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RESEARCH

TRANSITWAY SURVEILLANCE, COMMUNICATIONS, AND CONTROL--MANUAL FOR PLANNING, DESIGNING AND OPERATING TRANSITWAY FACILITIES IN TEXAS

in cooperation with the
Department of Transportation
Federal Highway Administration

RESEARCH REPORT 425-2F
STUDY 2-8/10/84-425
TRANSITWAYS

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16. Abstract

Transitways are exclusive, physically separated, limited access roadway facilities for high occupancy vehicles (buses, vans, carpools). The complexity of operations (reversible flow) and, in many applications, the restrictions to cross-section width, emphasizes the need for an active traffic operations management system which includes capabilities for surveillance, communications, and control.

The importance of coordinating Surveillance, Communications and Control (SC&C) considerations with both the planning and design processes for transitways cannot be overstated. Operation of a transitway is critical and should be considered early in the design phase. This report addresses Transitway Surveillance, Communication, and Control as Chapter 4 of the previously prepared "Manual for Planning, Designing and Operating Transitway Facilities in Texas" (Research Report 425-2F).

This chapter of the manual presents information for assessing the need for SC&C systems on transitways, describes the basic concepts, systems and technologies associated with SC&C, outlines some general guidelines for selecting the appropriate SC&C system, and provides criteria for the actual design of a SC&C system.

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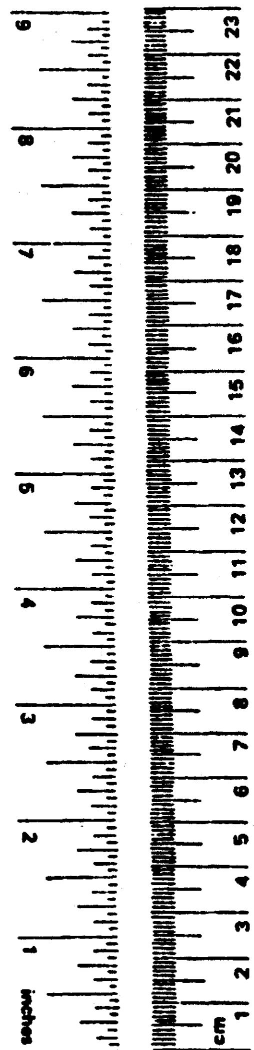
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

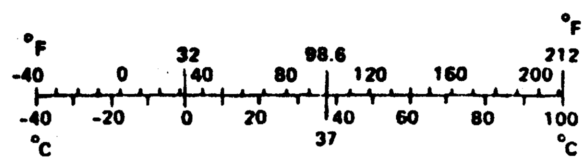
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



TRANSITWAY SURVEILLANCE, COMMUNICATIONS, AND CONTROL

Research Report 425-2F (Chapter 4)
Study Number 2-8/10-84-425

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ABSTRACT

Transitways are exclusive, physically separated, limited access roadway facilities for high occupancy vehicles (buses, vans, carpools). The complexity of operations (reversible flow) and, in many applications, the restrictions to cross-section width, emphasizes the need for an active traffic operations management system which includes capabilities for surveillance, communications, and control.

The importance of coordinating Surveillance, Communications and Control (SC&C) considerations with both the planning and design processes for transitways cannot be overstated. Operation of a transitway is critical and should be considered early in the design phase. This report addresses Transitway Surveillance, Communication, and Control as Chapter 4 of the previously prepared "Manual for Planning, Designing and Operating Transitway Facilities in Texas" (Research Report 425-2F).

This chapter of the manual presents information for assessing the need for SC&C systems on transitways, describes the basic concepts, systems and technologies associated with SC&C, outlines some general guidelines for selecting the appropriate SC&C system, and provides criteria for the actual design of a SC&C system.

IMPLEMENTATION STATEMENT

Project 425 was established to assist the Texas State Department of Highways and Public Transportation in the planning, design, and operation of transitways and related support facilities through the preparation of a manual with relevant technical information for this purpose. This document comprises Chapter 4, Transitway Surveillance, Communications, and Control, of this manual. Application of the information presented herein should enhance the cost-effectiveness of future transitway projects.

DISCLAIMER

The contents of this document reflect the views of the authors who are responsible for the technical data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas State Department of Highways and Public Transportation. This document does not constitute a standard, specification, or regulation.

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4. SURVEILLANCE, COMMUNICATIONS AND CONTROL

4.1 GENERAL

Transitways are a special application of high speed, limited access roadway design. High person-volumes are achieved with low volumes of vehicles. The transitway maintains control of access through geometric design and vehicle authorization procedures. The type of operation (reversible flow, etc.), incidents and, in many applications the restriction in roadway width, places greater emphasis on the need for an active traffic operations management system.

Management of transitway operations may be accomplished by a range of technological and manpower means. Minimal control might be exercised at a low level with on-site personnel and passive signing/delineation. Maximum control might involve sophisticated surveillance and detection with complete computer integration and dynamic, real-time signing/delineation. The level of control will depend upon vehicular demand, complexity of operations, and the extent of the transitway system. Operational control might even evolve from low- to high-level as the transitway system and usage becomes more extensive.

The importance of coordinating Surveillance, Communications and Control (SC&C) considerations with both the planning and design processes for transitways cannot be overstated. It is equally important to coordinate city and state freeway corridor (mainlanes, frontage roads, and arterial street connections) SC&C systems with the SC&C system for transitways. Details of the PEGASUS (People Goods And Services Urban System) freeway corridor traffic management system which addresses this SC&C coordination are given in the appendix.

This chapter of the manual presents information for assessing the need for SC&C systems on transitways, describes the basic concepts, systems and technologies associated with SC&C, outlines some general guidelines for selecting the appropriate SC&C system, and provides criteria for the actual design of a SC&C system. The information presented in this Chapter draws heavily upon experience gained in designing the SC&C system for the Houston transitway network (1).

4.2 JUSTIFICATION

Use of SC&C concepts to improve the capacity and efficiency of urban freeways is not new. As early as 1955, the City of Detroit implemented a freeway surveillance project on the John Lodge Expressway with a test installation of closed circuit television for traffic surveillance and lane use signals and changeable message speed signs for control. During the early 1960's, the Cities of Chicago, Detroit, Houston, Los Angeles, and Dallas pioneered in the application of freeway surveillance and control, and in New York the technology was being applied to increase the flow of traffic through the Hudson Bay tunnels. Based on the success and experience of these early experiments, freeway surveillance and control systems are now being developed and placed in operation in a number of metropolitan areas in the United States and abroad. The growing need for better management of freeways to provide increased levels of capacity, service, and safety is becoming more and more apparent.

Experiences to date have proven that SC&C systems can significantly improve the movement of people. They accomplish this by (2):

- More rapidly and effectively detecting and responding to accidents, disabled vehicle and other incidents which affect the flow of traffic.

- Restraining the flow of traffic at certain points to prevent congestion at more crucial points, thereby helping traffic move in the most highly productive range of speeds through critical bottlenecks.

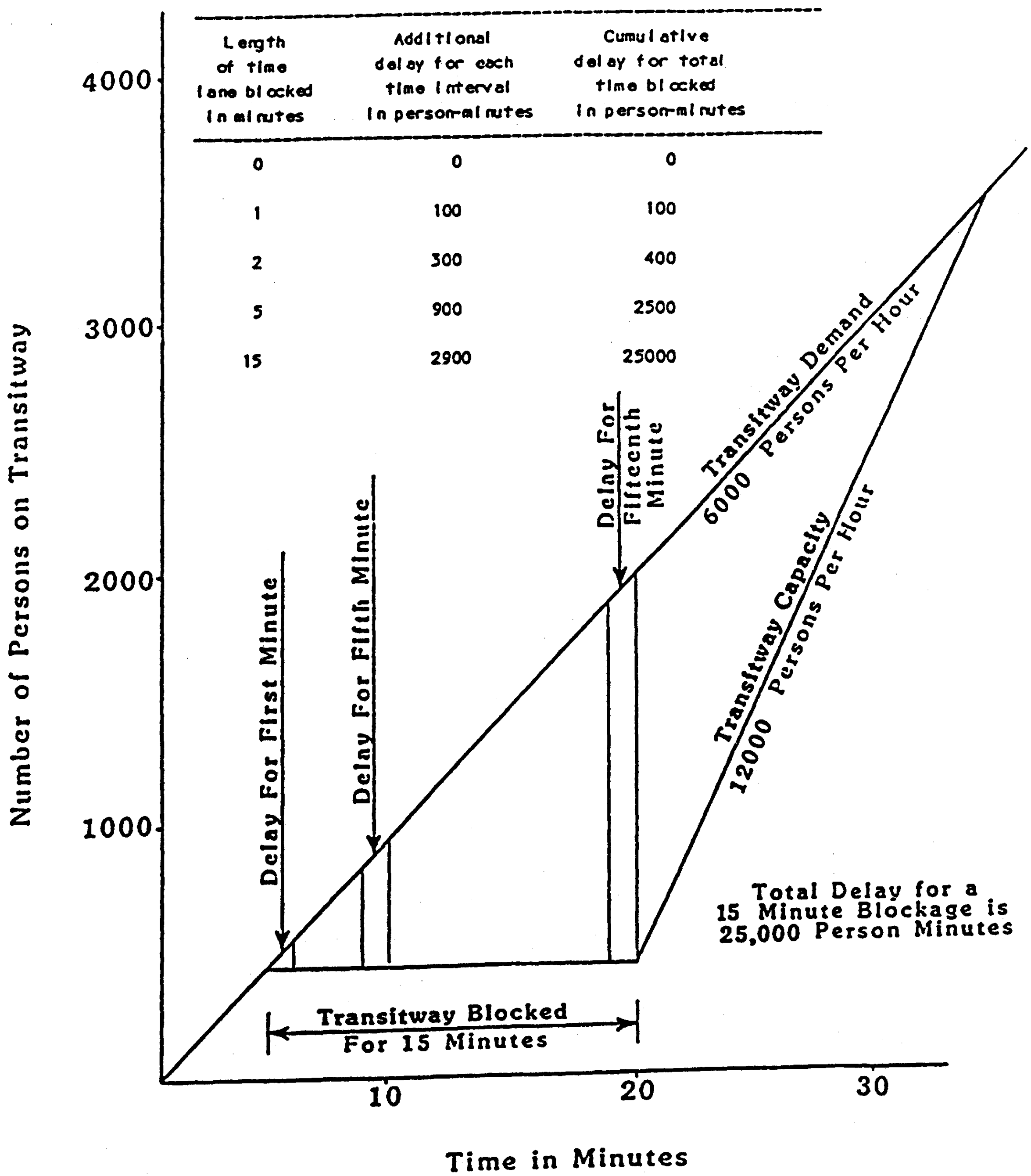
- Giving priority treatments to higher occupancy vehicles such as buses and carpools which increases the person-moving capacity of the freeway.

- Diverting traffic from congested sections of a freeway to under-used facilities serving the same corridor.
- Reducing congestion, vehicular conflicts and traffic flow turbulence which results in lower accident rates.
- Providing real-time information to the motorists which aids them in the efficient utilization of the freeway system.

Experience has shown that SC&C systems can offer specific tangible benefits in terms of improving freeway operations. One might wonder, then, why SC&C systems have not been more widely used. The basic reason is the misconception on the part of many that the design, implementation, and operation of such systems is far too complex for them to undertake. While the design and operation of SC&C systems is a challenge, it is not an insurmountable one.

SC&C systems for transitways are designed to provide the authorized users with information on traffic and roadway conditions. Perhaps more importantly, SC&C systems are intended to detect and respond to disabled vehicles, wrong-way operations and unauthorized vehicles (2).

A partial or full blockage of a transitway in a narrow cross section can occur as a result of mechanical failures or driver error that results in an accident. The length of time the transitway is blocked is critical to both the efficiency and safety of the lane. For each minute that the transitway is blocked, the delay cost per minute increases. As shown in Figure 4-1, a lane carrying 6000 persons per hour will be delayed 50 person-minutes for the first minute the lane is blocked. An additional 50 person-minutes of delay will result when the blockage is removed and the queue is dissipated. The second minute of delay will add an additional 300 person-minutes and for the fifth minute of the delay, 900 person-minutes. Hence, early detection and rapid removal of incidents are crucial in maintaining high levels-of-service on transitways.



Length of time lane blocked in minutes	Additional delay for each time interval in person-minutes	Cumulative delay for total time blocked in person-minutes
0	0	0
1	100	100
2	300	400
5	900	2500
15	2900	25000

Source: (3).

Figure 4-1. Effect of Lane Blockage

4.3 CONCEPTS, SYSTEMS AND TECHNOLOGIES

Surveillance, Communications, and Control refers to automated systems which safely and efficiently manage and control traffic operations on high-speed limited access facilities such as freeways and especially transitways. The collection and processing of data by detectors is traffic surveillance. The provision of information to the motorists through signs, delineation, signals and/or auditory means is communications. The application of traffic restraints on direction of flow by signs and signals is traffic control.

The surveillance function is required to monitor the system, to detect and evaluate the nature of problems encountered, and to determine the appropriate action necessary to restore normal operations. Typically, the surveillance system will monitor the following:

- Volume
- Speed
- Vehicle Classification
- Direction of Travel
- Incident Detection
- Incident Verification and Clearance
- Presence (Ramp Control)
- Vehicle Authorization (Identification, Usage Rates)
- Presence (Merging Warning)
- Operating Rules (Speed, Headways, Passing, etc.).

A variety of surveillance concepts have been used for incident detection. In some instances, the concepts include some elements of verification and the type of response that is appropriate to remedy the problem. However, in most cases, the detection process is an independent function and some form of follow-up is normally required to ascertain the nature and extent of the incident and type of response that is required. The most common surveillance concepts used in the detection of incidents are (2):

- Electronic Surveillance
- Closed-Circuit Television

- Aerial Surveillance
- Motorist Call Systems
- Motorist Alarm Systems
- Citizens-band Radio and Cellular Phone
- Police and Service Patrols

Electronic Surveillance. Incident detection by electronic surveillance is a real-time monitoring of traffic data through the use of detectors installed at critical locations along the roadway. When a delay-causing incident occurs, the capacity of the roadway is reduced at the point of occurrence and, if it is reduced to some figure less than demand, the traffic flow upstream of the incident will be affected. If detected changes in the traffic flow are greater than some predetermined value, the occurrence of an incident would be indicated. In this manner, incidents are detected by logically evaluating the variations in flow characteristics (2).

The main advantage of electronic surveillance is that the system provides a continuous network-wide monitoring capability at relatively low cost. In addition to serving the purpose of incident detection, it can also be used for many other tasks such as establishing metering rates for traffic-responsive ramp metering systems. Its main disadvantage is that the nature of the incident cannot be identified by the system and some follow-up surveillance is required to determine what response is needed (2).

Closed-Circuit Television. Incident detection by closed-circuit television (CCTV) is a real-time monitoring of the traffic stream whereby operators in a central control room can monitor traffic conditions at those locations where cameras have been placed. When an incident occurs, the operator can readily determine the nature of the incident and the type of response that is likely to be required. In general application, closed-circuit television is limited to those locations where delay causing incidents are a chronic problem and fast response is essential. In this use, the television normally serves as a follow-up to electronic surveillance where incidents are detected automatically and an alarm is used to alert the operator (2).

The major advantage of closed-circuit television is that it provides a full view of what is occurring over a section of roadway on a real-time basis. The major disadvantages are (2):

- It is expensive to install and maintain. However, recent technological developments may alleviate this problem.
- It is often difficult and expensive to obtain good monitor pictures under conditions of adverse weather, darkness and bright sunlight.
- Monitoring of the TV screen is a tedious task and without an automatic alarm, operators tend to lose interest and consequently fail to notice incidents immediately.
- Continuous monitoring of TV screens by qualified operators is quite expensive.

The value of closed-circuit television has been difficult to assess. It has proven to be very useful during the initial evaluation and adjustment phases of freeway management projects. It has also demonstrated its value in monitoring critical links on a system where a fast response is often needed to maintain an acceptable level of flow. There is a general opinion that television surveillance is a necessary element of an urban freeway surveillance system but that it should be used on a selective basis (2).

Aerial Surveillance. This type of surveillance is primarily used by police authorities and commercial radio stations to get a general overview of traffic in a particular area or corridor. Through the use of light planes or helicopters, they can observe where the bottlenecks are occurring and determine whether incidents are a major contributing factor. This information can then be broadcast to motorists in the form of advisories or can be used to dispatch assistance to the scene of the incident. Due to the expense of this type of surveillance, a wide geographical area usually has to be covered and, consequently, there is often considerable time delay in the identification and removal of incidents (2).

In general, it has not been conclusively demonstrated that aerial surveillance is a cost-effective technique especially when compared with other techniques. The equipment and the labor-intensive aspects of the system are expensive and its effectiveness is sometimes limited by weather conditions (2).

Motorist Call Systems. One of the earliest incident detection systems used on freeways was a system utilizing motorist call boxes or emergency telephones. With this system, a motorist experiencing an incident or even witnessing an incident proceeds to the nearest call box or telephone and informs the operating agency of the nature of the incident being experienced either by selecting a button having coded messages or by using voice communication. Telephones are generally the preferable mode since the voice communication gives the motorist an opportunity to explain exactly what services are required. Also, the cost of the call box is considerably less than radio voice transmission (2).

The major advantage of a motorist call system is that it is an efficient system of signaling a motorist's need for service. A major disadvantage is the time delay inherent in this type of operation. This is primarily due to the delay associated with the motorist's determining that an incident has occurred, determining that the proper action involves using the call box, locating the nearest call box, and then proceeding to the call box to inform the operating agency. Often, the detection delay in this type of system is quite significant. Another major disadvantage is the large number of "gone-on-arrival" calls that are generated; i.e., the motorist remedies his problem through some other means and when the servicing agency arrives, the disabled vehicle is no longer there (2).

Citizen-Band Radio and Cellular Phone. Another means by which incidents can be detected on freeways is through the use of citizen-band (CB) radios and cellular phone systems. Drivers of vehicles equipped with a CB radio report observed incidents to a central monitoring center which in turn transmits the information to the appropriate agency who dispatches the required assistance. The key elements of this system are the motorists who are knowledgeable about the system and are willing to report the incidents they observe. Because of this volunteer aspect of the CB system, the detection capability of the system is always a function of the number of motorists on the freeway who have the necessary CB equipment and are willing to provide their cooperation. The CB type of system has performed well in Detroit and Chicago and it may have considerable potential (2). The use of cellular phones is still limited, but has proven effective in a number of locations.

Police and Service Patrols. A variety of patrol systems have been used on urban freeways to provide incident detection. The most common is the use of police patrols that circulate in the traffic stream and have as their primary objective the identification of incidents and the determination of the nature and extent of the incident and the type of response that is needed. The major advantage of police patrols is that the detection and response happens almost instantaneously. The major disadvantage is the large number of patrols that are required to effectively cover a freeway system. The costs are high and in many instances police involvement cannot be obtained on a regular basis (2).

Another commonly used system is the service patrol. This system involves the use of light-duty service vehicles and, similar to the police patrols, provides for the detection of incidents as well as minor services such as fuel, oil, water, and minor mechanical repairs (2). This approach is more cost effective than police patrols in that the service patrol can perform other activities concurrently.

The communications system provides information to the users of a facility that will enable them to select and follow the best course of action. The communications task can be accomplished through one or more of the following means:

1) Changeable Message Signs (CMS) which communicate operating rules and general information;

2) Dynamic Signs (DS) which may be used to indicate general facility status (lane open or closed) and advisory/warning messages (merge area ahead, etc.); and

3) Lane Control Signals to indicate (confirm) direction of flow, warning of wrong-way operation, warning of incident or lane closure ahead, etc.

The control function of the SC&C system provides the response in terms of the appropriate control necessary to maintain or restore normal operations. Typical control elements and their functions include:

1) Lane Control Signals
   - Facility Status (lane opened or closed to traffic)
   - Operating Conditions (advance warning of hazardous conditions ahead)
   - Warning Messages (speeding, wrong-way vehicles).
2) Ramp Control Signals
   - Reduce conflicts at transitway intersections
   - Control rate of flow onto transitway
3) Transitway Intersection Signals
   - Close transitways and direct traffic to off-ramps
   - Close ramps and direct traffic to other routes
   - Warn motorists of incident or other hazardous conditions ahead
4) Transitway Vehicle Authorization System
   - Purpose: Refuse entry of unauthorized vehicles to transitway
   - Systems:

     a) Gate System Control
        - Farm type security gates (manual operation by transitway deployment crew).
        - Automatic security gates (remote or local control by transitway authority).
        - Automatic railroad type gate for authorization (local control by transitway users).

     b) Vehicle Identification System (control by enforcement agency).

     c) Manual control by enforcement personnel.

Some of the devices have dual functions of communicating with the driver, while imposing traffic control at the same time. Lane control signals may warn motorists of hazards ahead while also requiring a reduction in speeds.

The following description of the SC&C system proposed for the Houston transitway network illustrates how the various elements of a SC&C system may be utilized.

The SC&C System which will be provided on the transitway system of Houston consists of electronic sensors in the pavement connected by cable to a central computer to measure traffic conditions. The computer will communicate with and control users of the transitway by devices placed over the transitway roadway and access ramps. These devices include programmable message signs, lane control signals, ramp metering signals, vehicle authorization gates, traffic signals and dynamic signs. To verify the electronic systems and to assist in other functions of operations, enforcement and maintenance, a Closed Circuit Television System (CCTV) will be provided.

The Houston SC&C System is designed with distributed logic at several locations to reduce costs and to provide greater system reliability. Local controllers will be used in the field where possible. Their operation will be supervised by an unmanned Satellite Control Center located on each transitway in the system. The Satellite Control Centers will be supervised by a manned Central Control Center some distance from the transitways. This concept reduces the number of operators, field crews, and equipment that would be necessary if each transitway operated independently.

This strategy also provides two levels of backup for continuing operations. The first is the utilization of the satellite control center as a backup control center for a freeway transitway. Each computer can be operated through terminals at the center to maintain control equal to that provided by the CCC. The second backup system consists of independent operation of each control unit in the field.

The Central Control Center (CCC) is a combination of automatic data processing, display and control, and of manual surveillance and control. The operators can monitor the data systems and traffic operations by the computer system printouts, dynamic display maps, and video displays.

The CCC may monitor the operations and controls on several transitways. The CCC can display traffic operations in real-time on closed circuit television, and operations status information on maps with dynamic displays, interactive graphics and computer cathode ray tube (CRT) monitors. The CCC can monitor actions taken by the computer system in response to traffic conditions sensed by the electronic surveillance devices.

The operators of the CCC can use the visual and electronic surveillance systems to determine if appropriate action is being taken by the computer programs. The operators can supplement, replace, or override the control decisions taken by the computer programs. The operators can also dispatch appropriate response services to any transitway.

The CCC can also assume responsibility for the security of the transitway system. The CCC can have radio communication with a central enforcement dispatcher, central transit service dispatcher, and on-site patrol vehicles assigned to each transitway, as well as the operations and maintenance crews.

The Central Control Center-Satellite Control concept provides several advantages to operations management of a transitway system. Advantages of central control include:

- It can be readily determined if equipment and personnel from other transitways should be deployed.
- Response to incidents will be more systematic and consistent throughout the transitway system.
- Expertise of central control supervisors will be enhanced by the opportunity to observe and direct the clearance of a larger number and variety of incidents.

However, costs of a small transitway system would favor the Satellite Control Center concept alone. For a single transitway, the Central Control Center could be completely eliminated without effecting operations. The control center concept at the Houston I-10W (Katy Freeway) transitway, for example, initially employs a <u>manned</u> Satellite Control Center. All "manned" activities of the Satellite Control Center will eventually be transferred to the Transitway System Control Center, which will come on-line as the transitway system nears completion.

4.4 SELECTING THE SC&C SYSTEM

As indicated in Section 4.2, some type of SC&C system is needed to insure the safety and operational integrity of a transitway. The sophistication of the SC&C system needed, however, is a function of the extent and sophistication of the transitway system. Consequently, selecting an appropriate SC&C system will be heavily dependent upon local conditions and resources. However, the SC&C system should be selected with the following general goals in mind:

- Minimize the effects of incidents
- Maximize safety of operation
- Maintain a high level of service of vehicular operations
- Provide facility users with information that will aid them in the efficient utilization of the transitway
- Provide aid to those who have encountered problems on the transitway (i.e., accidents, breakdowns, etc.)

To accomplish these goals, the SC&C system must be capable of monitoring the following:

1) Traffic Conditions such as traffic volumes, speeds and traveltimes;
2) Incidents (accidents, breakdowns);
3) Violations such as violation of lane restriction, wrong-way movement, speeding, etc.

Techniques for collecting traffic data have been well developed and the methodology to be used is generally dependent on what kinds of data are needed and the budget that is available. Table 4-1 summarizes several methods of measurement and lists the parameters each method is capable of measuring (4).

Table 4-1. Methods of Measuring Freeway Traffic Characteristics

Method	Measure							
	Volume, Composition, Vehicle Occupancy[a]	Capacity	Speed & Travel Time	Density & Occupancy[b]	Speed Changes	Headways	Gap Acceptance	Queues
Manual Counts	X	X				X	X	X
Automatic Detectors	X		X	X	X	X		X
Moving Vehicles			X		X			X
Aerial Photography	X	X	X	X	X	X	X	X
Time-Lapse Photography	X		X	X		X	X	X
Closed-Circuit TV	X		X	X		X	X	X

Source: (2).

[a] Vehicle Occupancy - Persons per vehicle

[b] Occupancy - Percent of time vehicles occupy a space on a lane

The use of manual counts is a very common method of gathering traffic data. This involves the use of a person or some groups of persons stationed at selected locations along a freeway to record specific kinds of data. The kinds of data that can be effectively recorded by manual counting includes volumes, vehicle occupancies (persons per vehicle), headways, capacity, gap acceptance and queues. The advantages of manual counting are that it is simple to perform, it doesn't require sophisticated equipment, and the time and cost in data reduction and analysis is generally minimal. The major disadvantage is that a large number of man-hours is required to cover a large system of transitways and consequently manual counting can become very expensive. In addition, the validity of the data is highly dependent on the quality of personnel used (2).

The use of automatic detection is another form of collecting traffic operational data. This type of detection may consist of either portable or permanently installed detectors, but the most commonly used for operational studies are the portable detectors consisting of a sensor (road tube or tape switch) and a recorder system. The principal use of automatic detectors is to measure traffic volume. However, the detectors can be adapted to collect other traffic characteristics such as speed, density, headways and queues. The major advantage of automatic detection is that data can be collected efficiently and economically at a large number of sites and over a long period of time. A major disadvantage is that it is more difficult to obtain accurate counts of vehicle distribution and vehicle occupancy counts. Also, the analysis of the data with certain types of detectors can sometimes be very laborious (2).

Detecting the location of incidents and violations of lane restrictions is a much more difficult task and the choice of methods by which the problems are identified depends to a large extent on what the goals are in connection with incident management. If complete and instantaneous knowledge of the situation is required, then a very sophisticated system such as an automatic detection system will be needed. If on the other hand, the goal is merely to provide aid to those who encounter problems on the facility, some method of communicating with the stranded driver would perhaps be adequate. The more difficult aspect in dealing with non-recurring problems, however, is determining how frequently they occur, how much of a reduction in capacity is caused by the various types of incidents, and how the overall safety of the transitway is affected (2).

In the case of transitways, the choice between manual and electronic surveillance systems is generally not an either/or situation. For example, while it may be possible to manually monitor traffic conditions on a single transitway, some type of automated system will probably be needed to effectively monitor incidents and violations of the lane restriction. Given the relative high-speed nature of transitways, it is essential that users of the facility be advised of incidents and other potentially hazardous situations immediately. Manual incident/operations management procedures will be labor-intensive and the analyst should carefully evaluate the economic trade-offs of manual versus electronic management.

4.5 SYSTEM DESIGN

4.5.1 Background

The system design guidelines presented in this section are designed to provide the users of the transitways with information on traffic and roadway conditions; and to detect and respond to disabled vehicles, wrong-way operation and unauthorized vehicles. This transitway SC&C system design is of a hierarchical form. This design processes data and makes control decisions at several levels. Each of the higher levels requires less data processing, and has the capability of commanding the lower level functions (Table 4-2). Two types of systems are presented: (1) A system with Satellite Control Centers operating independently; and (2) A system with a Central Control Center. Both designs can be implemented in phases and provide back-up capability in case of equipment outage. For example:

Table 4-2. **Distributed Logic System Design for Surveillance, Communication and Control.**

Level of Control	Location of Controller
Highest ↓ Lowest	Central Control Center Controllers Satellite Control Center Controllers Field Controllers

- The communications and control devices can be operated manually in the field from a controller installed near the device. This level of control could be stage one of an operations plan and used for back-up in the event of malfunctions in the computer or data transmission equipment used to send data to and from the Satellite Control Center.
- The SC&C system can be operated manually or automatically by controllers located in a Satellite Control Center adjacent to the transitway. The data from the surveillance systems (CCTV and electronic detection) are processed at the Satellite Control Center. This could be the second stage of an operations plan and a back-up to the Central Control Center.
- The SC&C system can be operated manually or automatically by the central controller at the Central Control Center by communicating with the satellite controllers. The processed data from the Satellite Control Center are transmitted to the Central Control Center for display and monitoring functions.

The Central Control Center concept is founded upon coordination and cooperation between all responsible agencies - city, state, transit authority. It is anticipated that each agency would be represented, either by personnel or equipment, within the Central Control Center.

The Central Control Center concept provides a high level of area-wide network operational control of normal and incident response conditions desired at an acceptably low level of manpower requirements. The Central Control Center concept, typically would have two operators on duty in the control room and unmanned Satellite Control Centers on each transitway. The deployment and enforcement crews would be assigned to the various transitways as required. Incident response systems would be designed to minimize the amount of equipment and personnel by coordination between adjacent transitways. The Satellite Control Center concept without a Central Control Center would require one operator in each of the Satellite Control Centers. As an example, five transitways with five Satellite Control Centers are currently authorized for development in Houston. A comparison of manpower and costs of the control centers and deployment crews is presented in Table 4-3.

As stated previously, the costs of a small transitway system would favor the Satellite Control Center concept. Based on current estimates of control center costs, the break-even point of providing manned Satellite Centers versus unmanned Satellite Centers with a Central Control Center is two transitways (1).

Table 4-3. Summary of Manpower and Equipment Needs for Houston SC&C System

Manpower and Equipment[a]	Type of Control Facility	
	Central Control w/Satellites	Satellites Only
Operators (two shifts)	4	10
Deployment/Response Crew (two shifts)	10	20
Police (as needed)	10	20
Response Vehicles	5	5
Service Patrols	0	5
Maintenance	5	5

[a] Assumes 5 Satellite Control Centers

4.5.2 The Central Control Center

4.5.2.1 Location

Factors which should be considered in evaluating candidate sites include:

1) Accessibility to satellite centers for data transfers;

2) Availability of existing space for the control center staff and equipment;

3) Expandability of site for future expansions of the SC&C system; and

4) Proximity to other similar facilities and services (dispatching, security, data communications).

4.5.2.2 Size and Layout

An example office layout for a central control center is shown in Figure 4-2. The area is approximately 2000 sq. ft., which is sufficient to accommodate all of the SC&C equipment, a control room with two operators, a mechanical room for the electrical and air conditioning equipment, two ofices and one clerical/reception room for staff.

4.5.2.3 Central Control Center Equipment

The equipment normally found in control centers would consist of the computer and its related peripheral equipment, communication consoles, display components, and equipment for dispatching emergency and maintenance vehicles to the problem locations. Table 4-4 lists the required equipment discussed in the following text.

Computer

The computer system receives data for all systems except the CCTV system and the voice communications. The computer processes the data and performs the following functions:

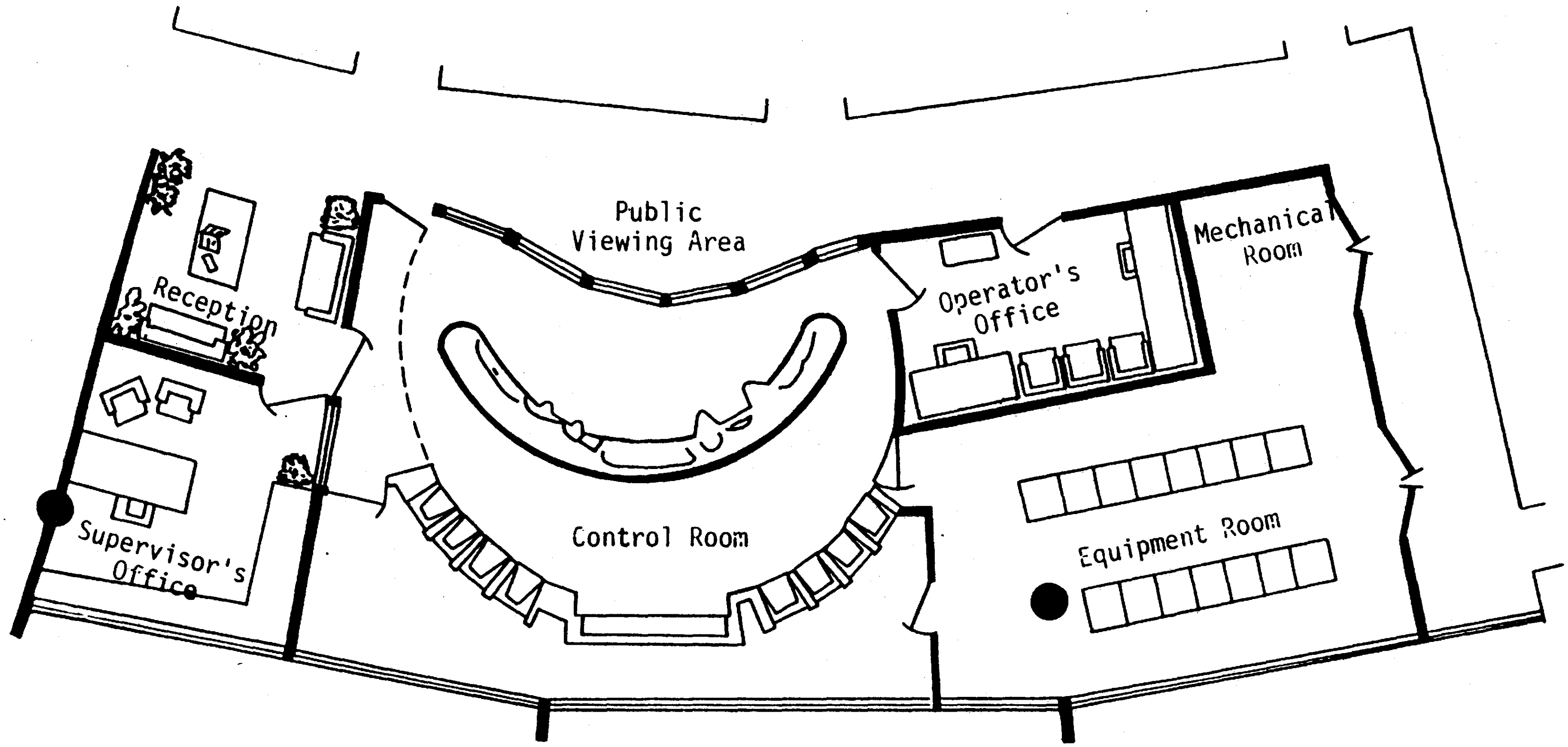


Figure 4-2. Example Central Control Center Layout

Table 4-4. **Surveillance, Communications and Control System Equipment for a Typical Central Control Center**

Computer	Closed Circuit Television	Dynamic Display Map	Control Panel	Communications Data	Communications Voice
Computer color graphics CRT's	17" monitors (wall display)	Graphic display of system	Control switches for SC&C devices	Digital data modems	Telephone headsets
CRT's with keyboards	14" monitors (console display)	Electronic display for SC&C device conditions	Control switches for display map	Computer Interface equipment	Radio systems
Disc Drive	Camera control systems with transitway		Control switches for computer reports		
Tape Drive	Switching system				
Line Printers	Video cassette recorders		Alarm for monitoring traffic conditions		
Character Printers					

Source: (1).

1) Monitors Status of Traffic Operations. The center's computer will monitor traffic volumes and speeds by type of vehicle using the transitway.

2) Activates Incident Alarm System. A satellite computer monitors the detection system for probable incidents that affect operations and/or safety (see Section 4.5.6). If an incident is detected, the satellite computer activates controls to display warnings to the transitway users, and notifies the central control computer of the situation.

The central control computer activates the alarm system to alert the operator and provides traffic operations status reports. The operator can use the CCTV systems, the radio communications system or other surveillance capabilities to verify the incident, and to determine the course of action required to return the transitway to normal operations.

3) Activates Wrong-Way Movement Alarm. The procedure for detecting and responding to a probable wrong-way operation is the same as that for detecting incidents in the same direction of flow. A different computer program is used to monitor the detection system for this function, and a different set of controls and warnings are displayed.

The central control computer activates the wrong-way movement alarm and the operator takes appropriate action to verify the operation and to respond to the situation.

4) Monitors Status of Signs and Signals. All of the electronic equipment in the field will be monitored for proper operation. If a probable malfunction is detected, the central control computer will record the information on hard copy on one of the printers and update a report that is available to the operator on the CRT.

5) Commands Sign Messages. The central control computer can command the changeable message signs by addressing predesignated codes cr by formatting a unique message.

6) Commands Lane Control Signals and Dynamic Signs. The central control computer can change the status of the lane control signals used to convey messages to the transitway users.

7) Controls Access to Transitway. If access facilities are provided with electronic authorization systems that use automatic gates or ramp metering signals that control demand, the central computer can override local controllers to allow or deny entry to the transitway.

Closed Circuit Television (CCTV)

The closed circuit television system receives video signals from cameras placed on 40-foot minimum height poles adjacent to the transitway at approximately 1-mile intervals. The CCC can access any camera through a switching system operated by the personnel in the control room. The number of camera locations that can be displayed simultaneously from the transitway on monitors installed in the wall should be determined in the design phase. The position of the cameras and the functions of the telephoto lens can be adjusted with a camera control system on the console. Video cassette recorders can be used to record the signals from any camera.

The CCTV is an important element of the surveillance system. Its primary function is verification of the electronic surveillance system. It also serves other important functions, such as those listed below:

1) Verification of Electronic Detection. Incident detection algorithms (Section 4.5.6) used to detect the full or partial blockage of the transitway are subject to error because of the spacing of detectors, the malfunctions of detectors, and the variations in traffic conditions. The CCTV enables the algorithm to be biased in the direction of early detection with a higher rate of false calls instead of a late detection with a lower rate of incidents not detected. False calls can easily be confirmed by the visual surveillance.

2) Confirmation of Equipment Operation. The SC&C system should have the capability to confirm the sending and receiving of commands to signs and signals. The CCTV provides an additional check on the proper operation of the device. Also, the operation of automatic gates, the position of manually operated gates and the operation of vehicle sensors can be monitored quickly by one operator from the control room.

3) Evaluation of Incidents. After an incident on the transitway has been detected, located and verified, the CCTV system can provide the operator with information that is useful in determining the actions to be taken. In many cases the type of emergency vehicles to be dispatched and the appropriate routes to be followed can be determined from the CCTV system.

4) Control of a Transitway. Traffic, pavement or environmental conditions undetected by electronic surveillance may dictate the opening or closing of a transitway. The operator with visual surveillance of a

transitway may be able to make these decisions directly or assist the field crews in assessing the conditions.

5) Operation of a Transitway. In addition to traffic incidents and wrong-way operations, there are other operational considerations that must be monitored on a transitway. Some of these are unauthorized use of the lane, speeding, violation of minimum headways, no passing, and in general, unsafe operations. The CCTV system can be used to monitor these operations and to assist the field crews in identifying unsafe drivers.

6) Training Transitway Users and Operators. Video tapes of signs and signals, proper and improper vehicle operations, and emergency procedures can be used to instruct persons that are authorized to use a transitway and the agency personnel that are charged to operate, enforce and maintain the facility.

Dynamic Display Map

The dynamic display map can provide a graphic representation of the transitway and the location and status of the SC&C devices. Computer driven lamps can be used to indicate traffic volumes, speeds and percent occupancy (roadway density) at various thresholds.

The map can provide the operator with real-time information in an easily recognizable format for an entire transitway network. Problem areas can be quickly identified, equipment failures displayed, and the general situation can be continuously monitored, while the operator uses the CCTV and computer systems to examine specific locations for more detailed data.

Control Panel

The control panel provides the operator with direct input to the computer, instead of the standard keyboard with coded inputs. This approach simplifies the actions of the operator, and reduces the time required to make control commands. The control panel can perform four basic functions:

1) Request reports to be displayed on a CRT or to be printed;
2) Activate the display map for its various functions;
3) Control the signs, signals and gates in the field; and

4) Display the visual and audible alarms for various operations, such as incidents, wrong-way travel, unauthorized entry, and condition of field equipment.

4.5.2.4 Staffing

Typically, a control center for a transitway system will be operated in two shifts, 5 days a week. The Central Control Center staff will consist of the following positions:

1 - Supervising Manager
4 - Control Room Operators (2 per shift)
1 - Technician
1 - Clerical/Receptionist

The Supervising Manager will be responsible for the day to day operations and will be present during both shifts. Control Room Operators will be assigned to morning and afternoon shifts. One operator will be able to monitor and control up to 3 transitways. The technician will be responsible for the repair and maintenance of the equipment. The position will require one person.

The CCC should be responsible for the security of the transitway system. The CCC will have radio communication with Police Dispatchers (Transit and Civil) and the police vehicles assigned to the transitway, as well as the deployment operations crew.

4.5.3 Satellite Control Centers

4.5.3.1 General

The ultimate design for a transitway SC&C system calls for a satellite control center housing a minicomputer system which would control and monitor the field equipment via a communications system. Visual surveillance and voice communications with each field cabinet would also be included. The system block diagram in Figure 4-3 illustrates this concept.

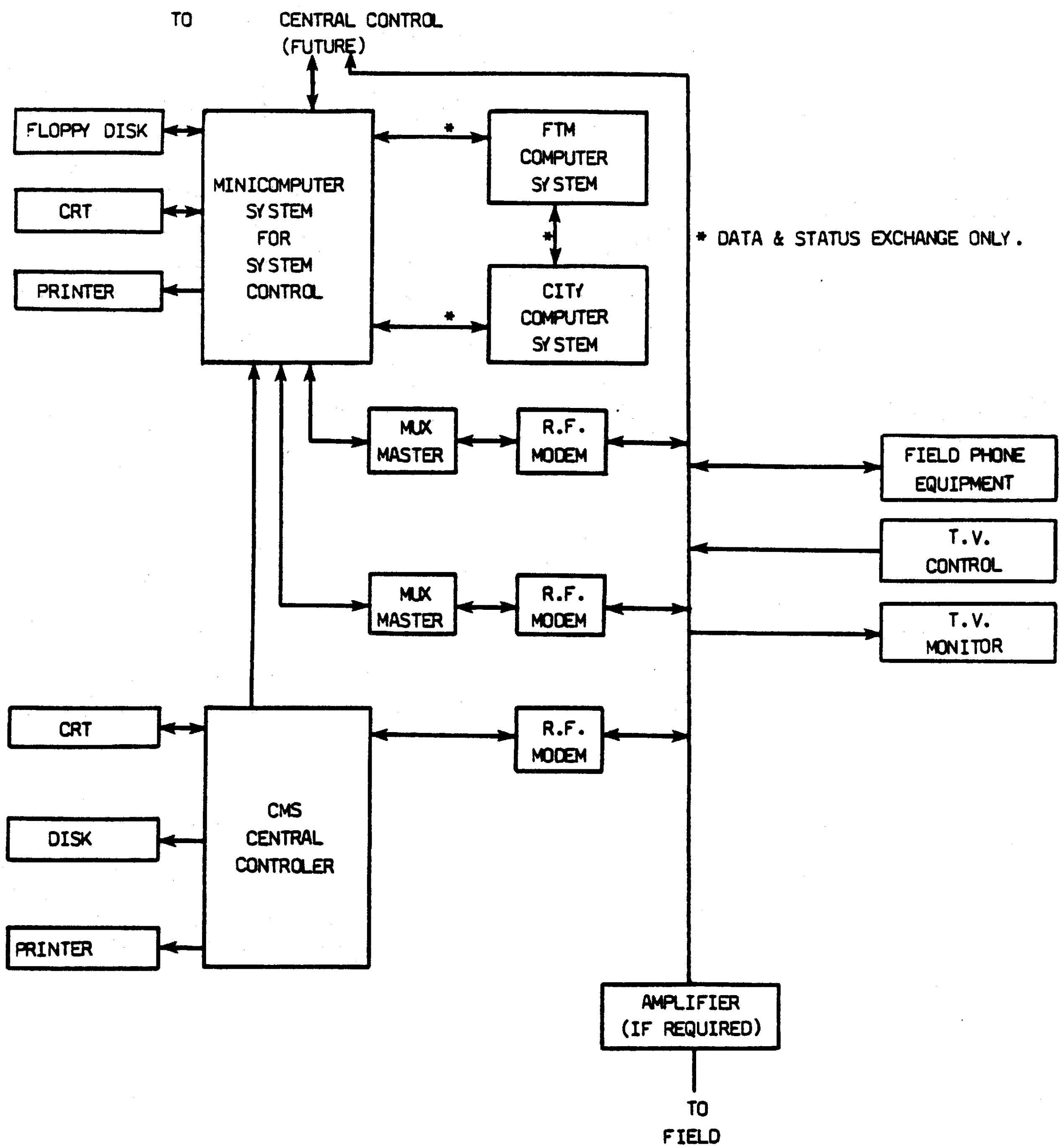


Figure 4-3. Typical System Block Diagram for a Transitway SC&C System

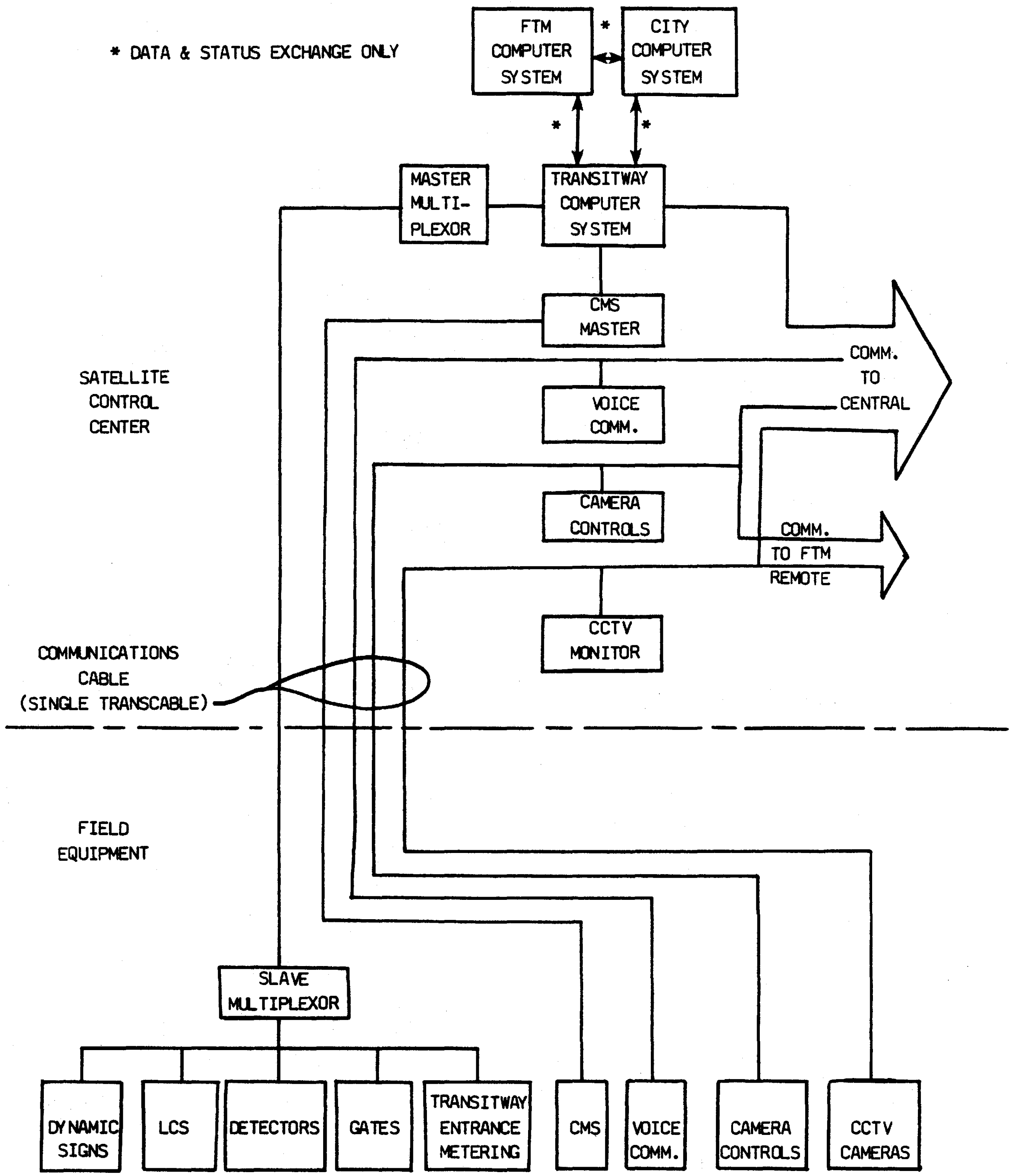
The satellite control center is intended to function as an unmanned control center capable of automatically controlling the transitway SC&C system. All manned activities such as report printing and operator overrides would ultimately be performed at the transitway central control center. Figure 4-4 shows the functional interrelationships between the units of equipment in the satellite control center.

The minicomputer and the associated software would provide the primary system control. The minicomputer would directly control and monitor the lane control signals (LCS), the dynamic signs and any future barrier gates. Any future transitway entrance metering equipment could also be supervised and monitored by the minicomputer. The minicomputer would process the detector data which would be returned to the satellite control center from the field loop detectors via slave multiplexors. The communication between the minicomputer and the field equipment would be via RF modems and multiplexors. The minicomputer would also supervise the central changeable message sign (CSM) controller which directly control the CMS along the transitway via the field CMS controllers. The TV system and the voice communications system would each operate independently over coaxial cable or fiber optic cable.

The following sections describe the key functional elements of the satellite control center system configured as a manned facility initially. All manned activities will ultimately be transferred to a Transitway System Central Control Center (5).

4.5.3.2 Satellite Control Center Building

A 500 square foot building (inside dimensions of 12' x 42') has been specified to house all of the central control equipment for the I-45N transitway SC&C system, the freeway traffic management system and a future city traffic signal system. Space will also be provided for the addition of future communications with the central control center. Figure 4-5 illustrates the equipment layout.



Source: (5).

Figure 4-4. Functional Diagram Satellite Control Center

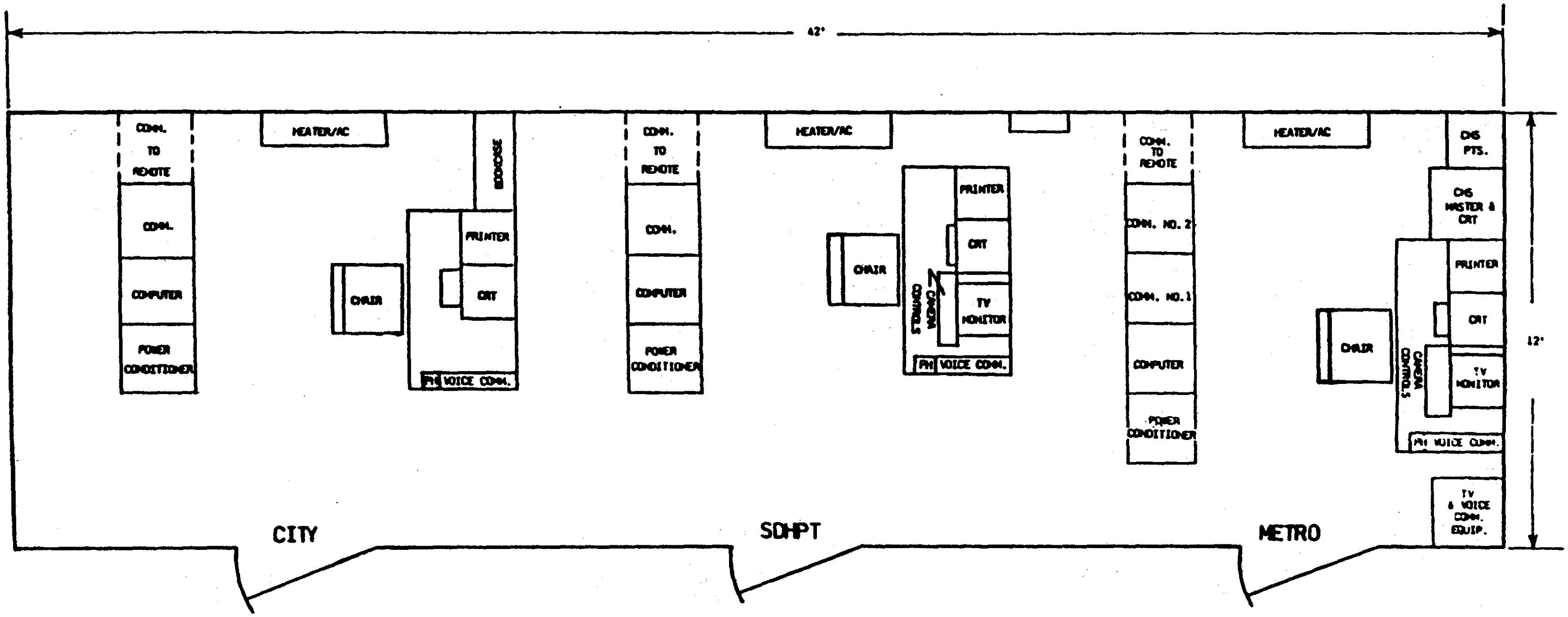


Figure 4-5. Typical Satellite Control Center Equipment Layout

The building will have a raised computer floor to permit the interconnecting cabling to be concealed, a fire protection system and a security system to alert officials in case of a break-in. Special grounding and lightning protection systems will also be specified. A chain link fence will be specified to enclose the building and parking lot.

4.5.3.3 Equipment

Equipment for a Satellite Control Center would typically consist of the following:

- TV monitor
- TV controls and electronics
- Changeable message sign central controller and peripherals
- RF modems
- Voice communications equipment
- Satellite minicomputer and peripherals
- Minicomputer line conditioner
- Master multiplexors
- Cabinets for satellite minicomputer and communications

4.5.3.4 Electrical Requirements

Grounding

A quarter inch thick suitably sized aluminum plate should be installed centrally located under the raised floor. Each unit of electronic equipment should have its chassis connected to this plate via a separate insulated ground wire sized in accordance with each manufacturer's recommendation. The plate itself should be connected to the safety ground at the entrance to the building via a 1/0 insulated ground wire.

AC Power Line Conditioner

The AC power line conditioner should include an isolation transformer of the electrostatically shielded type. The transformer should be a single-phase, common-core, air cooled, dry-type, with a maximum 150°C rise above

40°C ambient, utilizing a 220°C (minimum) insulation system and be convection cooled. The transformer should have an average 3.5% regulation, 3% reactance, 55 dB minimum common mode noise attenuation, and common/transverse mode attenuation at 10 KHz of 80 dB. The transformer would typically produce less than 0.5 percent of harmonic distortion and a full-load efficiency of 97%. The transformer's primary input should be compatible with the satellite building's electrical power.

A minimum of 4 additional full capacity voltage compensation taps each at 2 1/2% increments, should be provided. Two taps would be above the normal ANSI standard systems voltage and 2 taps below. These taps would provide compensation for final site voltage irregularities.

The output of the line conditioner should feed a circuit breaker panel similar in construction to the main circuit breaker panel. The panel would feed the following single phase equipment:

- TV monitor
- TV demodulators
- Changeable message sign central controller
- RF modems

AC Power Line Input Surge Protection

The AC power line input surge protection should be provided with a UL listed, totally sealed, secondary class lightning arrestor, factory wired and electrically located at the input to the AC power line conditioner. The lightning arrestor should pass surge energy to the building safety ground at the incoming connection to the building. The lightning arrestor should be rated at a maximum 2.6 KV discharge crest voltage and 1,500 amperes peak current, assuming an 8 x 20 microsecond surge current waveform.

4.5.3.5 Minicomputer Subsystem

A minicomputer system will provide the primary control for the I-45N transitway SC&C system. The peripherals to be provided with the minicomputer include a dual floppy disk drive, a CRT/keyboard for operator interface with the system, and a character printer to obtain copies of reports.

4.5.3.6 Central Communications Subsystem

The necessary master multiplexors for the I-45N communications subsystem would use modems to interface the master multiplexors with the communications cable. Each master multiplexor and modem will serve up to four slave multiplexors that are located along the transitway.

4.5.3.7 Changeable Message Sign (CMS) Controller Subsystem

The master controller for the CMS should be provided by the manufacturer of the CMS. A CRT and keyboard would permit operator interface with the system and a floppy disk drive should be provided for loading of the control program and sign message library. A printer would also be provided primarily as a hard copy logging device. An RS232 interface will be provided for interface with the minicomputer. The output from the CMS controller will be connected to a modem for transmission over the communications cable to the changeable message signs along the transitway.

In the normal mode, the central CMS controller will act as slave to the minicomputer. It will periodically receive commands from and send status data to the minicomputer.

The central CMS controller can function as a stand-alone subsystem without the minicomputer. From the CMS keyboard/CRT, the operator can generate commands to the field CMS controllers. Return status from the field can be displayed on the same CRT.

In either operational mode, the central CMS controller will generate routine polls to all the CMS. Any equipment failure will be flagged on the CRT and/or reported to the Nova 4 minicomputer.

4.5.3.8 Voice Communications Subsystem

Central phone equipment will be provided for the I-45N satellite control center to permit the operator to have "party line" voice communications with personnel at any of the field cabinets. Voice communications will be via the communications cable network using a frequency modulation (FM) technique.

4.5.4 <u>SC&C Hardware</u>

4.5.4.1 General

The monitoring of traffic performance and the monitoring of motorist communications and traffic control systems is termed surveillance. The information provided by surveillance systems is used in many functions. These include: 1) Determination of the status of the communication and control systems; 2) Detecting and locating the occurrence of incidents; 3) Selecting control strategies that are responsive to traffic conditions; and 4) Evaluating the effectiveness of control.

A transitway network will typically employ the following three methods of surveillance: 1) Field observation by the field crews, bus drivers and Police; 2) Electronic Surveillance with loop sensors in the pavement connected to a mini-computer; and 3) Closed-circuit television from roadside camera installations. These systems provide continuous, network-wide monitoring during the times the transitways are operational.

Communications systems provide, real-time information to the users of the transitway that will enable the motorists to drive more safely. The messages may be regulatory, advisory or informational, depending on the device and the needs. The Houston transitway network will employ the following four methods of communications: 1) Radio communications with transit vehicles and the radio dispatcher; 2) Changeable message signs of a dot matrix design; 3) Dynamic signs with a single message when activated; and 4) Lane control signals that control operations and communicate with transitway users. The communications systems provide vital information on traffic and roadway conditions ahead and actions to be taken by the transitway users.

The control systems for the transitway network are concerned primarily with access to the transitways. But, as noted earlier, control can also be applied to traffic on the transitway by the communications systems. The Houston transitway network will employ the following four methods of control of access: 1) Barrier gates operated manually by the field crews; 2) Ramp metering signals; 3) Intersection traffic signal systems; and 4) Automatic gates activated by automatic vehicle identification systems. These control systems will be used to secure the transitway during times the transitways are not open, meter the traffic that enters from interior ramps, control transitway intersections with entrance ramps, and monitor/control unauthorized use of the transitways.

This section of the manual describes the system requirements for the detection and surveillance, and communications and control devices which may be required to operate a transitway network. As with earlier sections, much of the material comes from experience gained in designing the SC&C system for the Houston transitway system. Nevertheless, the basic design considerations should be applicable to other similar urban areas as well.

4.5.4.2 System Requirements

Detection and Surveillance

A detection system is used to record the time a vehicle passes a point on the roadway or to determine when a vehicle is occupying an area of the roadway. This information is transmitted to a control unit or a computer which makes control decisions or calculates traffic variables from which to measure the traffic performance. The functional requirements are the same as those used at traffic-actuated signal installation for the assignment of rights-of-way at intersecting roadways.

There are six types of vehicle detectors that are available for use on streets and highways. They are: induction loop detectors; magnetic detectors; magnetometers; pressure sensitive devices; radar; and sonic detectors. There are also two detectors that may have special applications to transitway operations: 1) High-intensity light detectors used for priority control of signals for emergency and transit vehicles; and 2) Photo electric systems used to detect overheight vehicles.

The induction loop detector has a number of advantages over the other types of detectors. These include: 1) Loops are the most commonly used sensor; 2) The loop detector can detect the presence of vehicles; 3) Loops are embedded in the pavement; 4) Equipment and installation costs are low; and 5) The detectors are accurate and reliable.

Many of these positive factors for loop detectors may rule-out use of the alternative types of detection. For example, radar, sonic and light sensitive detectors required overhead mounts which may be impractical for transitway designs. Pressure sensitive detectors do not measure presence. Magnetic detectors do not detect slow moving vehicles accurately. Experience with the magnetometers has indicated that they are unpredictable. In general, the loop detector appears to be the best technology available for sensing vehicle presence.

The detection system is used to measure vehicle speeds, volumes, lane distributions, vehicle classification and direction of travel. The detection system design for the main lane of the Houston transitways places detection stations at approximately one-mile spacings. Each detection station consists of three loops separated by 30 feet. Each loop is 6-foot by 6-foot and is installed in the center of the transitway.

The detection station spacing of one mile is recommended because of incident detection requirements. One possible incident detection program would use a closed system count-in count-out procedure for detecting flow discontinuities. The time required to detect a blockage would be dependent on the maximum allowable travel time between detection stations. A second possible algorithm that uses a statistical approach. This algorithm appears to be more practical for higher volume conditions. These algorithms are described in Section 4.5.6.

For the worst case condition, a speed of 15 mph was considered the minimum speed for determining the maximum allowable travel time. This speed represents a crawl speed which would result from passing a stalled vehicle on the transitway. Experience from the North Freeway Contraflow project in Houston indicates that the response and clearance time for incidents should not exceed 20 minutes. The calculation of the worst case drive time for emergency vehicles indicated the detection time should not exceed 4 minutes. This requires a detector spacing of 1 mile.

The use of 3 loops at each detector station is suggested to be utilized with a computer program that will distinguish when two successive detectors are occupied by one vehicle. The spacing of the loops 30 feet apart will enable the classification of transitway traffic by vehicle length in order to count the number of buses, vanpools and automobiles using the lane.

The computer program will also measure speeds of the vehicles by detecting the travel time between two successive loops. It will also determine the direction of travel. Three loops would be used to provide three measures of speed and verification of the direction of travel. Also, in the event that one loop malfunctions, the two remaining loops will provide sufficient information for continuous operation.

The detection system is the most critical element in the surveillance of the transitway. It provides information on which traffic control, communications and incident response decisions are made automatically by the control computer. Because of the limited width of most transitways and the long distances between access points, the time required to detect, locate and remove incidents must be minimized.

The detection system also provides the data on which the efficiency and effectiveness of the transitway can be measured. Manual collection of the data on a regular basis would require two or more persons.

A typical loop detector installation consists of an amplifier/detector, lead-in wire to the loop, loop wire in the pavement, and other materials to protect the wire. A typical design would have a 6-foot by 6-foot loop placed in the center of the travel lane with lead-in wires brought to the edge of the pavement and into a concrete pull box. From the pull box, wires placed in conduit would run to the amplifier/detector that would be in a controller cabinet within 700 feet of the loop.

The cost of an amplifier/detector is approximately $120 to $140 and the cost of labor and materials to install the loop and lead-in averages $300 to $350 (as of 12/85). The length of lead-in runs, locations of loops in the pavement and type of pavement are some of the variables that affect costs. A major cost factor in installation is the control of traffic if the roadway is open. This can often result in hundreds of dollars per loop in manpower and equipment to handle the traffic. Since the transitway is separated from normal traffic, these costs are typically not important factors.

The technology for loop installation is well defined. There is no special installation expertise required. But with any electrical circuits, the wire must not be damaged during installation. Careful placement of the wire in the saw cuts and conduit is essential.

Closed Circuit Television (CCTV) has been used to monitor traffic operations for over 25 years. Its greatest application has been on facilities with very limited access, such as bridges and tunnels. The transitway design has the same characteristics with the additional restrictions of narrow widths and reversible operations.

For the Houston transitway network, the CCTV cameras are located on the transitway terminals, at each transitway interchange, and along the transitway such that the spacing is approximately one mile. With full pan/tilt and zoom lens capability, the maximum viewing distance is 0.5 miles. This design provides approximately 100 percent coverage of the transitway mainlane. There will always be a few blind spots caused by structures and roadway alignment, but each location should be field-checked to provide the best location for the camera mounts. The cameras are installed on 40 foot poles on the side of the freeway so that maintenance crews can service the camera without blocking a lane of travel. The video signal is transmitted over coaxial cable or fiber optics cable to the Satellite Control Center and to the Central Control Center by microwave or cable. The Satellite Control Center is equipped with one monitor and a camera controller for use in maintenance of the system. A video switcher enables the maintenance technician to call up any one of the cameras on the transitway.

The data transmission system is designed to send all of the video signals from Satellite to the Central Control Center. Typically, a Central Control Center for a transitway network will have four monitors for each transitway, a video switcher and a camera controller. The operator can simultaneously display the video signals from the four cameras. This enables the operator to view an incident scene from downstream and upstream locations while monitoring major access points. The number of cameras to be displayed simultaneously is a design decision.

The CCTV system should be capable of providing clear pictures when the light level is low. The movement of vehicles or an incident causing a lane blockage should be identifiable at light levels as low as 0.2 footcandles.

The primary function of the CCTV system is verification. The CCTV will be used by an operator in the Central Control Center to confirm that the signs, signals, gates and detectors on the transitway are working properly. After a probable traffic incident is detected by one of the surveillance systems available to the operator, the CCTV system can be used to verify the location, type and severity of the incident. The CCTV system can be useful in directing emergency vehicles to the scene as well.

Visual surveillance will be useful in monitoring the normal operations of the transitway for events such as unauthorized use of the lane, improper use of the lane, and hazardous conditions such as water, ice or debris on the roadway. The CCTV can be a labor saving system in performing maintenance activities and in the routing operation of reversing the lane.

The 1985 unit costs for a CCTV camera link, including the camera controls and Central Control Room and equipment is about $22,000.

Communications and Control

Changeable message signs (CMS) can be used on the approaches to entrances and interchanges to the transitway to provide the transitway users with information on the condition of the lane, special actions that may be required to improve safety and reduce travel times, and other information that is pertinent to the operation of the transitway. Because of the number of messages that may be required, a sign system that has the flexibility to develop unique messages as well as display pre-programmed messages should be considered.

Table 4-5 presents a comparison of two types of dot matrix technologies which may be considered for a transitway network. Changeable message signs typically use a disc dot matrix configuration with each character formed by a 5 x 7 dot matrix. Illumination is provided to improve the night time visibility.

The rotating drum design may be considered for locations that do not require unique messages. This technology has the advantage of changeable color for backgrounds to increase the visibility and impact of messages.

The CMSs will typically consist of signs with three lines of 20 characters each, and a fixed header reading. The letter height will be 18" for locations on the high speed approaches on the mainlanes of the freeway and 12" for locations on low speed approaches on city streets. The changeable message signs can be operated from three locations: in the field at a control panel accessible from the transitway; from the Satellite Control Center; and from the Central Control Center.

Table 4-5. **Comparison of Two Types of Dot Matrix Technologies**

Characteristic	Technology: Lamp Matrix	Technology: Disc Matrix
Capital Cost	$80,000	$60,000
Operating Cost	$1,975/year	$195/year
Reliability	Bulb life, 1500 hrs Bulb failure 25 bulbs/ month	Disc life, 100,000,000 rotations, No. of failures = 0.03 disc/month
Visibility		
Daylight	Depends on sun angle can wash out	Depends on ambient light, Normally good
Night time	Good	Good if illumination provided
Default Condition	No message during power failures	One of three conditions: 1) Last message 2) Default message 3) Blank

Source: (1).

The signs should be located on the approaches to the entrances to the transitway and on the transitway approaching the interchanges to access ramps. The signs on the approaches to the transitway should indicate whether the lane is opened or closed, if there is congestion or incidents along the lane, and other information such as operating regulations and authorization procedures.

The signs on the transitway approaching the intersections can be used to identify the access ramps, to advise of traffic conditions ahead, and to close the lane and direct traffic off the lane at the intersections if conditions warrant. The use of the changeable message signs on the transitway simplifies transitway signing and provides a more responsive communications system for the transitway users. A design of 12" letter heights should be used on the transitway.

The transitway operation requires special considerations for motorist information. The times of operation will vary due to weather and traffic conditions. The transitway must be opened, the direction of travel reversed, and the transitway closed each day. There are special authorization and enforcement procedures that need to be communicated to the users of the transitway. The changeable message sign system enables the Central Control Center to perform these functions, reducing the manpower requirements for the field crews.

The unit cost for the typical changeable message sign used on transitway network is approximately $65,000. This is based on 1 large (18" letter height) and 5 small (12" letter height) signs, and one micro processor controller. The cost of the structure and interconnecting cables are not included.

<u>Dynamic signs</u> (DS) are single-message signs that are made operational during selected time periods. They are used on the transitway network to advise motorists approaching the access facilities if the transitway is open for use. Three types of single message signs may be considered: 1) A fixed message that is readable at all times, but is operative only when flashing lights are on; 2) "Blank-out" signs that can only be read when illuminated; and 3) "Fold-out" signs that can only be read when hinged parts of the sign are activated to an open position.

The fixed message with flashing lights sign, is recommended for use on transitways for the following reasons: 1) This type of sign is commonly used with traffic control systems; 2) The yellow flashing lights increase the target values (for the users of the transitway who are not repeat drivers, the message is conveyed at distances far exceeding the legibility of the sign); and 3) Maintenance for this type of device is low.

A yellow and black sign with the message "TRANSITWAY OPEN WHEN FLASHING" should be positioned on the approaches to the access ramps to the transitway. The signs should be placed far enough in advance to permit drivers to adjust their routes of travel. Two 8-inch yellow lights should be attached to the sign to flash alternately to activate the message. The signs can be activated by the Satellite Control Center, under the supervision of the Central Control Center.

Typically, transitways will open and close according to a preplanned time schedule. However, there may be situations that will require the time schedule to be modified. Also, transitway users will frequently approach the transitway at times just prior to the scheduled time of opening. The advanced warning signs for the lane will assist the driver in making the proper decision in the route to use. This will reduce travel delays and improve safety on the transitway approaches.

The estimated cost for installation of a 36" by 35" sign with two yellow lights and flasher unit is $500. This cost does not include the service connections which provide power for control and communication devices.

Lane control signals are part of the communications and control systems of the transitway. Specific messages are to be conveyed to the transitway users by the manner in which the signals are displayed. Table 4-6 shows typical signal indications for key transitway messages.

Two types of signal heads maybe considered for a transitway network; fiber optics and programmable. The fiber optics design was selected because of its reliability and visibility. The characteristic of being visible from the freeway lanes outside the transitway was not considered to be a problem. The signal face of the lane control signal is 18 inches wide and 18 inches high.

The lane control signals should be located at each entrance to the transitway to inform approaching motorists that the transitway is opened or closed, and which lane on the ramp to use, if multilane ramps are available. The lane control signals should be located on the transitway mainlane near each ramp intersection to confirm to motorists entering the lane that they have made a proper turn from the entrance ramp.

Additional lane control signals should be placed along the transitway with spacing between successive signals of approximately one mile. The

Table 4-6. **Typical Transitway Lane Control Sign Messages**

Message Conveyed	Signal Indication[a]	
	Inbound	Outbound
Transitway Open	Green Arrow	Red X
Transitway Open - proceed with caution	Flashing Yellow Arrow	Red X
Wrong Way Vehicle	Flashing Yellow Arrow	Flashing Red X
Transitway Closed	Red X	Red X

[a]When the lane is reversed, the signal indications are also reversed.

purposes of the signals are to confirm the proper direction of flow and to provide information on traffic conditions ahead. The design should be such that at least one lane control signal is in view of the transitway user at least 90 percent of the time. The signal head should be at least 16" in height.

The Manual on Uniform Traffic Control Devices (6) requires the use of special overhead signals when the direction of travel on a lane or ramp is reversible, or on a freeway where it is desired to keep traffic out of certain lanes at certain hours. These requirements are supplemented by the need to inform users of the transitway of traffic conditions ahead.

The cost of one two-way lane control signal with a standby timer is estimated to be approximately $3500.

Ramp metering signals are used on entrances to freeways to control the rate of flow and to improve the merging maneuvers of the ramp traffic (7). For transitways that have intermediate access facilities, most designs specify right angle intersections with the transitway. Therefore, the metering signal would not impact the merging maneuver, but would be used to control the rate of flow on the mainlane of the transitway.

The SDHPT design for ramp metering should be used on transitway ramps. This consists of traffic signal controllers with pre-set rates of flow that can be activated by information from the Satellite Computer. Two standard 3 color indicator signal heads mounted on both sides of the ramp are operated by the controller which is installed adjacent to the ramp. A loop detector on the approach to the signals is used as a demand detector to activate the signals. Usually, the signal timing is set to permit one vehicle to pass for each green/yellow phase, and the rate of flow is determined by the length of the red phase.

The ramp metering system should be used only on the interior access ramps of the transitway. The signals are placed downstream of the changeable message sign, lane control signal and dynamic signs used on the access ramps. The ramp metering system should not be placed on a bridge structure, unless absolutely necessary. If there is no other alternative location, a different presence detector, such as a sonic or radar unit can be mounted above the roadway, or a micro loop can be mounted under the bridge deck.

Estimates of demands for transitways with only vanpools and transit vehicles do not appear to be sufficient to justify ramp metering. However, the introduction of carpools may significantly increase the transitway volumes. If the definition of a carpool is set at 3 or more persons, transitway demand may exceed capacity, at least during the peak periods.

Because of the high volumes of persons on the transitway, a disruption of flow caused by congestion or incidents should be avoided. Ramp metering has proven to be very beneficial on high volume freeways, with cost/benefit ratios in excess of 12 to 1.

The cost to install a metering system is estimated to be $20,000 per transitway ramp.

<u>Unauthorized Use</u> of a transitway network is a major concern in SC&C design. In preliminary planning for securing a transitway network from the entry of unauthorized vehicles, automatic gates may be installed on the access ramps and police officers may be stationed at the transitway

transitway terminals. The automatic gates may be activated by either active or passive devices issued to the transitway users. These systems may be installed at a later date after evaluating the problems of unauthorized use of the transitway.

One approach used on a transitway network is to use police to monitor the high volume entry points at the transitway terminals and to issue citations to unauthorized users as they exit the transitway. As the network increases and more access points are constructed, monitoring the transitways will be more difficult. Therefore, the installation of Automatic Vehicle Identification (AVI) systems on the ramps may be considered. These systems will detect unauthorized vehicles and alert the Central Control Center operators, and/or the police at exit points.

A list of options for AVI equipment, with advantages, disadvantages and costs, is shown in Table 4-7. The optical reader with bar code label was recommended for the following reasons:

1) it is not subject to vandalism;

2) costs are comparable to other systems (except the lower cost card reading systems which are subject to vandalism);

3) no maintenance required on vehicles;

4) installation of label on vehicle requires minimal effort; and

5) the reader has good performance record with Delaware River Port Authority.

The AVI system should be installed on the entrance ramps to the transitways. They should not be placed on bridge structures if loops are to be used in the pavement. The AVI system must be positioned such that only vehicles committed to enter the transitway will be detected. The AVI should be connected to the data communications system and monitored by the Satellite and Central Control Computers. The Central Control Operator may verify any unauthorized entries by CCTV and radio the appropriate police unit to respond to the situation.

Table 4-7. **AVI System Advantages and Disadvantages**

Manufacturer	Type (Cost)[a]	Advantages	Disadvantages
Automatic Toll System	Optical Reader ($105K)	1. Requires no active equipment on vehicles - only passive label. 2. No maintenance required on authorized vehicle responders. 3. Cost for each vehicle is $0.08.	1. Cost per entrance is $20,000. 2. Requires slow speed close to optical reader to read labels. 3. Optical reader somewhat susceptible to vandalism.
Sarasota Automation	RF XMTR/RCVR	1. Speed of vehicle not critical. 2. Lateral location of vehicle is not critical within a normal traffic lane. 3. Cost per entrance is $400.	1. Requires that electronic equipment be mounted underneath the vehicles and connected to vehicle power system. 2. Cost per vehicle is $40-$75. 3. Requires active equipment on each vehicle. Being mounted underneath vehicle makes it more susceptible to damage. 4. Unique installation required for various vehicles.
Philips Industrial Automation	Microwave XMTR/RCVR ($88K)	1. Speed of vehicle not critical. 2. Transponder can be mounted on dash. 3. Lateral location of vehicle is critical within a normal traffic lane. 4. Requires no power connection to vehicles.	1. Has not been used in outside traffic environment although it has been subjected to wide temperature ranges in manufacturing process. 2. Requires active equipment on vehicles. 3. Requires maintenance of electronic equipment for each vehicle. 4. Cost per vehicle is $60 and cost per entrance is $5,675.

Table 4-7. (Cont.)

Manufacturer	Type (Cost)[a]	Advantages	Disadvantages
Alta Technology	Strobe Light & Infrared ($120K)	1. Speed of vehicle not critical. 2. Lateral location of vehicle is not critical within a normal traffic lane. 3. Cost per vehicle is $10. 4. Transponder can be mounted on dash. 5. Requires no power connection to vehicle.	1. Requires electronic equipment in vehicle. 2. Requires active equipment for each vehicle. 3. Cost per entrance is $15,000 - $20,000. 4. No operational systems to verify operation.
Cincinnati Time	Magnetic Card ($7K)	1. Cost per vehicle is $1.30. 2. Cost per entrance is $600-$800. 3. Requires no active equipment on vehicle.	1. Cards must be inserted in a slot which is subject to vandalism. 2. Vehicle must stop for card insertion. 3. Card is very portable and could be lost or forgotten. 4. Lateral location of vehicle is critical to be able to reach card reader.
Cincinnati Time	Proximity Card - ($11K)	1. Cost per vehicle is $6.20. 2. Cost per entrance is $600-$800. 3. Requires no active equipment on vehicle. 4. Does <u>not</u> require insertion of card in a slot. Not subject to vandalism.	1. Vehicle must stop for card to be read. 2. Card is very portable and could be lost or forgotten. 3. Lateral location of vehicle is critical to be able to reach card reader.

Table 4-7. (Cont.)

Manufacturer	Type (Cost)[a]	Advantages	Disadvantages
Federal Signal	Magnetic Card - ($11K)	1. Cost per vehicle is $1.50. 2. Cost per entrance is $1,500. 3. Requires no active equipment on vehicle.	1. Vehicle must stop for card to be read. 2. Card is very portable and could be lost or forgotten. 3. Lateral location of vehicle is critical to be able to reach card reader.

Source: (1).

[a] Cost estimated for 5 entrances and 750 vehicles.

Because of the limited access points to the transitways and their special operating conditions, it is important for the safety and efficiency of the transitway network that only persons who have the training and information available through the authorization process be allowed to use the transitway. The type of authorization control system to be used will depend on the size of the transitway network and the design and operation of support facilities. The use of staging areas with signs, signals and good circulation pattern will reduce the possibility of inadvertent entry by unauthorized vehicles.

The use of the automatic vehicle identification will have to be compared with the use of manual surveillance to determine the most cost effective approach. A typical system would cost approximately $20,000 per entrance ramp.

Intersection Traffic Control Signals are used at the intersection of the entrance ramps with the mainlanes of the transitway (7). The signals are used to permit or deny certain movements at these intersections. For example, if an incident has blocked the transitway downstream of the intersection, the traffic signals would indicate a red signal over the thru lane and green arrows in the direction of the access ramps. The purpose of this control is to close the transitway and divert traffic from the incident to the city street system or normal freeway lanes.

Summary

The typical design for a transitway network may have the following features: 1) Two terminals; 2) Access ramps at 2.5 mile spacings; 3) Changeable message signs on all approaches to terminals and access ramps; 4) CCTV cameras at one mile spacings; 5) Detection stations at one mile spacings and on each access ramp; 6) Signal control at access ramp intersections; and 7) Lane control signals at one mile spacings and on access ramps.

The discussion of hardware included ramp metering signals and automatic vehicle identification systems. These surveillance and control systems should be implemented on an as needed basis; i.e., if volumes and/or violation rates increase to levels that affect the efficiency, safety and integrity of the transitway operations.

For the typical design the average cost for SC&C hardware is $265,000 per mile. This represents less than 5 percent of the cost of construction of a typical at-grade transitway with elevated interchanges.

The majority of the hardware is concentrated at the critical sections of the transitway where transitway vehicles interchange with the street system. If a reduction in hardware costs was required, the following equipment in order of priority could be deleted: 1) CCTV cameras between transitway interchanges; 2) CMS on the approaches to the transitway from the adjacent street system; and 3) Lane control signals between transitway interchanges. This would result in a reduction of approximately $65,000 per mile, but total visual coverage of the transitway would not be available, and a different form of dynamic signs would be required to replace the CMS's on the ramp.

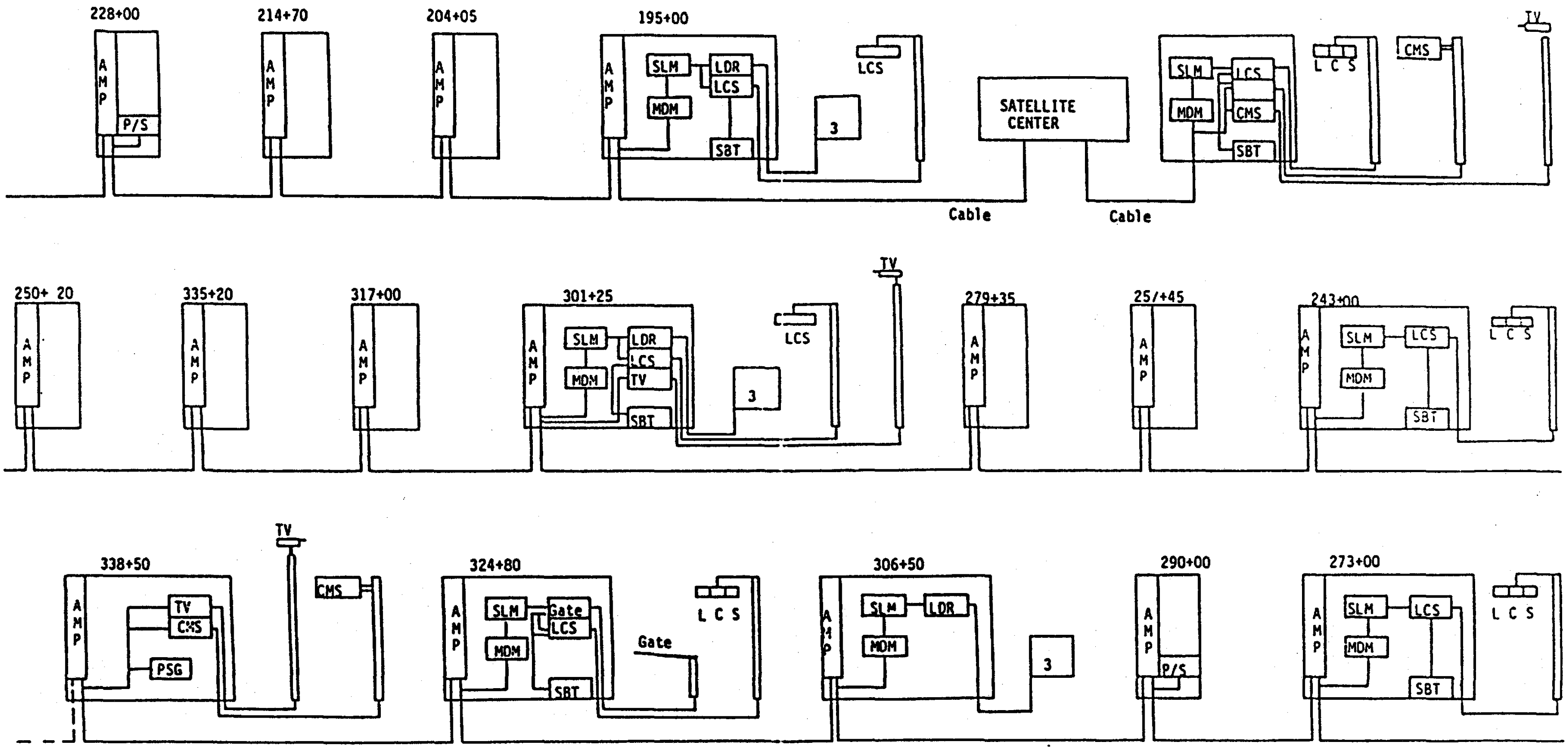
Figure 4-6 presents an example of a field layout for a surveillance, communication and control system on a transitway. Figure 4-7 illustrates the functional diagram associated with a field controller.

4.5.5 Data Transmission Systems

4.5.5.1 General

Five types of communications systems may be evaluated for possible use in a transitway network: (1) Microwave; (2) Coaxial cable; (3) Fiber optics cable; (4) Wire pair cable; and (5) Air path optics. Due to video transmission requirements, the wire pair cable and air path optics technologies seem to be infeasible for use in a transitway SC&C system.

The recommended design for the first Satellite to Central Control Center communications link is a microwave system. The primary reason for this



AMP - Line Amplifier
CMS - Changeable Message Sign
LDR - Loop Detector
LCS - Lane Control Signal

MDM - Modem
P/S - Power Supply/Battery Backup
PSG - Pilot Signal Generator

SBT - Standby Timer
SLM - Slave Multiplexor
TV - Television Modulator

Figure 4-6. Example of Transitway SC&C System Design

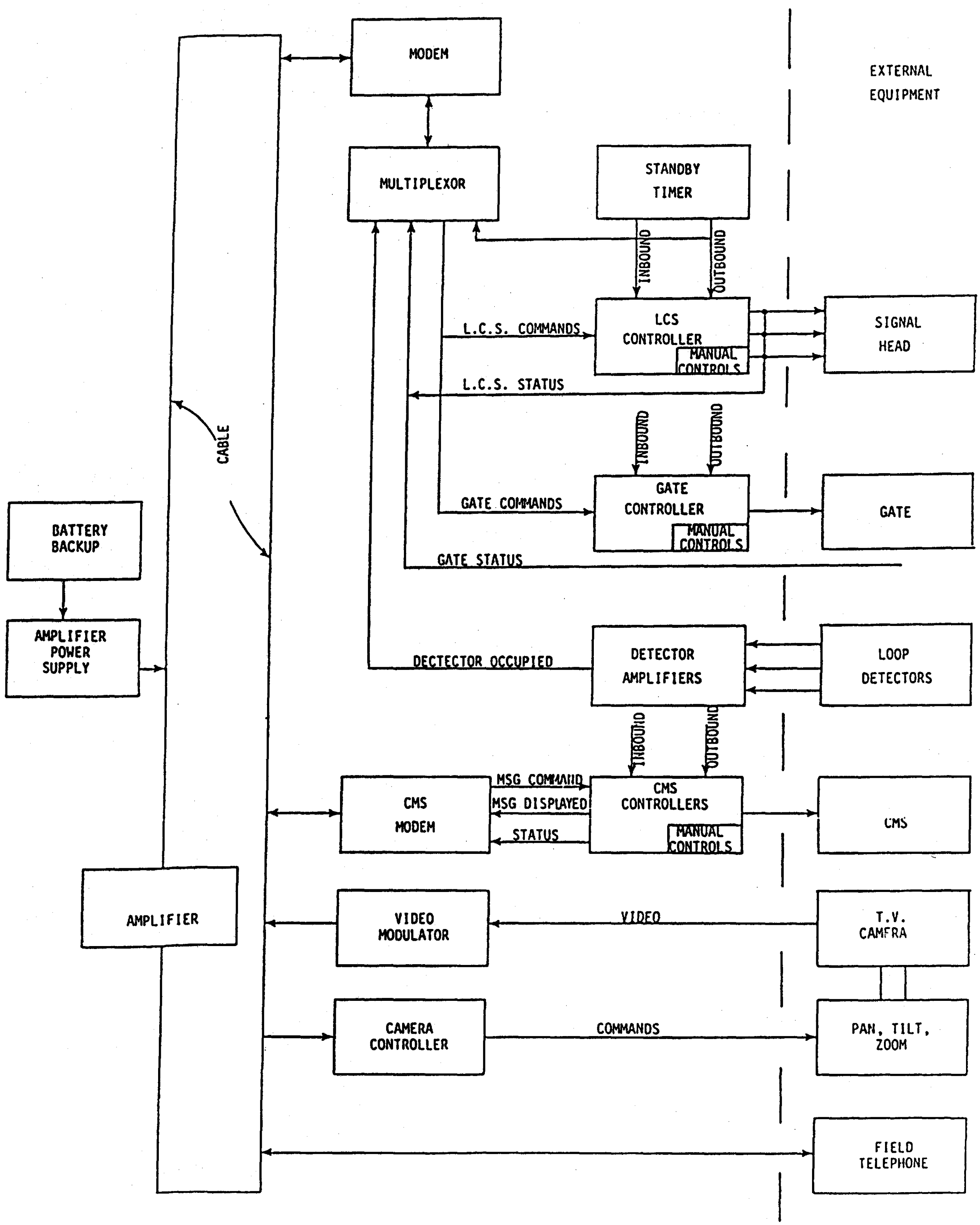


Figure 4-7. Field Controller Equipment

suggested design is cost. If the installation of the coaxial or fiber optic cables cannot be combined with other projects, then microwave is the best choice. The costs of cable installation is approximately 80 percent of the costs of those systems.

However, as the SC&C network for transitways develop and cable systems are implemented, combined use of cables and conduits for the Satellite to Central Control Center link is possible. It is recommended that future projects should select the fiber optics option.

This section of the manual presents some general data transmission system requirements and a general comparison of the microwave, coaxial cable, and fiber optics technologies. This information should be useful in selecting the appropriate technology.

4.5.5.2 System Requirements

Typically, SC&C systems will require the following types of data transmissions between the Satellite and the Central Control facilities: 1) Two-way data transmissions for receiving information from the field and issuing commands to the SC&C devices in the field; 2) One-way video transmissions from the field to the Central Control Facility; 3) One-way video selection and camera control from the Central Control facility to the Satellite in the field; and 4) Two-way voice communications for maintenance and enforcement activities.

Two Way Data Transmission

This transmission channel should be a full duplex data channel with a data rate of 9600 bits per second. This rate provides sufficient speed of transmission for an expanded transitway network.

After processing the raw data from the field, the computer in the Satellite Control Center sends data regarding the status of all field equipment to the Central Control computer, such as:

- Vehicle Detectors - operational/failed, central/standby/manual mode and message displayed.
- Changeable Message Signs - operational/failed, central/standby/manual mode and message displayed.
- Lane Control Signals - operational/failed, central/standby/manual mode and signal displayed.
- Dynamic Signs - operational/failed, central/standby/manual mode and sign on/off.
- Transitway Entrance Metering - operational/failed, central/standby manual mode and gate open/closed.

The satellite computer updates the Central Control computer with the field equipment status data and, the Central Control computer updates the dynamic display map, color graphic CRTs and the operator's CRT.

In the outbound direction the Central Control computer issues control commands to the satellite computer when the operator requests some control of the field and/or satellite equipment.

One-Way Video Transmission

For typical design of four simultaneous displays of CCTV cameras on each transitway, four (4) conventional 6 MH video channels will be transmitted from the satellite control center to the Central Control facility. The video transmission will be one-way and continuous.

One-Way Video Selection and Camera Control

These transmission channels require 1200 bits per second simplex data channels. However, a rate of 9600 bits per second can be used with microwave systems in order to combine the data and voice channels with one or more video channels to conserve overall channel band width.

Video select codes can be generated by a key pad and/or switches in Central Control and transmitted to the video channels for display on the Central Control monitors.

Camera control codes for functions such as pan, tilt and zoom can be generated by the camera controller in Central Control and transmitted to the field camera controllers via the satellite control center.

No confirmation data are required from the field or the satellite because the selection and control functions can be readily verified in Central Control by viewing the video picture of the camera.

Two-Way Voice Communications

This transmission channel should be a two-way voice band channel for voice communications among personnel in the Central Control facility, the selected Satellite Control Center and at any field cabinet of that transitway system.

4.5.5.3 Comparison of Technologies

Microwave Systems

A microwave system capable of transmitting multiple video and data channels is one method of implementation for the communications link between the Satellite Control Centers and the transitway Central Control. One such system, known as an amplitude modulation link, uses low power microwave communications to provide a means of sending up to sixty 6 MHz video channels over one link.

The microwave system is limited to line-of-sight communications due to the fact that the very short microwave wavelengths behave essentially the same as the propagation of a beam of light. Antenna towers must be installed with the antennas high enough to clear high buildings and variations in the height of the intervening terrain. One of the key advantages of microwave communications is that very narrow transmitted beam widths can be achieved with relatively small antennas.

Coaxial Cable System

A coaxial cable system could use the cable TV technology where the sub-VHF (5-30 MHz) and VHF (50-300 MHz) spectra are employed to send data and TV signals over a coaxial cable. The cable would be installed between the Satellite Control Centers and the transitway Central Control building. This cable system would use the shortest routes along the roadway.

Repeater amplifiers would be spaced at 1600 to 2500 foot distances to minimize losses. Low gain trunk amplifiers (22-215 dB gain at 300 MHz) are required to make up cable losses so that signal levels are held relatively constant at either the amplifier input or its output. RF modems are used to interconnect data functions and video modulators and demodulators would be used to transport video signals.

Fiber Optics System

Fiber optics cable forms a communications medium which is very similar to the coaxial cable. However, there are a number of advantages that might lead to selecting fiber optics over coaxial cable: low loss cable presents lower losses to signal propagation than typical coaxial cable, resulting in fewer amplifiers; fiber optics cable is small in size and has great flexibility; and third, it is totally immune to radio and electrical interference.

Summary

As shown in Table 4-8, each of the communications systems has advantages and disadvantages. Many of the factors are site specific. For example, the distance between control centers is the major factor in cable versus a radio system, but line-of-sight, frequency allocations and climatic conditions must also be considered. The time required to implement the system might be critical. At this stage, known or proven technology may be preferred over

Table 4-8. **Advantages and Disadvantages of Candidate Communications Systems**

Microwave Communications	Coaxial Cable Communications	Fiber Optic Cable Communications
ADVANTAGES	ADVANTAGES	ADVANTAGES
1. All microwave communications are wireless and hence have the most important economic advantage of requiring no in-ground or overhead cable installation. This accounts for 80% of the coax cable link costs and makes microwave comm. The cheapest media for this purpose.	1. Single Cable Interconnect. All video and data signals can be transmitted over one coaxial cable.	1. Single Cable Interconnect. All video and data signals can be transmitted over one multifiber cable.
2. Has large channel capacity for adding TV channels (60 or more) for the multiband microwave systems described above.	2. Has large channel capacity for TV and data channels.	2. Has larger channel capacity than coaxial cable for data channels.
3. Established Technology. Is about same technical age as CATV in coax.	3. Weather Immunity. Unlike wireless microwave, coaxial cable is not subject to weather conditions.	3. Weather Immunity. Unlike wireless microwave, fiber optic cable is not subject to weather conditions.
4. Simplier to put into operation than either coax or fiber optics. Only requires tune up of terminal equipment. Antennae must be properly aimed; but this is a routing exercise when installing towers and antennae.	4. Interference Immunity. Coaxial cable systems are superior to microwave in regard to R.F.I. and E.M.I.	4. Cable Installation and Pulling Costs Lower. Since fiber optics cable is much smaller and more flexible than the coaxial cable required for the satellite to central communications, its conduit is smaller, and pulling costs are lower thus overall installation cost is less.

Table 4-8. (Cont.)

Microwave Communications	Coaxial Cable Communications	Fiber Optic Cable Communications
ADVANTAGES	ADVANTAGES	ADVANTAGES
5. No cable, repeater amplifiers or field equipment to maintain.	5. Channel Isolation. Due to the high frequency bands used in the coax system of 5-300 MHz, adjacent data channels can be sufficiently spaced in frequency to achieve isolation from adjacent channel cross talk.	5. Interference immunity. R.F.I. and E.M.I. immunity is total with fiber optics. This is especially attractive when considering conduit proximity to high power and high voltage power lines. This type of cable also provides total isolation from lightning strikes which may affect a particular equipment without being transmitted to other parts of the system.
	6. CATV Industry Well Established Hardware. The amplifiers are well developed, extremely reliable and readily acquired off-the-shelf.	Cable Splicing. The fiber optic cable splicing technique once mastered, is easier and less expensive than splicing 1/2 inch and larger coaxial cable. Fusion splicing is very simple requiring no connective hardware, as in the case of coaxial cable.

Table 4-8. (Cont.)

Microwave Communications	Coaxial Cable Communications	Fiber Optic Cable Communications
DISADVANTAGES	DISADVANTAGES	DISADVANTAGES
1. Transmitter Modules are required for each TV channel. This could get quite expensive for a large number of channels, but is not much of a problem for the Satelite link applications, where a limited number of TV channels are involved.	1. Transmission Electronics. Repeater amplifiers are needed every 2500-3000 ft.	1. Multi-Channel Electronics. The requirements for a number of subcarrier channels with a fiber optic system is not as well developed as for the coaxial cable system. Whereas only 4-5 video channels are used on the satellite links, this is a minimal disadvantage.
2. FCC Licensing required since radio communications is used (using radio bands) with power exceeding the FCC minimum, where licensing might otherwise not be necessary.	2. Cable Pulling. Pulling 3/4 inch semi rigid CATV type coaxial cable is significantly more difficult and expensive to install than the much smaller and more flexible fiber optic cables now available.	2. Higher Risks. Electronics not used in the field as long as for coax/CATV industry. Fiber splicing demands special skills and equipment as compared to coaxial cable connectorization.

Table 4-8. (Cont.)

Microwave Communications	Coaxial Cable Communications	Fiber Optic Cable Communications
DISADVANTAGES	DISADVANTAGES	DISADVANTAGES
3. Some Environmental Limitations Heavy rain will attenuate signals at microwave frequencies (10-13 GHz). A heavy rain-fall of 50 mm/hr (1.96 in./hr.) or more results in a reduced signal-noise ratio. This means poorer video picture and higher data transmission error rate. At higher precipitation rates communications may be lost. Also line-of-sight interference and multipath interference are possible problems especially where large office buildings intervene in the microwave link line-of-sight.	3. System Integration and Tune Up. Coax cable systems are more complicated to design than fiber optics, require careful gain and slope adjustment at each amplifier with proper choice of equalizer and temperature compensation. Requires higher technology to maintain than fiber optics.	3. Contractor unfamiliarity with the relatively new fiber optics system installation.
	4. Since cable must be purchased and installed over entire length of link it costs much more than microwave.	4. Since cable must be purchased and installed over entire lenght of link it costs much more than microwave.

Source: (1).

new technology for data transmission from the Transitway Satellite Control Centers to the Central Control Facility.

Table 4-9 presents cost estimates which were prepared for the three candidate communications systems considered for the three Transitway Satellite Control Centers proposed in Houston. These cost estimates include the full costs of cables, conduits and installation for all three systems, operating as a trunk line from control center to control center. The majority of the costs for the two cable options is in the installation of conduit and laying the cable. If the trunk line can be installed in existing conduit or in combination with other cable, then the cost of the trunk line decreases.

The fiber optics cable communications mode from the field to the satellite control center was selected for the SC&C systems on the Gulf and North Freeway. A major factor in this decision was the ability of fiber optics to carry large amounts of data over long distances without amplification. This technology would be applicable to the trunk line operation from the Satellite to the Central Control Center.

As the SC&C networks are developed in the Houston area, fiber optic cable systems will be installed along the right-of-way of the I-610 Loop Freeway. At that time, the costs of the fiber optics option as the trunk line medium are expected to be comparable to the microwave option.

Table 4-9. Estimated Transmission System Costs - Satellite to Control Center, Houston

Item	Gulf Freeway	Katy Freeway	North Freeway
Transmission Distance	13 miles	11.5 miles	5 miles
Microwave	$328,300	$328,300	$292,000
Fiber Optics Cable	$834,200	$747,600	$400,000
Coaxial Cable	$1,100,000	$988,100	$520,000

Source: (1).

4.5.6 Transitway Incident Detection Algorithms

4.5.6.1 Difference Counter Approach

The basic assumption behind this method is that every vehicle that enters the transitway must exit or be stalled on the transitway (i.e., every vehicle that crosses Location A has either passed Location B (Figure 4-8) or is between A & B). Assuming that every vehicle which passes location "A" must also pass location "B", or be somewhere between location "A" and location "B", then the following assertion is valid:

If the "diff" counter is equal to or greater than one, and if the "time" counter is greater than a variable "x", then an incident has occurred. (X is a value that represents the maximum time allowed for a vehicle to go from Location "A" to Location "B")

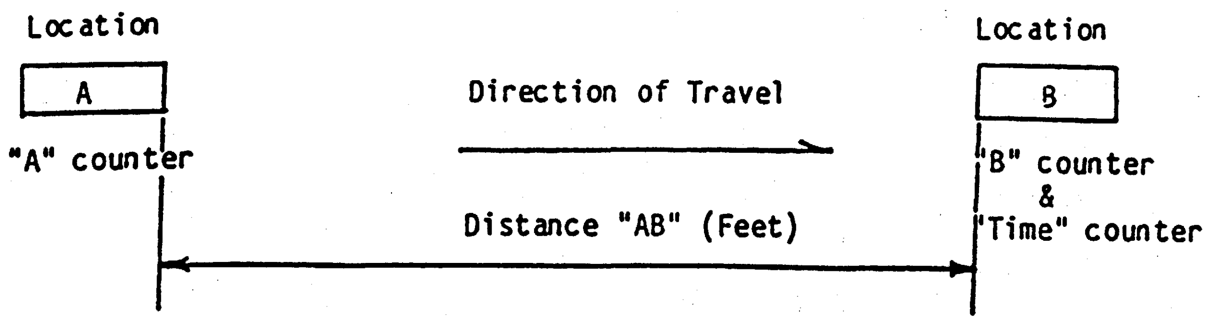
Example: Let the distance A to B = 1 mile = 5280 feet

Then @ 60 mph time required to go from A to B = 60 seconds.
@ 30 mph time required to go from A to B = 120 seconds.
@ 15 mph time required to go from A to B = 240 seconds.

If X is set to 240 seconds, the "time" counter = 240 or greater, the "diff" counter = 1 or more, then an incident is flagged by the program.

4.5.6.2 Statistical Approach

The purpose of the algorithm is to detect incidents which result in flow changes and/or queueing between transitway surveillance stations. The general structure of the algorithm is discussed below and illustrated in Figure 4-9.



("A" counter)	Location A counter = the continuous number of vehicles that have entered the TRANSITWAY since START UP TIME.
("B" counter)	Location B counter = the continuous number of vehicles that have passed Location B since START UP TIME.
("Diff" counter)	Difference counter = "A" counter - "B" counter = the number of vehicles between location "A" and location "B" at any time.
("Time counter)	Time between vehicle actuations at location "B" (counts the time between vehicles); i.e. resets itself to zero every time a vehicle crosses the detector and increments time every second.

Figure 4-8. Schematic of Difference Counter Approach for Incident Detection

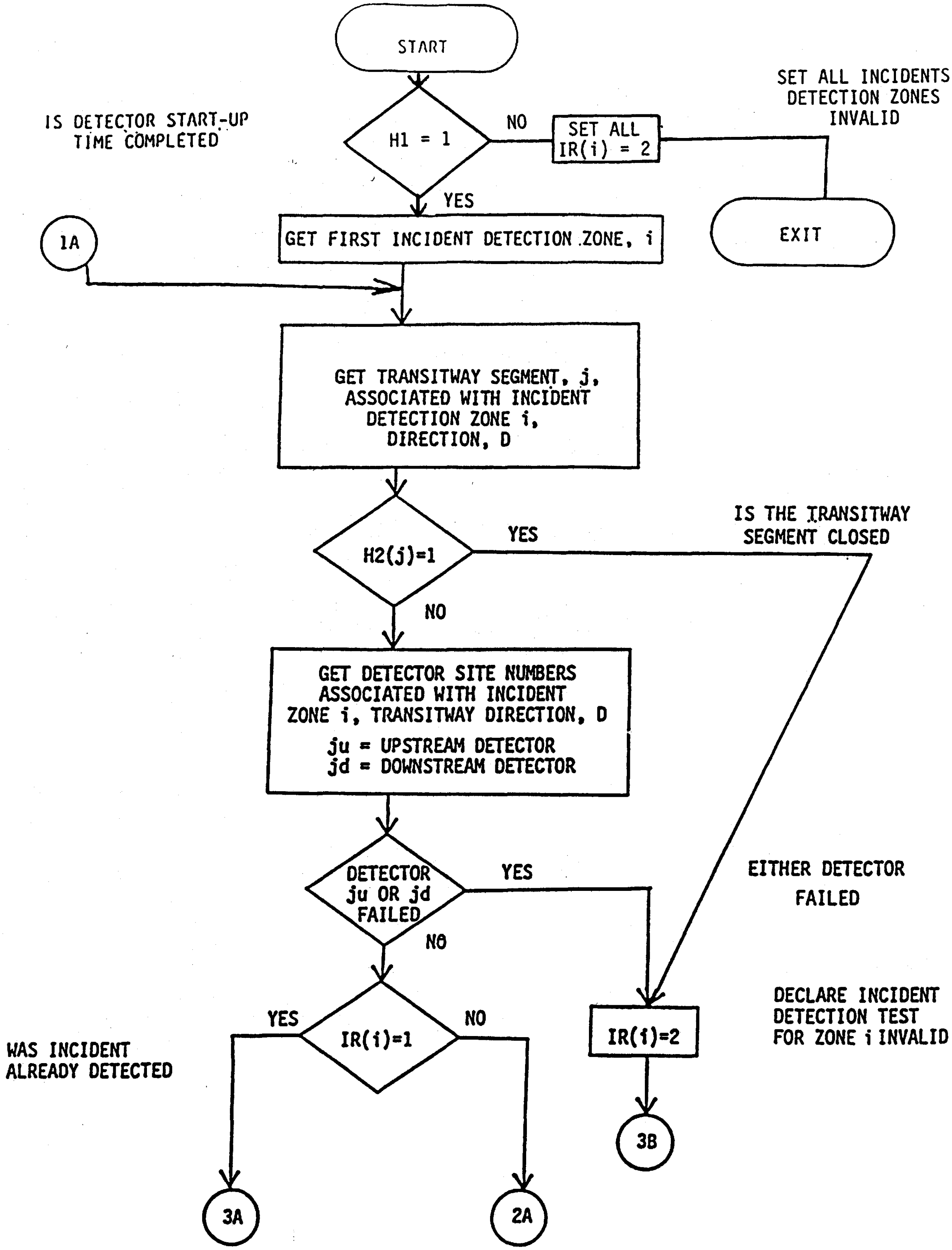


Figure 4-9. Flow Chart for Statistical Approach to Incident Detection

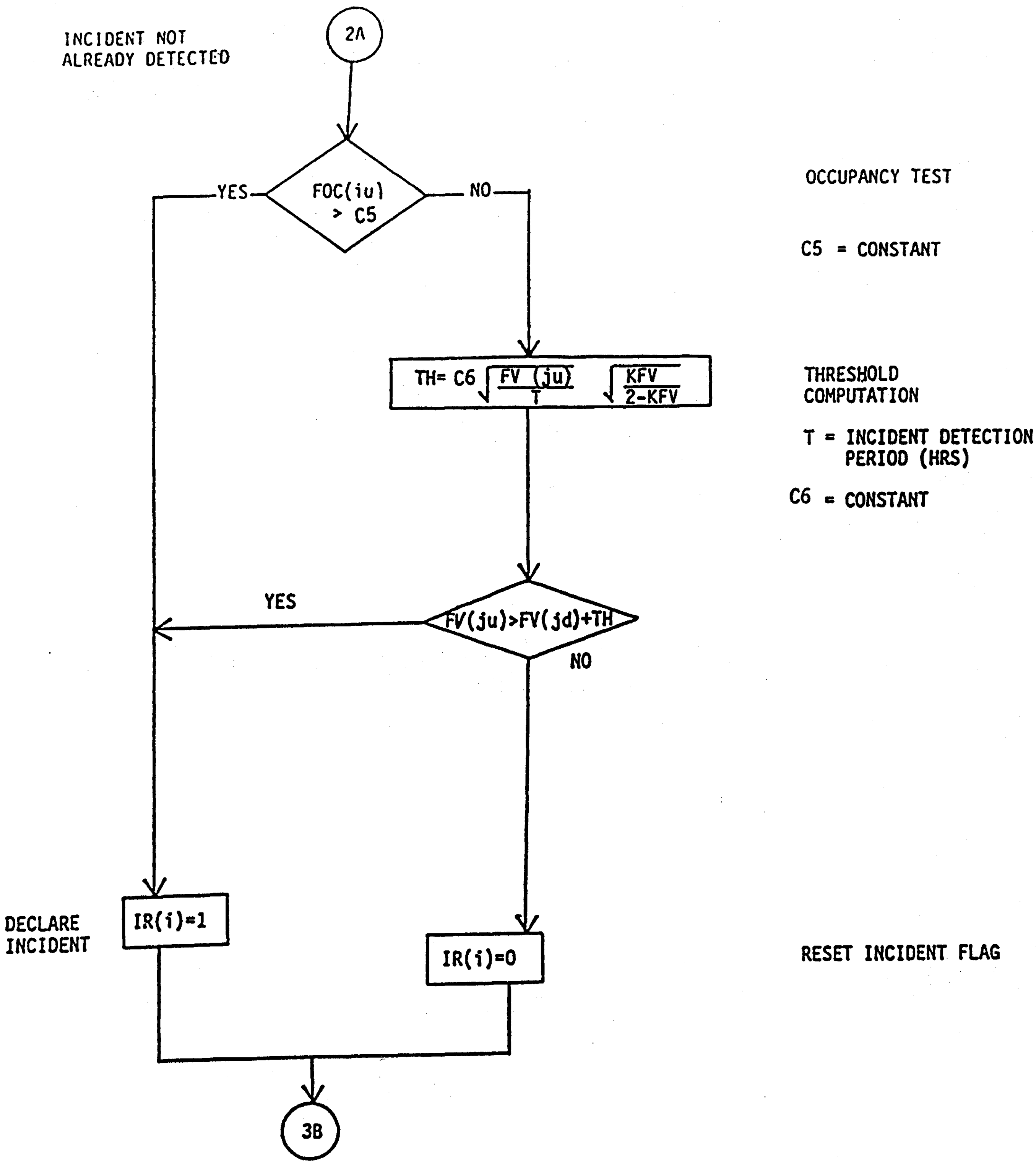


Figure 4-9. (Cont.)

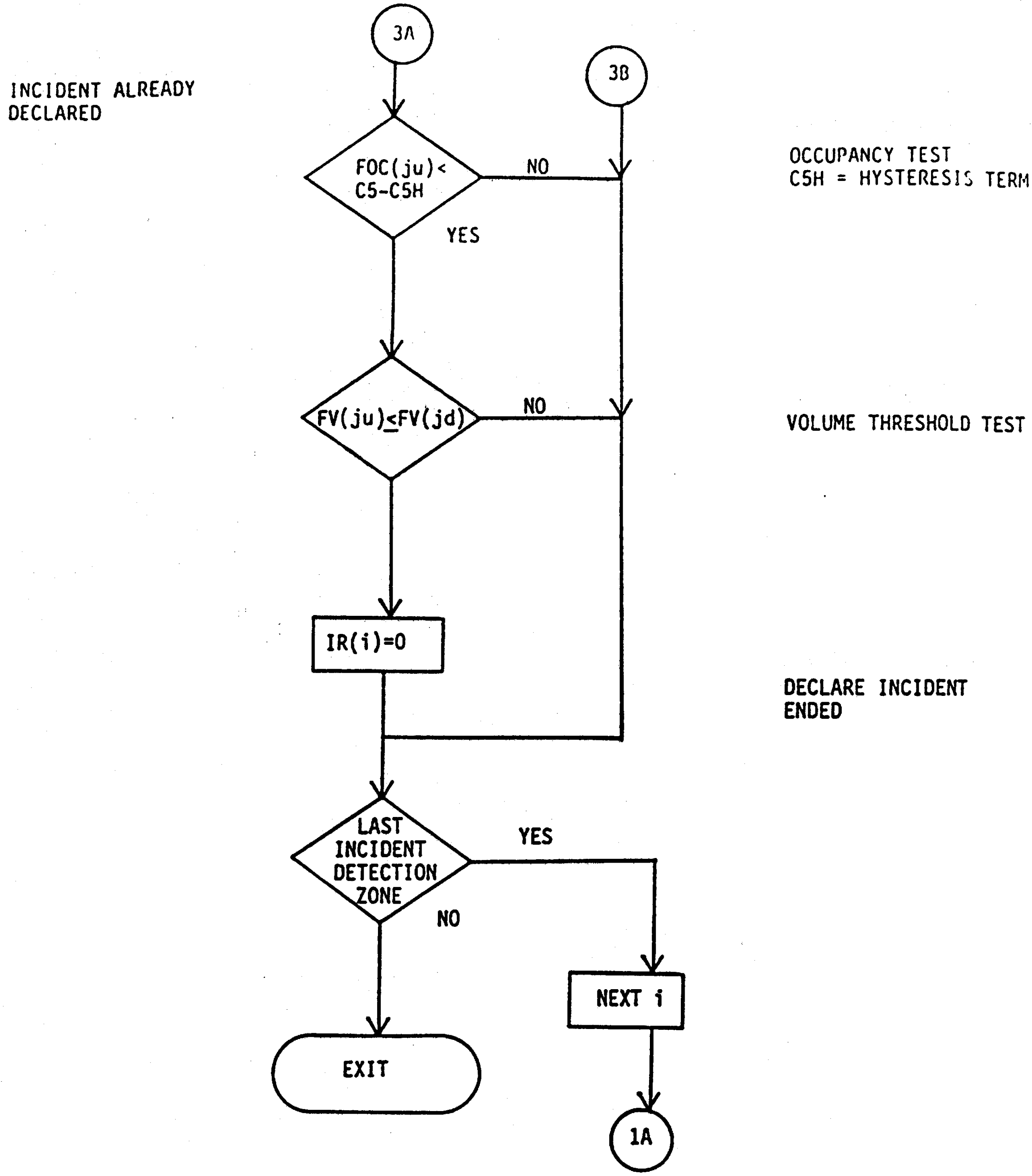


Figure 4-9. (Cont.)

Inputs

ju, jd	Upstream and downstream detector sites associated with an incident detection zone. These values are stored for each direction of travel on the transitway in a table for each incident detection zone.
D	Transitway Direction, 0 = Inbound 1 = Outbound 3 = Special
	Detector Site Failure Flag
FOC(n)	Filtered occupancy, detector site n
FV(n)	Filtered volume detector site n
KFV	Volume filter constant

Repetition rate: Every 30 seconds

Computation

A set of tests is made for each pair of adjacent transitway surveillance stations. The tests are:

a) Has a queue appeared over the upstream detector in the pair (as determined by occupancy greater than a threshold, C5)?

b) Does the upstream volume exceed the downstream volume by a value which exceeds threshold TH? The threshold is computed and is a function of the upstream surveillance system filtered volume. By a judicious choice of coefficient C6, the performance of the algorithm may be altered. As C6 is increased the threshold is increased. This has the effect of decreasing both the false alarm rate and the responsitivity.

The algorithm will identify incidents which restrict the downstream station's volume to less than that being admitted through the upstream detector. The distance between these volumes exceed a threshold so that normal statistical variations in the traffic do not indicate an incident.

The first radical term in the threshold computation is an estimate of the statistical unfiltered volume variation (assuming that FV is scaled in VPH and T by the filter).

If the system is operating in the manual control mode and the transitway is never closed, this algorithm should detect the "end" of an incident. The algorithm is inhibited whenever the "lane closed" flag is set or when the surveillance restart flag H1 is set.

The end of an incident is detected by the same type of tests as described above, except that a hysteresis is built-in to prevent cycling.

Output

- To automatic sign and lane control algorithm: once every 30 seconds.
- To minicomputer report: once every 30 seconds.
- To minicomputer audio alarm: once every 30 seconds.
- To graphics microcomputer: once per minute.

4.6 SUMMARY

Transitways are priority usage facilities for high occupancy vehicles designed to be physically separated with limited access for high level of service. The operational characteristics (reversible flow, vehicle mix, etc.) and, in many applications the geometric design (restrictive widths) of transitways highlight the need for an active traffic management system of surveillance, communications, and control (SC&C). It is essential to coordinate SC&C considerations with both the planning and design processes for transitways if future projects are to be implemented successfully.

SC&C systems for transitways are needed to provide the users vital information on traffic and roadway conditions. More importantly, SC&C systems are needed to detect and respond to disabled vehicles, wrong-way movements, and unauthorized vehicles. Guidelines for assessing the need for SC&C systems on transitways are presented.

Descriptions of the basic concepts and technologies associated with SC&C systems are given. The various functions and equipment involved in monitoring and detection are identified and discussed. The tasks of communications and control are also explained in detail.

The various elements of a transitway network SC&C system and their capabilities are outlined. Some general guidelines for selecting an appropriate and applicable SC&C system for a particular transitway are given.

Design considerations for transitway SC&C are elaborated for two types of control centers (central and satellite). Factors discussed include location, building, size, layout, manned versus unmanned, hardware requirements, software requirements, computer subsystems, video subsystems, controller subsystems, voice communications, and data transmission equipment.

4.7 REFERENCES

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4.8 APPENDIX

4.8.1 PEGASUS System

4.8.1.1 Introduction

PEGASUS for Traffic Management (PEGASUS stands for PEople, Goods And Services Urban System) is a flexible system design for incorporating three surveillance and control components (freeway, corridor streets, and transitways) into an integrated freeway corridor system. Minicomputers are being (or will be) utilized for one or more of the three above mentioned components. The minicomputer and communications multiplexors are being purchased by requisition and will either be installed by SDHPT personnel or provided to a contractor for installation.

The minicomputer permits the application of one software package (with adaptations as needed) which is developed and maintained by SDHPT personnel. One basic hardware and software design will also make the minicomputer, multiplexor and modem maintenance less complicated in that the hardware will be interchangeable in all systems and maintenance personnel will be familiar with one basic system. The following discusses the approach being taken to install the PEGASUS concept in Houston, Corpus Christi, and El Paso.

4.8.1.2 Houston System

At present eight freeway corridor traffic management systems are under development and installation through the cooperation of the SDHPT Houston District Office and Austin Office (Traffic Engineering Section and Division of Automation), the Houston Metropolitan Transit Authority, and the City of Houston. A design team comprised of personnel from these agencies are developing the overall system design. The system will consist of control and surveillance for a transitway lane located within the freeway median area, freeway control and surveillance, and freeway corridor street control and surveillance (including both the frontage roads and corridor streets). Included in the system will be: (1) transitway lane controls, Changeable Message Signs (CMS), and closed circuit TV, (2) freeway ramp meter and gate control, CMS and closed circuit TV, and (3) freeway corridor street traffic responsive control. Surveillance and off-peak incident management will be provided in addition to surveillance and traffic management for recurring and non-recurring peak period congestion.

Each freeway corridor system is designed around the use of three minicomputers. A minicomputer system is to be provided for each of the three freeway corridor components - the transitway lane, the freeway, and the freeway corridor streets. The three minicomputer components are to be located in a building located along each freeway. The satellite minicomputer system (satellite computer) will operate on a stand along basis with no operators located at the satellite building.

The operation and maintenance of the satellite computer system will be as follows:

1. The Metropolitan Transit Authority (MTA) will operate and maintain all traffic control and surveillance along the transitway lane including the minicomputer for its system component.
2. The SDHPT will operate and maintain the control and surveillance for the freeway including the minicomputer for its system component.
3. The City of Houston will operate and maintain the control and surveillance for the frontage roads and corridor streets including the minicomputer for its system component.
4. There will be joint use of the coaxial cable modems which will be maintained by the MTA.
5. There will be joint MTA and SDHPT use of the CMS and closed circuit TV which will be maintained by the MTA.

The satellite computer system is also designed so that each minicomputer will share information with the other minicomputers. For instance, when one minicomputer makes a pattern change, it will advise the other two minicomputers. If either or both of the other two computers has pre-agreed upon patterns to change to also, the second and/or third computer(s) will change to their new pattern.

The separate satellite computer concept rests with SDHPT policy in which MTA operates and maintains the control and surveillance for the transitway lane, the city operates and maintains the traffic signals (including the frontage road signals), and the SDHPT operates and maintains the freeway control and surveillance.

Each of the three satellite minicomputers will provide a stand alone system with no operators present and will operate on a traffic responsive basis. Each satellite minicomputer will summarize data and transmit information to the computers at each agency's control center on a 20 second basis.

A control center building may be provided for each agency, but it is hoped the City and SDHPT centers will be combined so that there will only be two center buildings (one for MTA and the second for the City and SDHPT). Personnel will be located at each control center who will analyze traffic data received and change the control patterns as necessary for each of the agency system satellite minicomputers. City and SDHPT personnel will be better able to coordinate their activities if they are located in one center. Each agency will utilize a minicomputer at its control center. The minicomputer at the control center will receive a system update from each of the satellite minicomputers on a 20 second basis. This information will be compiled and presented on a CRT and (when called for) in hard copy. The information will include equipment diagnostics reports as well as the status of traffic operations. Based on the reports, the operator at the center will be able to make manual traffic control pattern changes, call out alternate control operations at malfunctioning intersection controllers, and report malfunctions to maintenance personnel. This information will also be utilized to develop new traffic control patterns and to carry out incident management activities. New patterns and/or pattern changes will be down loaded from the control center computer to the satellite computer.

The SDHPT and MTA control centers will be provided with closed circuit TV monitors. The SDHPT control center operator will be able to alter traffic operations commands during incidents along the freeway mainlanes and will work with the City of Houston operator at the control center to modify arterial street traffic control patterns.

The plans and specifications are being prepared at this time for a complete freeway corridor system and it appears that the first joint use project on I-45 North Freeway in Houston will go to contract in July 1986. Installation is being completed along I-10 West (Katy Freeway) in Houston at this time which will incorporate all of the PEGASUS surveillance and control features for an HOV lane within the freeway median.

4.8.1.3 Corpus Christi System

The Corpus Christi system involves the SH 358 (Padre Island Drive) freeway corridor which consists of six freeway interchanges and approximately 40 signalized intersections. The initial traffic signal system (consisting of 7 intersections), which was developed jointly by the city of Corpus Christi and the SDHPT, is in operation at this time. The Corpus Christi system utilizes the same type satellite minicomputer as is being used in the Houston systems. The same traffic signal SDHPT developed software to be used for the freeway corridor streets in Houston is being used in Corpus Christi. Telephone communications are used to transmit information to a CRT and printer at the City traffic engineering office and a second at the traffic signal maintenance shop. Future SDHPT freeway control and surveillance will be provided by a second satellite computer of the type installed in Houston. There are no plans at present to provide a transitway lane within the freeway median area in Corpus Christi as is being done in Houston so the third component of the PEGASUS will not be applied.

4.8.1.4 Austin, El Paso, and Ft. Worth Systems

The Austin, El Paso and Fort Worth systems utilize the City's central computer for traffic control along corridor streets and freeway frontage roads with a satellite minicomputer to be installed for the freeway control and surveillance. The satellite minicomputer will, as with the Houston and Corpus Christi systems, share information with the City's computer so as to permit pattern changes during incident conditions. Should a transitway system be installed within the freeway median area in the future, it is anticipated that the transitway will have its own satellite minicomputer.