحلة دنيا خضراء لكل مرحلة عهد كحد أقصى الخضراء. إذا كان الطلب على نهج واحد لا يكفي أن تبقى على الأخضر حتى هذا الحد (أي مركبة تبقى فور وصوله قبل أن الحد الأقصى الفجوة سوف تنتهي)، ومرحلة ما انتهت بعد أن أقصى درجات الاخضر حينها على تجاوزها. وفي هذه الحالة، ويقال إن تنتهي مرحلة "maxed للخروج".

ويوضح الشكل العملي لمفهوم 9-21 مراقب تعمل. عندما يصبح مرحلة معينة نشطت الاخضر هو الحد الأدنى displayed اولا. عقب ذلك، فإن الأخضر هو الذي تقدمه هذه السيارة بمرور الزمن. تبعا والتي هي - actuations، خضراء تمتد من مرور الدنيا والفترة الزمنية بخصوص كل سيارة يحدث تفجير. وإذا ما يحدث داخل إحدى بمرور الزمن يحدث تفجير بعد استراحة أخرى تضاف مرور فترة زمنية فاصلة (إذا قيس من وقت يحدث تفجير جديدة، وليس من نهاية الفترة الزمنية الفاصلة المقطع السابق). وأخيرا إذا أنهى الاخضر وفقا لأحد آليتين: مرور الزمن

Get this job done by a human translator!
 **Powered by Language Weaver Farm - Automated language translation software**
 About Machine Translation Technology



traveler information systems has been modest to date. Several reasons could be provided

ترجمة:

Erweiterte arterielles Traffic Control (dass) Systeme

wurde Schnittmengen spielen eine wichtige Rolle bei der Bestimmung der Einstufung (arterieller Netze und viele andere Typen von Transport Einrichtungen. Sie sind die Punkte, in denen widersprüchliche Traffic Streams treffen und Wettbewerb für die gleichen physikalischen Raum. Erstellen viele potenzielle Konflikte. Für eine lange Zeit.

Trans-Portierung Praktiker wurden Denken der Wege, wurde Inter-Abschnitte effizienter zu machen. Und ein Schlüsselinstrument, Sie haben versucht zu nutzen In dieser Hinsicht ist die Informationstechnologie (IT). Weitgehend. Verbesserung der Leistungsfähigkeit der Schnittmengen wurde durch den Einsatz hat zentriert auf zwei einfachen Ideen, die erste Idee Versuche, um die Traffic Signal intelligenter und mehr reaktionsfreudige an die tatsächlichen Traffic Forderungen. Das Konzept ist die Verwendung Traffic Sensoren oder Schleifendetektoren. Ähnlich wie die in bezug auf unterrichtsfilme. Auf die Ansätze für den Schnittpunkt. Diese Sensoren würde das Vorhandensein oder durchfahrt der ab-Cles und würde übermittelt diese Angaben den Signal Controller. Auf der Grundlage dieser Informationen. Das Signal Controller würde versuchen zur Optimierung der signal Plan zur Minimierung des Fahrzeugs Verzögerung an der Kreuzung. Diese Signale werden KOM-monly gemäß als angetneben Traffic Signale.

Die zweite Idee beinhaltet Kontrolle eine Gruppe von Signale, IIC entlang einer großen Korridor in ein integriertes oder, um Signal Kontrolle Terminologie, in einem zu-dinated weg. Das bedeutet, daß das Signal Pläne der einzelnen Schnittmengen wäre koordinierte in einer Weise, dass ein Platoon von Fahrzeugen discharged von einem Schnittpunkt nicht gestoppt sofort auf einem nachgelagerten Inter-ABSCHNITT. Sondern vorgehen würde durch eine Sequenz von koordinierten Inter-Abschnitte ohne beenden. Zusätzlich zu angetneben und koordinierte Signale. Dass Anwendungen enthalten Adaptive Traffic Control und signal preemption, damit Emergency vehicles sicher an ihren Bestimmungsort erreichen so bald wie möglich. Die folgenden Abschnitte beschreiben diese Anwendungen im Detail beschrieben.

angetneben Traffic Signale

angetneben Signal Kontrolle könnte als eine der ersten Anwendungen zu

Transportproblemen. Die älter als der Begriff der von mehreren Jahren. Im Gegensatz zu PRE TIMED Signale. angetneben Signale haben die Fähigkeit zur Überarbeitung ihrer Timing Pläne auf der Grundlage von eigentliche Verkehr Forderungen aus Traffic Detektoren. Die Idee hinter die Verwendung von angetneben Controller ist eine ADAP-tive Art der Kontrolle, reaktionsfreudige der ständig wechselnden Verkehrsbedingungen con-conditions. Für PRE TIMED Steuerungen. Die implementierten Signal Plan ist nur optimal für die Volumes angenommen bei der Entwicklung der "Offline"-Plans. Diese Mengen könnten, sehr verschieden von der tatsächlichen Mengen, insbesondere wenn Signal Pläne sind nicht regelmäßig aktualisiert werden, die oft der Fall ist. angetneben Steuerungen in der Lage sind Optimierung der Zuweisung der Zeit auf der Grundlage von Real Verkehrsmengen. Zum Verständnis der grundlegenden Konzept für Operationen für angetneben Steuerungen, als erstes müssen wir

definieren Sie die folgenden drei Parameter:

Minimum grün. Jedes Signal Phase einer angetneben Controller ein Minimum grün Zeit. Diese Zeit ist typischerweise getroffen werden, gleich der Zeit, die eine Queue Fahrzeuge potentiell gespeichert zwischen der Haltestelle Linie und der Ansatz Detektor Lage zu geben Sie den Schnittpunkt.

Passage Zeitintervall. Die Passage Zeitintervall ist die Zeit es dauert ab-CLE zu reisen von den Detektor Lage an der Haltestelle Linie. Die Passage Zeit auch Legt die maximale Kluft,

die die maximale Zeit Frist zwischen den Fahrzeugen' Ankünfte an den Detektor für den Ansatz, behalten die Grün. Wenn ein Zeitraum gleich die Passage Zeitspanne verstreicht ohne Fahrzeug Betätigungen am Detektor, grün zum ist der Ansatz hatte-de, und ein anderer Ansatz, mit einem Aufruf für Service warten, erhält die Grün. In einem solchen Einfachheit, die zur Einstellung Phase ist, hat die "gapped."

maximale grün Zeit. Zusätzlich zur Zuweisung jeder Phase A MINIMUM grün, jede Phase zugeordnet ist eine maximale grün. Wenn die Nachfrage auf ein Ansatz ist ausreichend, behalten die grüne bis diese Grenze (d.h. , Fahrzeuge halten arriving before Der maximale Abstand läuft), die Phase wird abgebrochen werden, nachdem die maximale grün Zeit überschritten wird. In diesem Fall wird die Einstellung Phase ist, hat die "Am."

Abbildung 9.21 zeigt die operationellen Konzept eines angetneben Controller. Wenn eine bestimmte Phase aktiv, wird das Minimum grün ist zuerst angezeigt. Der grün ist Verlängert durch das Fahrzeug Passage Zeit. Je nach Ab-CLE Betätigungen, die minimale grün ist verlängert durch die Passage Zeitintervall für jedes Fahrzeug Betätigung. Wenn eine spätere Betätigung erfolgt innerhalb von einem Durchgang Zeitintervall, einem anderen Passage Zeitintervall wird hinzugefügt (gemessen an der Zeit der neuen Betätigung, und nicht mit dem Ende der vorangegangenen Passage Zeitintervall). Schließlich ist die grüne beendet nach einer der zwei Mechanismen: a Passage Zeit

Zeit-Raum Diagramm und signal Koordinierung

ein mächtiges Werkzeug, seit jeher verwendet werden, um Design koordinierte Signal Systeme ist die Zeit-Raum Diagramm frühere Einführung in Kapitel 2. Auf der Pre-gesendet Zeit. Die Verwendung der Zeit-Raum Diagramm für das Projekt des koordinierten Signal Pläne hat weitgehend ersetzt worden durch mächtiger Traffic Simulation Soft-Ware und Optimierung Algorithmen. Dennoch das Diagramm ist noch recht nützlich bei der Veranschaulichung der Konzepte. Faktoren. Und die Herausforderungen der signal Koordinierung.

Abbildung 9.22 zeigt eine typische Zeit-Raum Diagramm für ein Signal Koordinierung Problem. Auf der linken Seite des .V-Achse der Diagramm. vertritt die Entfernung. Wir ziehen Maßstab einen Plan für den Flur oder Strasse entlang der sich die Signale zu koordinieren sind, Abbildung

9.22

Signal Koordinierung auf Zeit-Raum Diagramm.

Wir dann Schwerpunkt auf einer bestimmten Richtung (sagen, daß die NB Richtung in diesem Beispiel), und in der Lage der einzelnen Kreuzung und entlang der .R-Achse. zeichnen wir eine schematische Darstellung der Phase Sequenzen für den ausgewählten S.-tion auf der jeweiligen Kreuzung. , damit es einfacher, wir üblicherweise nur Plot die Dauer der wirksamen grün (d.h. die Grün + Die gelbe) als eine leere Zeile, und die wirksame rot wie eine durchgezogene Linie. Bei der Vertretung der signal Plan für jedes Schnittpunkt, es ist wichtig, korrekterweise den Beginn der Grünen für jedes Signal. Fahrzeuge" trajectories könnte dann gezeichnet und ihre interac-tions mit dem Signal Plan untersucht.

Wie aus Abbildung 9.22 , das erste SIGNAL leuchtet grün auf Zeit, T_1 , fol- "durch das zweite Signal an Zeit, T_2 , und die dritte zum Zeitpunkt t_3 . Der Unterschied zwischen dem Zeitpunkt, als ein Upstream Signal grün leuchtet, wenn die unten-Stream grün leuchtet bezeichnet man als das Signal Offset. Typischerweise den Offset ist definiert als $(T_2 - T_1)$ oder $(T_3 - t_2)$ und daher ist normalerweise eine positive Zahl zwischen 0 und die gemeinsame Zyklus Länge für die koordinierte System von Signalen. Auch gezeigt in Abbildung 9.22 ist das Konzept der Bandbreite. Dies ist der Betrag der Grünen verwendet werden kann durch eine Platoon von Fahrzeugen Bewegen durch eine Reihe von Schnittmengen ohne Stop jeden dieser Schnittmengen.



[Get this job done by a human translator!](#)

[Powered by Language Weaver - Automated language translation software](#)

[About Machine Translation Technology](#)

