APPENDIX IIIA

EVALUATION OF IVHS TECHNOLOGY FOR THE DALLAS URBAN AREA

Form 433-A
Rev. 9/92

Texas Department of Transportation

MEMORANDUM

Date 10-17-94

To: Brian Burk

From: CESAR MOLINA

Enclosed are the other technical memorandums from the Dallas study. Based on the outcome of today's meeting, it appears that some of the work on incident mgmt may be of interest to you. Also, Andy Oberlander, Dallas Dist., is checking on a police contact for your use in promoting the courtesy patrol. If you want to speak to Andy ~~directly~~ personally, his number is 214-373-6870.

DALLAS AREA-WIDE IVHS PLAN
DOCUMENTATION

October 15, 1992 - September 30, 1994

TEXAS TRANSPORTATION INSTITUTE

Dallas, TX Arlington, TX

TECHNICAL MEMORANDUM 1980-1

TRAFFIC SIGNAL AND SIGNAL SYSTEM CAPABILITY INVENTORY

Dallas IVHS Planning Region

REVISED

October 7, 1993

OVERVIEW

In order to assess the potential for compatibility with an area-wide traffic incident management plan, a survey of existing signal capabilities was conducted. In this inventory and compilation, only those cities with freeways within their corporate limits or which had arterials which might reasonably serve as alternate routes to freeways. Table 1 presents a summary of findings. The data were accumulated from a number of sources including the North Dallas County Signal System Project, the North Dallas County Arterial Incident Detection and Response Project, data provided by individual cities and TxDOT District 18, and field observation.

TRAFFIC SIGNAL LOCATIONS

There were 2059 signal locations within the study area with nearly 60 percent(1191) in the City of Dallas. TxDOT maintains and operates approximately 45 signals in the smaller cities. Most of these are located on freeway frontage roads.

COORDINATED SIGNALS

Of the 2059 traffic signals in the area, 78 percent are in coordinated subsystems. Signal management by some form of central system(central computer or closed loop) was possible at 462 locations, or approximately 22 percent of the signals in the area. Of the remaining coordinated signals, 871 were coordinated by local time based coordination(TBC) with 28 being coordinated by local masters or two locals being slaved.

AREA-WIDE CAPABILITY

Cities with existing central or closed loop systems have the ability to remotely access data and otherwise communicate electronically which will be necessary for area-wide traffic management. Most cities with this capability have staff devoted to system operation. Newer controllers with TBC and standard design (NEMA or Type 170) obviously have the capability to be integrated into a coordinated system. This equipment is typical of several of the smaller cities but they do not have staff devoted to the day-to-day operation of signals.

SUMMARY

The opportunity exists to develop an area-wide, cooperative traffic management plan with individual cities retaining the ability to exercise control within their jurisdictions. Those cities with existing system capability and staff have indicated their commitment to participate in developing a such system. The hardware does not have to be a barrier. However the area wide system must also involve those cities which do not presently have system or staff capability. Subsequent tasks in this project will consider means to bring this about.

REVISED 10/7/93

Traffic Signal and Signal Systems Inventory

Dallas Area IVHS Plan

PopulationXFreeway Miles(1000s)	123000	4495	2020	1620	1100	645	450	423	410	180	176	155	120	119	108
	Dallas	Irving	Mesquite	Garland	Grand Prairie	Plano	Richard-son	Lewis-ville	Carroll-ton	Duncan-ville	Lancas-ter	Desoto	Cedar Hill	Balch Springs	Allen
Number of Signals	1191	155	60	106	97	89	83	29	44	42	7	16	4	4	4
Number of Signals Coordinated	1030	57		99	44	89	81	29	34	36	0	8	2	2	0
Central Computer	381						81								
Closed Loop		50		99					25						
Field Master Control					17			5					2	2	
Time Based Coordinators	649	7			27	89		4	9	36		8			
Interconnect Medium															
Owned								5	9						
Signal Cable		9		99	17										
Twisted Pairs	216														
Fiber															
Radio	21														
Microwave															
Leased															
Telephone Pairs															
Fiber															
CATV															

PopulationXFreeway Miles(1000s)	72	50	45	31	25	18	9	8	8	6	6	4	4		
	Farmers Branch	Rock--wall	Seago-ville	Park Cities	Glen Heights	Addison	Hutchins	Sunny-vale	Wylie	Red Oak	Wilmer	Ferris	Cockrell Hill		
Number of Signals	50	10	0	35	0	24	0	1	3	2	0	0	3		
Number of Signals Coordinated	44	0		27		22		0	0	2			0		
Central Computer															
Closed Loop	33					18									
Field Master Control										2					
Time Based Coordinators	11			27		4									
Interconnect Medium															
Owned															
Signal Cable															
Twisted Pairs	33					18				2					
Fiber															
Radio															
Microwave															
Leased															
Telephone Pairs															
Fiber															
CATV															

TECHNICAL MEMORANDUM 1980-2

EXISTING INCIDENT MANAGEMENT PROCEDURES
Dallas IVHS Planning Area
October 7, 1993

In order to assess existing incident/accident procedures utilized by governmental agencies in the planning area, informational interviews were conducted with all cities which had freeway facilities passing within or adjacent to corporate limits. Twenty- four cities met this criteria and are shown in Table 1. Cities are shown ranked by the number of freeway miles in their city; the 1990 population; and a factor which was computed as the product of population (in 1,000's) and the freeway mileage.

An interview form (included in Appendix) was used so that consistent types of information would be collected. Due to the varying characteristics such as population, staffing capabilities, and other factors some questions were not appropriate for all cities. A list of cities and departments within the cities surveyed is shown in Table 2.

FINDINGS

NOTIFICATION AND RESPONSE

INITIAL NOTIFICATION OF INCIDENTS
The great majority of notification of accidents and other incidents is by 911, and most of these come by mobile cellular phone from drivers in the vicinity of the accident. In addition, calls may come from mobile radio in City vehicles and in some cases from occupants of high rise buildings adjacent to freeways. In the latter two instances, information is usually more accurate as to location of the incident. However, with mobile phones, there are likely to be more inaccuracies as drivers may be unsure of their exact location or the direction of travel at the incident location. A call to 911 from a fixed phone ties down the location of the caller; from cellular phone it is less likely that an accurate location can be determined since the location could be anywhere within a "cell."

NOTIFICATION POINT
Notification of incidents usually will come directly to the local police dispatcher, although the call in a few cases may come through a main city switchboard. Larger cities generally have a separate dispatcher for police and fire(usually including emergency medical service). However these dispatchers are in direct communication, sometimes occupying the same room. Smaller to medium sized cities generally have one dispatcher for both functions with the dispatcher under the supervision of the police department.

TABLE 1

POPULATION AND FREEWAY MILEAGE FACTORS
DALLAS AREA IVHS PLAN
10/06/93

RANK	POPULATION(K)	
1	DALLAS	1000
2	GARLAND	180
3	IRVING	155
4	PLANO	129
5	MESQUITE	101
6	GRAND PRAIRIE	100
7	CARROLLTON	82
8	RICHARDSON	75
9	LEWISVILLE	47
10	DUNCANVILLE	36
11	PARK CITIES	31
12	DESOTO	31
13	FARMERS BRANCH	24
14	ROWLETT	23
15	LANCASTER	22
16	CEDAR HILL	20
17	ALLEN	18
18	BALCH SPRINGS	17
19	ROCKWALL	10
20	ADDISON	9
21	SEAGOVILLE	9
30	WYLIE	8
22	SACHSE	5
23	GLEN HEIGHTS	5
24	COCKRELL HILL	4
25	HUTCHINS	3
26	RED OAK	3
27	FERRIS	2
28	SUNNYVALE	2
29	WILMER	2

RANK	FREEWAY MILEAGE	
1	DALLAS	123
2	IRVING	29
3	MESQUITE	20
4	GRAND PRAIRIE	11
5	GARLAND	9
6	LEWISVILLE	9
7	LANCASTER	8
8	BALCH SPRINGS	7
9	RICHARDSON	6
10	HUTCHINS	6
11	ALLEN	6
12	CEDAR HILL	6
13	PLANO	5
14	SEAGOVILLE	5
15	ROCKWALL	5
16	CARROLLTON	5
17	GLEN HEIGHTS	5
18	DUNCANVILLE	5
19	DESOTO	5
20	SUNNYVALE	4
21	FARMERS BRANCH	3
22	WILMER	3
23	FERRIS	2
24	RED OAK	2
25	ADDISON	1
26	COCKRELL HILL	1
27	SACHSE	1
28	ROWLETT	1
29	PARK CITIES	1
30	WYLIE	1

RANK	FREEWAY MILES X POPULATION(K)	
1	DALLAS	123000
2	IRVING	4495
3	MESQUITE	2020
4	GARLAND	1620
5	GRAND PRAIRIE	1100
6	PLANO	645
7	RICHARDSON	450
8	LEWISVILLE	423
9	CARROLLTON	410
10	DUNCANVILLE	180
11	LANCASTER	176
12	DESOTO	155
13	CEDAR HILL	120
14	BALCH SPRINGS	119
15	ALLEN	108
16	FARMERS BRANCH	72
17	ROCKWALL	50
18	SEAGOVILLE	45
19	PARK CITIES	31
20	GLEN HEIGHTS	25
21	ROWLETT	23
22	HUTCHINS	18
23	ADDISON	9
24	SUNNYVALE	8
25	WYLIE	8
26	RED OAK	6
27	WILMER	6
28	SACHSE	5
29	FERRIS	4
30	COCKRELL HILL	4

NO FREEWAYS (shaded) ASSUME 1 MI.

TABLE 2

INCIDENT MANAGEMENT SURVEYS

DALLAS AREA IVHS PLAN

10/07/93

CITY	FREEWAY MILES	AGENCY INTERVIEWED		
		POLICE	FIRE/EMS	TRAFFIC
DALLAS	123	X	X	X
IRVING	29	X	X	X
MESQUITE	20	X	X	X
GRAND PRAIRIE	11	X	X	X
GARLAND	9	X	X	X
LEWISVILLE	9	X		
LANCASTER	8	X		
BALCH SPRINGS	7	X		
RICHARDSON	6	X	X	X
HUTCHINS	6	X		
ALLEN	6	X		
CEDAR HILL	6	X		
PLANO	5	X	X	X
SEAGOVILLE	5	X		
ROCKWALL	5	X		
CARROLLTON	5	X	X	X
GLEN HEIGHTS	5	X		
DUNCANVILLE	5	X		
DESOTO	5	X		
SUNNYVALE	4	X		
FARMERS BRANCH	3	X	X	X
WILMER	3	X		
FERRIS	2	X		
RED OAK	2	X		

DISPATCH ACTION

The single most important factor in determining what action to take is the experience and training of the dispatcher. The dispatcher may, depending on the validity of the information of the call, dispatch special units such as heavy duty wreckers or HazMat teams, but will usually rely on the officer on the scene to determine if other units are required. Dispatchers are aware of the distinction between an accident and another type of incident(such as mechanical breakdown or spilled load) and may dispatch accordingly but in many cases dispatch fire, EMS, and police units to the scene. Dispatch logs are kept by all cities and most are entered into a computer. Most logs are reviewed daily by a supervisor to identify irregularities, abnormal happenings,and in some cases, to identify improved procedures for incident management.

JURISDICTIONAL CONSIDERATIONS

Freeways in the IVHS planning area traverse numerous jurisdictions. For example IH 635(LBJ Freeway) passes through no less than 10 separate jurisdictions. However, jurisdictional boundaries do not appear to be a major problem in the handling of incidents and accidents. Without exception, it was reported that the first officer on the scene would work an incident and "hand it over" to the appropriate officer when the jurisdictional determination was made and an officer from the appropriate jurisdiction was on the scene. Some cities have agreements to routinely dispatch units outside their jurisdiction where freeway access would dictate. For example on US 75, Plano will initially dispatch and work an accident south of their city limits(in Richardson) and Richardson will work a northbound accident north of their city limits(in Plano) since each city can more readily access those areas without having to make a turnaround on the freeway. Most cities have mutual aid agreements which define where assistance may be requested or provided.

AT THE SCENE

At least three cities(Dallas, Garland, and Mesquite) no longer investigate accidents which do not involve injury and where vehicles are driveable. With the exception of Dallas, cities had no designated off-freeway accident investigation sites although all indicated it was their policy to finish paperwork at sites away from the freeway(such as parking lots or side streets) whenever possible. All police personnel interviewed were aware of the State's "Move-It" policy for driveable vehicles but felt that the public was generally not aware or did not follow it.

ON- SITE AUTHORITY

No city indicated that there is a designated freeway incident manager. However, it is generally understood that the first police officer on the scene is in charge unless relieved by a higher ranking officer. Police officers support fire personnel until accident victims have been attended to or fire is under control. Fire units sometimes support police by protecting officers with an engine or pumper placed in a freeway lane. There appears to be a high level of cooperation and respect between police and fire personnel in all cities.

TRAFFIC MANAGEMENT

Police have no reluctance to shut down a freeway and divert traffic to a frontage road or city street if the situation so dictates. The officer on the scene is authorized to make the decision to close the freeway and to determine when it should be reopened. Authorities in adjacent jurisdictions are usually notified when a freeway is closed. TxDOT is not normally notified although they may be requested to provide signing if the incident warrants. Officers sometimes direct traffic at intersections affected by freeway closure. None of the agencies interviewed indicated that there was any specialized training for freeway traffic management as there is for street traffic control. Police personnel sometimes ask for assistance from TxDOT where special equipment or sand is required. All agreed that TxDOT was cooperative and helpful,but getting to the accident scene in the urbanized area during rush hour was difficult. Those cities outside the IH 635 ring were generally pleased with the response time.

ACCIDENT CLEARANCE

Although police personnel generally recognize the need to restore capacity to the freeway as soon as possible, safety of the officers and accident victims at the scene is of prime importance and will take precedence over rapid clearing of the freeway. Some police vehicles are equipped with push bumpers and officers will push vehicles out of the roadway. However, at least one department is phasing out pushbumpers because of safety and liability concerns. Another department cited an instance where use of push bumpers caused activation of airbags and catapulted equipment in the front passenger compartment to the rear seat. Most cities have wrecker service contracts requiring arrival at the scene within some specified time after notification, usually 15 to 45 minutes. Although Dallas has a system of rotating calls to several wrecker companies, most other cities contract with only one or two companies with the contract being bid and renewed annually.

Injuries

Non-trauma victims are generally taken to the hospital of their choice. Emergency personnel were very aware of where nearby hospitals were located. In the event a severely injured victim is to be transported, EMS would go to the nearest trauma center unless Bi-Tel (at Parkland) indicates that the facility is overloaded. The transporter would then be directed to another trauma unit. It is generally EMS that makes the determination to call Care-Flight for transport. However, a police officer on the scene may call in the absence of EMS personnel. There is an opportunity to "wave off" Care-Flight by radio if it is determined that it is not needed. EMS personnel will always attempt to resuscitate a victim uncles obviously deceased and are not authorized to certify death has occurred. Consequently, some victims may be transported , with trauma care ending at the hospital.

Fatalities

A particular hindrance to rapid clearing of the roadway is when a fatality occurs at the site. Most cities are adamant about not moving any vehicle containing a fatality until the victim is declared dead by a specific authority. In Dallas County, that authority is the county medical examiner(M.E.) Because of distance, traffic, weather, or other circumstances, arrival of an M.E. may take an hour or more. In some counties, a justice of the peace can make the determination. The only circumstance where a vehicle with a body would be moved is if it posed a severe hazard to other traffic, citizens, or officers on the scene.

Hazard Material Spills

All cities are aware of special precautions and regulations which must be followed in the event of a hazardous material(HazMat) spill. They are also trained in the symbology used on transport vehicles to indicate types of material on board. It is generally not practical to maintain equipment and highly trained personnel in a city since the occurrence of such spills is infrequent. Cities can call in a commercial HazMat specialist if necessary. Some cities expressed interest in a regional HazMat team to serve the area.

DOCUMENTATION

The officer in charge of the accident scene is responsible for accident reports. Fire and police prepare records separately and the two records are not generally examined jointly unless a specific need exists. The City of Dallas and some other cities computerize and analyze accident records. All cities transmit records to Austin for entering into the statewide database. Statistics on response time, duration, and clearance time are sometimes available from dispatch logs and accident records but such data are highly variable and dependent on the nature of the accident, location, time of day, weather, and other factors. This information is not routinely tracked and is difficult to obtain. (Efforts to secure one week of such data from various cities were unsuccessful.)

All cities indicated that accident and incident records were considered public records and that they would attempt to respond to requests for copies made through proper channels.

CLOSURE

Although incident response and management techniques varied from city to city, emergency services showed a high degree of professionalism and cooperation between the various jurisdictions. Several procedures were identified for improvement or standardization. Recommendations will be set forth in a subsequent technical memorandum.

APPENDIX

Incident Management Questions

Incident Notification and Initial Response

1. How do you find out there is an incident?
2. Who receives the notification of an incident?
3. How do distinguish between an incident and an accident?
4. Is there any attempt to verify certain types of calls before dispatching (e.g., emergency wreckers)?
5. Is there a priority for dispatching responses to an event? What is the priority, where do traffic incidents rank in the priority?
6. Who dispatches the call? Is there a single dispatcher or do various response agencies perform their own dispatching? If multiple dispatchers are responsible, how do they coordinate their activities?
7. Who makes the initial determination of how many and what types of units (e.g., police, fire) to dispatch? Is there a procedures manual that is followed in making this decision?
8. What happens when the incident is near a jurisdictional boundary?
9. What happens when the incident is on a jurisdictional boundary?
10. What are the coordination procedures involving 911 and other agencies (including other city's 911 facilities)?
11. Do all emergency services agencies share the same jurisdictional boundaries?
12. Is there an anticipated initial response time cutoff beyond which the dispatcher(s) calls for assistance from surrounding jurisdictions?
13. Are logs of dispatch activities kept? Are they reviewed and summarized routinely? Are they available to TTI? What changes in dispatching have been made in response to review and analysis of dispatch logs?

At The Scene

1. Is there an on-site incident manager? If so, does the manager's rank and/or type of service (e.g., police, fire) vary by type or severity of incident? If not, who does everyone recognize to "be in charge"?
2. What authority does the on-site manager have? Can they ask for additional units of any type or are some of these decisions relegated to specific types of emergency services (e.g., police, fire)?
3. Are there policies for off-site investigation for moveable vehicles?
4. What actions are taken to service diverted traffic (e.g., officer directing traffic at downstream intersections, manual signal control)?
5. Who can shut a freeway down? What are their criteria and guidelines for doing so?
6. Who can open a freeway up after an incident? What are their criteria for doing so?

7. If a freeway is shut down, are affected agencies and jurisdictions notified (when and who, if so notified)? Is traffic operations (not police, but traffic signal operations) notified?
8. Who can ask for a CareFlite helicopter?
9. When must a coroner be called?
10. Who can ask for the coroner? What is their response time? Can the incident be cleared while awaiting the coroner?
11. Can a vehicle containing a corpse be moved?
12. Can a corpse be moved before a coroner arrives? Who decides if a body is dead at the scene?
13. What are the impacts of a hazardous spill? Who is responsible for the clean-up? Are there any special agency coordination procedures involved? What special actions must be taken when an eighteen wheeler is involved with cargo?
14. Is billing attempted for clean-up of dumped cargo? How is the cost determined?
15. Who decides what hospital an accident victim goes to? Does it vary by the type and/or severity of the injury?

Documentation

1. Who prepares documentation "paperwork" on an incident?
2. Where is paperwork kept? Is it entered into a computer?
3. Is the documentation consolidated for a given incident across all emergency services?
4. What kind of periodic reports and analysis of incidents are made? What actions are taken in response to this analysis? Can TTI get copies of summary and/or detailed statistics?
5. Are statistics available for response times, location of incidents, types of incidents, duration of incidents, types of equipment involved, injuries, etc.?

General

1. What are your worst problems?
2. What works and what doesn't work?
3. Where are the worst problems? Where is traffic the biggest hinderance to incident management?
4. What would be the biggest help in managing incidents?
5. Do police cruisers routinely push stalled vehicles off freeways?
6. How does the presence of the press impact the management of an incident? Are the press notified in some cases? What action is expected of them if they are notified?
7. Are special provisions made prior to an anticipated generator of incidents (e.g., snow, ice, fog, rain, festival)?

8. How are emergency wrecker services companies selected? What is their required response time?
9. What impact does roadway construction play regarding an incident (frequency, duration, traffic, etc.)?
10. Is there any special equipment that has proven to be especially beneficial to managing, clearing an incident in the last few years?
11. Subsequent to an incident how much time and effort is involved in legal issues related to these incidents?
12. How much training have various agencies received regarding traffic control during an incident?
13. Are you aware of the "move-it" policy? Do you use it?
14. What is your policy on abandoned vehicles?
15. Do you use off-freeway accident investigation sites?

TECHNICAL MEMORANDUM 1980-3

INCIDENT MANAGEMENT IMPROVEMENT OPPORTUNITIES

Dallas IVHS Planning Region
October 7, 1993

Incident Management Requirements to Reduce Congestion
For MAJOR Incidents

<u>Requirement</u> <u>Goals and Issues</u>

Detection

1. Immediate detection and notification

   a. 911 calls from cellular phones
      1) Police dispatcher notify fire, Traffic Control Center
      2) Location of accident still a problem
   b. Freeway speed detection to Traffic Control Center (TCC)
   c. Other means of detection (helicopter, radio stations) to TCC

Response

2. Immediate response of appropriate emergency teams

   a. 5 minutes typical for police and fire, if location correct
   b. Access secured for emergency equipment
   c. Traffic safety officer (TSO) summoned by police on scene
   d. Heavy equipment summoned by police or TSO
   e. Special needs: Haz Mat, sand, coroner

3. Immediate response of appropriate TCC

   a. Changeable Message Signs (CMS) for motorists upstream
   b. Lane Control Signals and speed warnings upstream
   c. Communication with other TCC's
   d. Communication with commercial radio
   e. Initiate Highway Advisory Radio (HAR) messages
   f. Initiate in-vehicle, in-home, and in-business advisory

Clearance

4. Reroute traffic and handle it efficiently (TCC)

   a. Notify involved cities' transportation managers on duty
   b. Electronically close lanes and ramps as necessary
   c. Follow pre-determined action plan, after cities' OK
   d. Adaptive signals monitored as needed
   e. Monitor queue back up, adjust CMS and a-d as needed.
   f. Monitor site on video and via telephone with TSO or police

5. Reopen some freeway lanes, as soon as safe

   a. TSO on scene w/equipment: arrowboard, cones, flashers, cellular phone, access to off-site resources
   b. TxDOT assumes responsibility for goods/loads removal
   c. Movable vehicles moved to shoulder immediately

Incident Management Requirements to Reduce Congestion For MAJOR Incidents

Requirement	Goals and Issues
Detection	1. Immediate detection and notification a. 911 calls from cellular phones 1) Police dispatcher notify fire, Traffic Control Center 2) Location of accident still a problem b. Freeway speed detection to Traffic Control Center (TCC) c. Other means of detection (helicopter, radio stations) to TCC
Response	2. Immediate response of appropriate emergency teams a. 5 minutes typical for police and fire, if location correct b. Access secured for emergency equipment c. Traffic safety officer (TSO) summoned by police on scene d. Heavy equipment summoned by police or TSO e. Special needs: Haz Mat, sand, coroner 3. Immediate response of appropriate TCC a. Changeable Message Signs (CMS) for motorists upstream b. Lane Control Signals and speed warnings upstream c. Communication with other TCC's d. Communication with commercial radio e. Initiate Highway Advisory Radio (HAR) messages f. Initiate in-vehicle, in-home, and in-business advisory
Clearance	4. Reroute traffic and handle it efficiently (TCC) a. Notify involved cities' transportation managers on duty b. Electronically close lanes and ramps as necessary c. Follow pre-determined action plan, after cities' OK d. Adaptive signals monitored as needed e. Monitor queue back up, adjust CMS and a-d as needed. f. Monitor site on video and via telephone with TSO or police 5. Reopen some freeway lanes, as soon as safe a. TSO on scene w/equipment: arrowboard, cones, flashers, cellular phone, access to off-site resources b. TxDOT assumes responsibility for goods/loads removal c. Movable vehicles moved to shoulder immediately

d. Set up screens around incident if possible
e. Open shoulder to traffic if feasible
f. Direct traffic slowly (30 mph) past scene, alternating lanes allowed to pass to eliminate queue jumping.

6. After incident cleared, maintain safety

a. Check adequacy of debris clean up in blocked lanes
b. Move official vehicles from lanes when emergency over
c. Notify TCC of clearance
d. TCC notifies media, HAR
e. Continue monitoring queue, adjusting CMS, etc. until clear

Incident Management to Reduce Congestion for minor Incidents

Requirement	Goals and Issues
Detection	1. Immediate detection and notification a. Cellular free calls to MAP number b. Detection by roving MAP vehicle c. Station MAP vehicles in recurrent congestion, perhaps on motorcycles to simplify access d. Local area TCC notified by detecting unit
Response	2. Immediate response of appropriate service provider a. Ten minute response time from MAP dispatch b. Thirty minute response from other equipment ordered 3. Immediate response by appropriate TCC a. Video check of incident b. Monitor queuing, activate advisory systems as needed
Clearance	4. Clear roadway within 15 minutes a. Secure safety with arrowboard, cones, flashers b. Determine action needed and request help if needed c. Implement action to clear roadway d. Notification to TCC of clearance e. Notifications via cellular phone as requested by the driver of the vehicle being assisted. f. Depart scene within twenty minutes, as a goal

MAJOR INCIDENTS

1.a.2: Location of cellular 911 calls:

Review and *change names* where different freeway locations have the same names.
Have dispatcher ask driver for next mile-marker sign (describe location in median)
Consider increasing visibility of mile-marker signs
City limit signs may need stronger definition

Long-Term: Automatic vehicle location of cellular 911 calls

2.a Emergency response time:

Obtain Opticom (or equivalent) for all cities' emergency vehicles

2.b Access for emergency equipment:

Review locations where barriers prevent access, identify solutions so that access can be provided every quarter mile.
Where emergency vehicles (additional ambulances, wreckers, sand trucks, etc.) are summoned after congestion has set in, have a direct route into the site specified by the requesting officer, and secured for safety (including blocking a ramp for wrong way access).
Provide cellular phones for police officers on accident scenes.

2.c Traffic Safety Officer:

Begin dialog with police, fire and TxDOT to define position and duties of TSO

2.d Heavy equipment:

Investigate possibility of purchase of large air bag system for uprighting semi-trailers
Consider reducing response time from 30 minutes to 20 minutes for wrecker service, with the first wrecker on scene towing after the 20 minute limit.

2.e Special needs:

Investigate potential for regional Haz Mat teams, jointly funded and staffed
Give police contact numbers to obtain TxDOT loaded sand trucks and arrange for round the clock availability within specified time period.
Request authorization from medical examiners to meet EMT at the hospital for most fatalities

3. Traffic Control Centers

Begin dialog to determine number, location, and users of area TCC's
Develop communication strategies and agreements

3.a Changeable Message Signs:

During daytime hours, respond to major incidents with information as available relating to safety and congestion.

Increase deployment of area-wide CMS, with cellular call-up capability

3.e Highway Advisory Radio:

Investigate role of portable, solar HAR, with new frequency range available

3.f In-home or in-business advisory:

Use probe vehicles (DART and others as identified) to monitor conditions on alternate routes

4.c Predetermined action plans

Jointly develop action plans for freeway blockages within area, including actions to be taken on frontage roads and parallel arterials, by time of day.

5.a Equipment on scene:

Put cellular phone on MAP vehicles for access to TxDOT resources

5.b TxDOT removal of spilled loads:

Develop local agreements to summon TxDOT, with prompt response

5.c Movable vehicles:

Use auto insurance renewals as means of publicizing Move-It
Establish liability of police pushing vehicles off roadway; new laws may be needed.

5.d Screen accidents:

Research means of screening accidents from other-direction traffic flow

5.f Direct traffic:

Develop training in directing freeway traffic to officers

6.a Debris clean-up:

All debris with safety implications swept off by wrecker crew before tow allowed

6.d Media notification after incident cleared:

Dialog with police for appropriate means

<u>minor incidents</u>

1.a MAP telephone number

Establish and publicize number (easy to remember)
Secure cellular companies cooperation in making it a free call
Establish signs along freeways giving the number

1.b Roving MAP vehicles

Increase program as rapidly as practicable; publicize as it proves itself
Identify minimum needs for MAP motorcycles for recurrent congestion, special events

4. Clearance time

Train MAP personnel to expedite procedures to assist *traffic*, as a primary goal.
Goal should be to provide minimum assistance needed to clear roadway, order up other help, get on to the next incident.
As TSO program comes on line, use MAP only for minor incidents, rather than tie up for major ones when other resources are available.

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Technical Memorandum 1980-6

Evaluation of IVHS Technology

for User Services

in the Dallas Urban Area

Draft February, 1994

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1. INTRODUCTION

1.1 Discussion

With the completion of the Interstate highway system, the attention of the transportation officials at the federal level has shifted from constructing new roadways to achieving better and more efficient use from the existing transportation system. The passage of the Interstate Transportation Efficiency Act (ISTEA) provides funding for state and local transportation agencies to begin developing and implementing Intelligent Vehicle/Highway Systems (IVHS). These systems use modern communication, computer, and control technologies to accomplish the following goals (1):

- Improve safety and mobility in the transportation network.
- Reduce the environmental impacts of transportation by reducing congestion and delay in the transportation network.
- Enhance economic productivity and viability by improving efficiency and operations of transportation in a region.
- Provide new services to travelers designed to enhance travel on existing systems and encourage the use of alternative modes of transportation.

FHWA has identified 27 potential IVHS user services that can be implemented by state and local transportation agencies to achieve better utilization of the existing transportation network (2). These user services are listed in Table 1-1. These user services provide the basis for state and local transportation agencies to develop IVHS deployment plans. The technology needed to provide these 27 user services can be grouped into seven functional areas (2):

- Surveillance
- Communications
- Traveler Interfaces
- Control Strategies
- Navigation/Guidance
- Data Processing
- In-vehicle Sensors.

Table 1-2 shows how these seven functional technology areas relate to the 27 user services.

The purpose of this document is to summarize the existing and emerging technologies in each of these functional areas as they apply to the user services. Therefore, subsequent chapters are organized by technology function.

Table 1-1 IVHS User Services

Type of Service	*Individual User Services*
Travel Planning	• Pre-Trip Travel Information • Ride Matching and Reservation
Travel Information	• En-Route Driver Advisory • En-Route Transit Advisory • Traveler Services Information • Route Guidance
Travel Management	• Incident Management • Travel Demand Management • Traffic Control • Public Transportation Management • Personalized Public Transportation
Travel Payment	• Electronic Payment Services
Advanced Vehicle Control Systems	• Longitudinal Collision Avoidance • Lateral Collision Avoidance • Intersection Crash Warning and Control • Vision Enhancement for Crash Avoidance • Impairment Alert • Pre-Crash Restraint Deployment • Fully Automated Vehicle Operation
Commercial Vehicle Operations	• Commercial Vehicle Pre-Clearance • Automated Roadside Safety Inspections • Commercial Vehicle Administrative Processes • On-Board Safety Monitoring • Commercial Fleet Management
Emergency Management	• Emergency Notification & Personal Security • Public Travel Security • Emergency Vehicle Management

Table 1-2 Mapping of User Services to IVHS Technologies

User Service No. #	*User Service*	17 *Surveillance*	*Data / Voice Communications* 24	20 *Traveler Interface*	5 *Control Strategies*	18 *Navigation / Guidance*	19 *Data Processing*	10 *In-Vehicle Sensors*
	TRAVEL PLANNING							
1	Pre-trip travel information	X	X	X		X	X	
6	Ride matching & reservation		X	X			X	
	TRAVELER INFORMATION							
2	En-route driver advisory	X	X	X		X	X	
3	En-route transit advisory	X	X	X		X	X	
4	Traveler services information		X	X		X	X	
5	Route guidance		X	X		X	X	X
	TRAVEL MANAGEMENT							
7	Incident management	X	X	X	X	X	X	
8	Travel demand management	X	X	X	X	X	X	
9	Traffic control	X	X	X	X		X	
16	Public transportation management	X	X	X	X	X	X	
17	Personalized public transportation	X	X			X	X	
	TRAVEL PAYMENT							
10	Electronic payment service	X	X	X			X	
	ADVANCED VEHICLE CONTROL SYSTEMS							
21	Longitudinal collision avoidance		X	X				X
22	Lateral collision avoidance	X	X	X				X
23	Intersection crash warning and control	X	X	X		X	X	
24	Vision enhancement for crash avoidance			X				X
25	Impairment alert		X	X				X
26	Pre-crash restraint deployment			X				X
27	Fully automated vehicle operation		X		X			X

User Service No. #	*User Service*	*Surveil-lance*	*Data / Voice Communi-cations*	*Traveler Interface*	*Control Strategies*	*Navigation / Guidance*	*Data Process ing*	*In-Vehicle Sensors*
	COMMERCIAL VEHICLE OPERATIONS							
11	Commercial vehicle preclearance	X	X				X	
12	Automated roadside safety inspections		X				X	X
13	Commercial vehicle administrative processes	X	X				X	
14	On-board safety monitoring			X				X
15	Commercial fleet management	X	X			X	X	
	EMERGENCY MANAGEMENT							
18	Emergency notification & personal security	X	X	X		X	X	X
19	Public travel security	X	X			X		
20	Emergency vehicle management	X	X	X		X	X	

1.2 Chapter 1 References

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2. SURVEILLANCE TECHNOLOGIES

Accurate and timely information about roadway and travel conditions is the cornerstone of improving traffic flow on the transportation network. With accurate information, traffic management agencies can implement control strategies, detect and manage traffic during incident conditions, and activate motorist information systems that will improve the quality of operations in the traffic network. Numerous technologies have been developed or are currently being developed that will improve both the quantity and quality of traffic and travel information.

2.1 Vehicle Probes

With the recent advances in computer, communications, and vehicle locating technologies, the vehicle itself can become an important surveillance tool for monitoring traffic conditions in the roadway network. Vehicles, acting as moving sensors (or probes), can provide speed and delay (thus sensing incidents) on each link traversed. This information can be transmitted to a central computer system where information from the probe vehicles can be "fused" with other information sources to provide an accurate representation of actual travel conditions in the transportation system.

The PATHFINDER experiment in Los Angeles, was one of the first projects in the United States to use the probe vehicle concept (1). Information on the vehicle's movement was used to collect real-time traffic and congestion information about the various links in the PATHFINDER network. Vehicle movement data were transmitted from the vehicle to a central computer once every minute via an FM data radio. Each vehicle was allotted a specific time slot to transmit its information to the central computer. Twenty-five vehicles were used in this initial experiment.

TravTek was the first large scale operational test in the United States to use probe vehicles to obtain travel time and incident information from the roadway network. In TravTek, one hundred Oldsmobile Toronados were equipped with on-board computers and communication devices that were used to monitor the vehicle's progress and position in a 1,200 square mile area surrounding the City of Orlando, Florida (2). Using this equipment, travel times on select links in this area were measured by the vehicle. The travel times measured on the last three links were then broadcast to a Traffic Management Center once every minute using an FM data radio. This information was combined with information from other sources to create a travel-time and incident/congestion database that was used in the in-vehicle route guidance and navigation systems.

Once fully operational, ADVANCE will be the largest operational test of the probe vehicle concept. ADVANCE is a dynamic route guidance system that will operate in a 300 square mile area in northwest Chicago. Unlike TravTek and PATHFINDER, the main source of real-time link travel times in the test network will be the 5,000 specially equipped vehicles, which will act as roving traffic probes. The equipment in the vehicle will monitor the time the vehicle takes to travel along each link in the road network and report these times to a Traffic Information Center over a two-way RF data radio system. To economize on the amount of transmissions, vehicles will report travel times at varying frequencies, depending on the classification of the road being traversed (3). Deployment of the 5,000 vehicles is expected to commence in early 1994 (4).

Other systems, such as Auto-Trac, Teletrac, and Pinpoint, could also be adapted so that equipped vehicles could serve as probes in an urban area like Dallas.

2.2 Inductive Loops

The inductive loop is the most common form of detector used for traffic management purposes (5 , 6 , 7 , 8). The principal components of an inductive loop detector are one or more turns of insulated wire buried in a narrow, shallow cutout in the roadway, a lead-in cable that connects the loop to the detector unit via a roadside pull-box, and a detector unit (sometimes called a detector amplifier) which interprets changes in the electrical properties of the loop when a vehicle passes over it. The loop system becomes active when the detector unit sends an electrical current through the cable, creating a magnetic field in the loop. When a vehicle passes over the loop, the ferrous material in the vehicle causes a decrease in the inductance of the circuit, which, in turn, increases the frequency of oscillation that is sensed by the detector unit.

Loop detectors can operate in either a pulse or presence mode. In the pulse mode, a short signal (typically about 0.125 seconds) is sent from the loop to the detector unit and can be used to provide volume counts. In the presence mode, the signal that is sent to the detector unit lasts only while the vehicle is in the detection area. Presence detectors are used to provide volume counts, presence detection, and occupancy measurements. Presence detection is used for most detector applications, and is the preferred mode for most system management purposes. Loops can be used to detect vehicle speeds by placing two loops in pulse mode a short distance apart. The distance between the loops divided by the time required for a vehicle to travel between the loops provides the speed of the vehicle.

Even though the actual cost of the technology and equipment is relatively low, the cost of installing inductive loops, especially on operating freeway lanes, can be high particularly when the delay cost to motorists are included. A more favorable time to install loop detectors is during construction or reconstruction of freeways.

2.3 Microwave Radar

Microwave radar detectors have been used in both law enforcement and traffic management applications for some time for monitoring vehicle speed (5,6). They are most commonly used by police agencies as a law enforcement tool to monitor the speed of individual vehicles. They have also been used for traffic management purposes for both counting vehicles and measuring vehicle speeds (8). A few advanced units can also be used as presence detectors in some situations. Some microwave detector units can also perform classification counts by measuring the profile of vehicles; however, these units are still experimental (5).

Most microwave radar detectors transmit electromagnetic energy at the speed of light in frequency bands near 10.5 GHz and 24.0 GHz (5). Because they use electromagnetic energy, they are typically unaffected by weather conditions, especially when measurements are made over a short distance. They can also be used for both day and night operations. One problem with microwave radar detectors, however, is that they tend to lock on to the strongest return signal, which is often produced by the largest vehicle in the traffic stream (i.e., a large truck). Smaller vehicles may not be detected by some microwave units. Therefore, the vehicle mix of the traffic stream may affect the accuracy of the data supplied by this type of technology.

The form of the electromagnetic wave transmitted by the detector determines the type of data that can be obtained by the unit (5). The most common type of microwave detector is Continuous-Wave (CW) devices. With CW units, electromagnetic energy is transmitted at one frequency. As illustrated in Figure 2-1a, vehicle speeds are measured using the amount of Doppler shift that occurs in the return signal frequency. (The shift in the return signal is proportional to the speed of the vehicle.) Because only moving vehicles cause a frequency shift in the return signal, these detectors cannot detect stationary vehicles, and, thus cannot be used as presence detectors.

Some types of microwave detectors can also use a frequency modulated continuous wave (FMCW) to detect the presence of stationary vehicles and to measure the speed of moving vehicles. Figure 2-1b illustrates a typical waveform of these types of detectors. Presence detection occurs in the portion of the waveform where the frequency changes with time. The portion of the waveform that is constant is used to measure the speed of vehicles in the same manner as the CW detectors.

Other types of microwave detectors use a pulsing waveform. This type of waveform is a variation on the FMCW signal. As illustrated in Figure 2-1c, it is generated by using different rates of change of frequency, time duration of each segment of the waveform, and numbers and sequencing of the segments of waveform. Detectors that use this type of waveform can measure differences between the range to the road and the vehicle, making it possible to provide not only vehicle counts and presence detection but also measurements of occupancy. Vehicle speeds can also be determined by measuring the time at which part of a vehicle crosses the beam produced by two closely-spaced detectors. Detectors that use this type of waveform are very similar in principle to ultrasonic and laser sensors.

Historically, microwave detector technology is expensive to purchase and operate, and can only be serviced by technicians with a Federal Communication Commission (FCC) license (6). However, this type of detector technology can be installed over a lane of traffic without an extensive lane closure. This can reduce installation costs considerably as compared to cutting loops on an operating freeway.

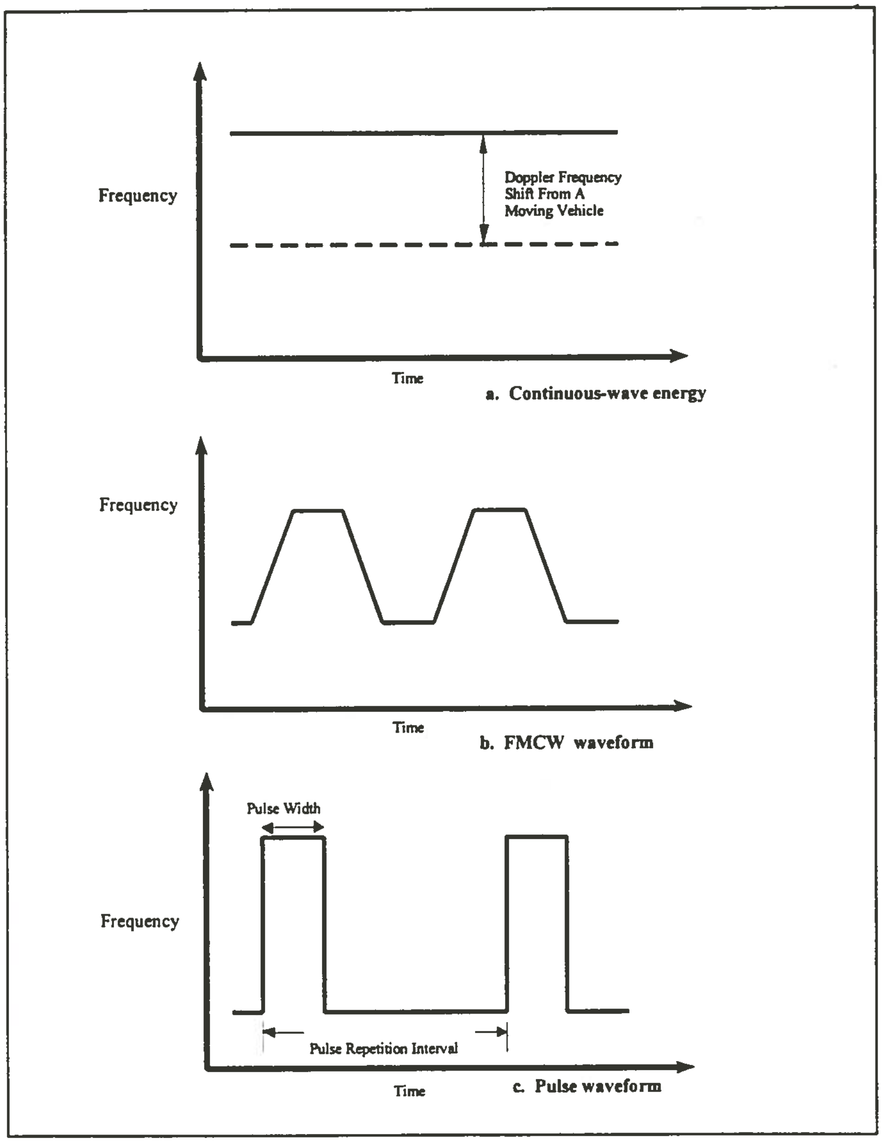

Figure 2-1 Waveforms Used with Microwave Vehicle Detectors

2.6 Ultrasonic Detectors

Ultrasonic detectors use an electronic sound wave signal and a receiving unit to detect vehicles traveling in the traffic stream (5, 8). Vehicles are detected when they pass through a high-frequency sound wave generated by the detector. Sound waves with frequencies between 20 KHz and 200 KHz (well above the range that can be detected by humans) are typically used with these devices. The sound wave acts as a pressure wave that propagates through the air and travels at a speed of approximately 740 mph at sea level. Signal processing techniques are then used to convert reflected waves into volume, speed, and occupancy measures. Ultrasonic detectors can be used for presence and queue length detection.

Because ultrasonic detectors use sound waves that propagate through the air, they are susceptible to attenuation and distortion from several environmental factors. Changes in ambient temperature, air turbulence, and humidity all affect the movement of the wave through the air. Furthermore, the surface of the vehicle may also affect performance of the detectors. Typically, textured or porous surfaces produce weaker reflected sound waves. This could make it difficult to detect some vehicles in certain situations. For example, snow on a vehicle may affect the ability of the detector to sense the vehicle.

2.7 Infrared Detectors

Infrared detectors can also be used in an IVHS environment to measure traffic conditions. There are two types of infrared detectors: active and passive. Active infrared detectors operate by focusing a narrow beam of energy onto an infrared sensitive cell. Vehicles are detected when they pass through the beam, interrupting the signal. Sensors can be mounted either above the pavement surface or adjacent to the roadside. They can be used as presence or pulse detectors; however, they may not provide accurate vehicle counts under high volume conditions. Unfortunately, detector performance can be affected by weather conditions (such as passing clouds, shadows, fog, and precipitation) by causing inconsistent beam patterns (6). Furthermore, the lenses used in some detectors may be clouded by environmental contaminants like moisture, dust, and road grime. These types of detectors have been used successfully to measure traffic in one lane (such as in a transitway) where sensors can be positioned on opposite sides of the roadway.

Passive infrared detectors do not transmit energy themselves, but measure the amount of energy that is emitted by objects in their field of view. The amount of energy that is emitted by an object depends on its emissivity (i.e., the ratio of the radiation intensity from an object's surface to the radiation intensity at the same wavelength from a blackbody at the same temperature) and temperature (5). The presence and passage of vehicles are detected by measuring the difference in the amount of energy emitted by a vehicle and the roadway. These types of detectors can be used to provide volume, occupancy, and presence detection. Like active infrared detectors, the ability of passive sensors to detect vehicles can be affected by fog and precipitation that can scatter and emit energy of their own. (5)

2.8 Video Image Processors

Video image processing systems detect vehicles by monitoring specific points in the video image of a traffic scene to determine changes between successive frames (9). Most systems consist of the following major elements:

- One or more video cameras,
- A microprocessor-based system for processing the video image, and
- Software for interpreting the processed images as vehicle detections.

The type of signal processing algorithm used by the image processor dictates the type of data that can be obtained by the system. Most video image processing systems use one of two algorithms. The first recognizes and counts vehicles entering a predetermined area in the field of view provided by the video camera. These types of systems can provide volume, occupancy, and presence detection. In more sophisticated systems, individual vehicles are "tracked" as they pass through the field of view. These types of systems can be used to obtain measurements of speed, vehicle classification counts, and potentially travel times in the detection zones. Other factors which may also influence detector performance include the following (5):

- The type of image being processed (i.e., upstream or downstream image),
- The mounting height of the video cameras,
- The number of lanes being processed, and
- The amount of movement in the video camera.

Furthermore, the effects of reduced visibility due to inclement weather and poor lighting on detection capability have not been fully defined (6). Tx Hwy Op

2.9 Aerial Surveillance

Aerial surveillance is typically used by police, commercial radio stations, commercial traffic reporting services, or traffic management agencies to provide an overall view of a major incident (10) or for subjectively evaluating and reporting traffic conditions. By using light airplanes or helicopters, agencies can observe where bottleneck and trouble locations are occurring in the transportation network and implement corrective actions to address these problems. For example, by using aerial surveillance, conditions on several alternate routes can be determined almost simultaneously. Traffic advisories can also be broadcast to motorists to divert traffic away from the congested area.

Because of the height advantage, aerial surveillance can be used to provide surveillance over a wide geographic area. Unfortunately, aerial surveillance is a costly means of providing surveillance. In general, aerial surveillance has never been shown to be a cost-effective surveillance technique for a traffic management agency. Also, because a wide area is often covered by a single aircraft, considerable delays can result in identifying incident conditions. Furthermore, inclement weather can limit the availability of this type of surveillance technique.

Aerial surveillance has also been accomplished by use of satellites and, for short term studies, from tethered balloons.

2.10 Automatic Vehicle Identification

Automatic Vehicle Identification (AVI) systems permit individual vehicles to be uniquely identified as they pass through a detection area. Although there are several different types of AVI systems, they all operate using the same general principles. A roadside communication unit broadcasts an interrogation signal from its antenna. When an AVI-equipped vehicle comes within range of the antenna, a transponder (or tag) in the vehicle returns that vehicle's identification number to the antenna. The information is then transmitted to a central computer where it is processed. In most systems, the transponder and reader/antenna technology is independent of the computer system used to manage and process the vehicle identification information (6).

The original AVI technology, which has been in use for several years, uses a radio frequency signal from the roadside to activate a transponder located in the vehicle. Transponders can be classified according to the type of source required power the transponder and the degree to which the transponder can be programmed (11):

Active -- With active transponders, power to the transponder is supplied from either an internal battery or a connection to the vehicle's power supply. The transponder is activated by an interrogation signal from the roadside communication unit (antenna). It responds to the signal by broadcasting its own signal, which contains the identification number for the vehicle, from an internal transmitter. This type of transponder generally has a greater operating range and is more reliable than other types of transponders. The life expectancy of an active transponder is between seven and ten years.

Passive -- With passive systems, the transponder does not require any internal or external power supply. Instead, the interrogation signal from the antenna is modulated and reflected to the reader. Because the return signal is weaker, passive systems typically produce less lane-to-lane interference than active systems. However, the weaker return signal also causes passive transponder systems to have shorter operating distances. Due to the simplicity of their circuitry, passive transponders have a life expectancy of approximately 40 years.

Semi-active -- Semi-active transponders use a similar operating approach as passive transponders in that they also are activated only after an interrogation signal is received from the reader. Unlike passive transponders, however, an internal power supply is used to boost the return signal to the reader. This increases the reading distance of the transponder. Like active transponders, the life expectancy of a semi-active transponder is approximately seven to ten years.

Transponders can also be classified according to the degree to which they can be programmed. Type I transponders are read-only tags that contain fixed data such as the vehicle or transponder identification number or vehicle classification code. They can be initially programmed either at the manufacturing facility or by the agency issuing the transponder; however, they cannot be reprogrammed without returning the transponder to the manufacturer. Most of these transponders contain 64 bit memory and can hold a 20-digit alphanumeric code.

Type II transponders have read/write capability. In these transponders, some of the memory contains permanent information (such as the transponder identification number) and cannot be reprogrammed while additional memory is provided that can be reprogrammed or written to remotely from the reader. These type of transponders are typically used in toll systems to record time, date, location, and account balance of entering and exit vehicles for toll collection purposes.

Type III transponders, also known as smart cards, have extended memory and are capable of full two-way communication. This is a new technology and is not currently being used in the United States in an operational capacity.

Currently, the most common application of AVI technology is for automatically collecting tolls on tollways. In this application, toll charges are electronically deducted from the driver's account when they pass through a toll booth or station. Because the tolls are collected automatically, the vehicle can pass through the toll plaza without stopping. AVI technologies are currently being used for electronic toll collection in several cities throughout Texas and the United States, including the Dallas North Tollway in Dallas; and the Sam Houston Tollway and the Hardy Toll Road in Houston.

However, AVI technologies have been proposed as a means of automatically collecting travel time information along a roadway (12). In Houston, AVI systems have recently been installed to monitor traffic operations on the main lanes and the high-occupancy vehicle (HOV) lanes on three major freeways (I-45 North Freeway, US 290 Northwest Highway, and I-10 Katy Freeway). Vehicles equipped with transponders are used as probes to collect current travel time information. This information is used to alert freeway operators of potential incidents and congestion on both the main lanes and the HOV facility (13).

2.11 Weigh-in-Motion

Weigh-in-Motion (WIM) systems permit the weight of commercial vehicles to be measured without requiring the vehicle to stop. With WIM systems, sensors (i.e., strain gauges and load cells) are installed in the pavement. As a vehicle travels over the sensor, processors installed either beside the roadway or off-site determine the vehicle weight from the weight of the axles, and the length and speed of the vehicle. WIM technology can also be used to classify vehicles based on the length, and the number and spacing of axles (8).

A number of technologies are available for installing WIM stations (14). The type of technology depends on whether the installation will be permanent or portable. Table 2-1 lists the type of WIM technologies that can be used with both permanent and portable WIM stations.

2.12 Automatic Vehicle Locating

Automatic vehicle locating (AVL) systems enable the approximate location of a vehicle to be determined and tracked as it traverses the transportation network. There are numerous techniques and technologies that can be used for locating the vehicle, including proximity beacons, radio frequency triangulation, Global Positioning Systems, and cellular telephone systems. In most cases, the position of the vehicle is compared to a map database using map matching techniques. Furthermore, most AVL systems allow for each equipped vehicle to be uniquely identified (8).

AVL systems are being used extensively by emergency services vehicles and transit applications. Commercial software and technologies are being marketed to aid in dispatching emergency vehicles. AVL systems are also being used by agencies to monitor transit operations on select facilities. This technology can also be used as a means of obtaining potential probe reports from vehicles traveling in the network. Software in a control center can automatically monitor travel speeds and transit times of vehicles equipped with AVL technology.

Table 2-1 Suitable Technologies for Permanent and Portable Weigh-in-Motion Systems

WIM System Configuration	*Installation Type*	
	Permanent	*Portable*
Strain Gauge Load Cells	X	
Hydraulic Load Cells	X	
Bending Plates with Strain Gauges	X	
Capacitive Weighmats		X
Strain Gauges Attached to Bridge Beams	X	X
Piezoelectric Cable	X	X
Piezoelectric Film	X	X

X indicates technology suitable for application

2.13 Closed Circuit Television

Closed circuit television (CCTV) systems have been used for many years for providing visual surveillance on the freeway system (10). They are used, for the most part, for detecting and confirming incidents. Operators in a control room monitor traffic conditions at locations where cameras are placed or use the image to verify traffic conditions indicated by another surveillance system. Most systems have pan, tilt, and zoom capabilities so that operators can view images from different locations.

CCTV systems allow control room personnel to visually monitor sections of roadway in real-time, and to react directly to the actual conditions on the roadway. Because operators can lose interest if required to view CCTV monitors constantly and may fail to notice incidents immediately after they occur, most current systems are being designed to automatically position cameras at suspected incident locations (as signaled by incident detection algorithms) and to alert the operator. Although in the past some CCTV systems may also be sensitive to lighting and environmental changes; several systems are available currently which perform adequately under low light conditions (6).

CCTV systems are the cornerstone of many freeway management centers in the North America. Several locations (including Seattle, Washington; Toronto, Ontario; Chicago, Illinois; Minneapolis, Minnesota; and locations in California cities rely heavily on CCTV as a means of providing surveillance on the freeways in their respective cities.

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3. COMMUNICATIONS

Improving communications among the various elements of the transportation system is one of the key components of IVHS. Through improved communication, users and operators of transportation systems will be better informed about conditions on the transportation network and the availability and accessibility of options. New communication technologies and services will permit traffic system operators to implement advanced control strategies that were previously impractical or prohibitive (from a cost standpoint). Three areas that are expected to be dramatically enhanced by IVHS efforts include the following:

- Communication between the vehicle and traffic management infrastructure.
- Communication between the various elements of the traffic management infrastructure, including those elements and organizations that support the traffic operations center.
- Communication between vehicles in the transportation network.

The communications technology options discussed in this chapter are organized in the same manner as the communications options suggested by MITRE in their 1992 "Working Paper on IVHS User Services and Functions" and further advocated in the 1993 FHWA "Intelligent Vehicle Highway Systems" seminar detailing the IVHS planning process (21, 1). In these documents, the IVHS user services were classified according to potential technologies as defined in Table 3-1.

Table 3-2 Technology Characteristics, summarizes the communications technologies, their associated frequency spectrum requirements, their information capacity, their costs and their risks (2).

Table 3-1 Mapping of IVHS User Services to IVHS Communications Technologies

		Vehicle to and from Infrastructure								*Within Infrastructure*				*Vehicle to Vehicle*	
#	*User Service*	*Local area broadcast HAR / AHAR*	*FM sub-carrier*	*Beacons infrared microwave*	*Wide-area radio system*	*Cellular radio services*	*Spread spec-trum*	*Commer-cial radio*	*Satellite*	*Land lines*	*Micro-wave*	*Wide-area radio system*	*Satellite*	*Micro-wave*	*Infrared / laser*
	Travel planning														
1	Pre-trip travel information									X	X	X	X		
6	Ride matching & reservation									X	X	X	X		
	Traveler information														
2	En-route driver advisory	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	En-route transit advisory	X	X	X	X	X			X	X	X	X	X		
4	Traveler services information					X									
5	Route guidance			X	X	X			X	X	X	X	X		
	Travel management														
7	Incident management			X	X	X			X	X	X	X	X	X	X
8	Travel demand management	X	X	X			X			X	X	X	X		
9	Traffic control									X	X	X	X		
16	Publice transportation management			X	X	X			X	X		X	X		
17	Personalized public transportation				X	X			X	X			X		
	Travel payment														
10	Electronic payment service				X	X			X	X		X	X		
	Advanced vehicle control systems														
21	Longitudinal collisioin avoidance													X	
22	Lateral collision avoidance													X	
23	Intersection crash warning and control			X										X	X
24	Vision enhancement for crash avoidance														
25	Impairment alert	X	X	X	X	X	X		X	X	X	X	X	X	X
26	Pre-crash restraint deployment														
27	Fully automated vehicle operation			X			X			X	X	X	X	X	X

#	User Service	Vehicle to and from Infrastructure								Within Infrastructure				Vehicle to Vehicle	
#	*User Service*	*Local area broadcast HAR / AHAR*	*FM sub-carrier*	*Beacons infrared microwave*	*Wide-area radio system*	*Cellular radio services*	*Spread spec-trum*	*Commer-cial radio*	*Satellite*	*Land lines*	*Micro-wave*	*Wide-area radio system*	*Satellite*	*Micro-wave*	*Infrared / laser*
	Commercial vehicle operations														
11	Commercial vehicle preclearance			X	X	X			X	X	X	X	X		
12	Automated roadside safety inspections			X	X	X			X	X		X	X		
13	Commercial vehicle administrative processes			X	X	X			X	X		X	X		
14	On-board safety monitoring				X	X			X						
15	Commercial fleet management			X	X	X			X	X		X	X		
	Emergency mangement														
18	Emergency notification & personal security			X	X	X			X					X	
19	Public travel security				X	X			X	X		X	X		
20	Emergency vehicle management			X	X	X			X	X	X	X	X		X

Table 3-2 Technology Characteristics

Spectrum / Media Application Area	*Frequency (MHz)*	*# Channels*	*Channel Bandwidth*	*Geographic Coverage Area*	*Info. Capacity (per channel)*	*Technology Availability*	*In-Vehicle User Cost*	*Infra-structure Cost*	*Technical Risk*	*Regulatory Risk*
FM Subcarrier (RDS)	88 - 108	1 (multiple)	10 kHz	10 - 40 mi.	< 1 kbps	Current	Low	Low	Low	Low
FM Subcarrier (High Data Rate)	88 - 108	1 (multiple)	20 kHz	10 - 40 mi.	8 kbps	Emerging	Low	Low	Med	Low
TV SAP	VHF/UHF TV	1 (multiple)	.	20 - 40 mi.	8 kbps	Current	Med	Low	Low	Low
TV-VBI	VHF/UHF TV	1 (multiple)	< 6Mhz per channel	20 - 40 mi.	50 kbps	Current	High	Low	Med	Med
VHF-Low Land Mobile	25 - 50	1250	25 kHz	20 - 50 mi.	10 kbps	Current	Med	Low	Low	High
VHF-High Land Mobile	150 - 174	800 (1000+)	30 kHz (new 1996, 5 kHz)	20 mi.	10 kbps (9.6 kbps)	Current	Med	Low	Low	Med
UHF-220 Land Mobile	220 - 222	5	5 kHz	< 50 mi.	9.6 kbps	Current	Med	Low	Low	Med
UHF Land Mobile	450 - 470	800 (1000+)	25 kHz new 1996 5 or 6.25 kHz)	20 - 30 mi.	10 kbps (9.6 kbps)	Current	Med	Low	Low	Med
UHF-TV Shared	470 - 512	many (800)	25 kHz new 1996 5 or 6.25 kHz)	20 - 30 mi.	10 kbps (9.6 kbps)	Current	Med	Med	Low	Med
Cellular (voice) Analog Switched	800 - 900	> 800, with limitations	30 kHz	Large (> 50 mi.)	2.4 - 9.6 kbps	Current	Med	Low	Low	Low
Cellular (Analog Packet)	800 - 900	> 800	30 kHz	Large (> 50 mi.)	2.4 - 9.6 kbps	Emerging	Med	Med	Med	Low

Spectrum / Media Application Area	*Frequency (MHz)*	*# Channels*	*Channel Bandwidth*	*Geographic Coverage Area*	*Info. Capacity (per channel)*	*Technology Availability*	*In-Vehicle User Cost*	*Infra-structure Cost*	*Technical Risk*	*Regulatory Risk*
Cellular (Digital)	900	8,500	5 - 15 kHz	10 - 20 mi.	4 kbps	Current	Med	High	Med	Low
ISM	902 - 928 2400 - 2500 5800	N.A.	N.A.	Short range (< 1 mi.)	< 500 kbps	Current	Med	High	Med	Med
VSAT	Ku -Ka band	Many	10 Hz - 10 Mhz	Global	4 kbps	Current & emerging	High	High	Med	Med
SMR Mobil Data Nets	800 / 900	200 - 280	25 / 50 kHz	Wide area nets (nation-wide)	10 kbps	Current & emerging	High	med	Low	Med
DRB (Digital Radio Broadcasting)	1452 - 1492 (L-band)	Multiple	1.5 MHz	20 - 50 mi. Urban	64 kbps (1 Mbps if dedicated)	Emerging	Med	Low	Low	Low
IR Beacon	860 nanometer			short range (< 200 meters)	512 kbps	Current	Low	High	Low	Low
Mobil Satellite LEO SAT	L-band, Ku band 930 Mhz, 1610-1626.5 Mhz 20-21 GHz	Many	6 kHz	U.S. nationwide, Mexico, Canada	6.75 kbps	Current & emerging	High	Med	Med	Low
PCS	900 - 2000	1,000 - 30,000	3 - 100 kHz	wide area nets (Nationwide)	25 kbps	Future	High	Med	Med	Med

3.1 System Architecture and Communications Protocols

The U.S. Department of Transportation has defined system architecture as "a description of how the many elements, or subsystems, work together to perform the system's intended functions or to provide user services." (3) FHWA views the development of a national IVHS architecture important because it can:

- Provide a common method for vehicles to communicate with roadside devices and transportation management centers.
- Permit IVHS equipped vehicles to travel across the country and utilize user services.
- Foster private sector development of products and services.

Architecture issues that impact technologies include: standards, communications protocols, assignment of functions (for example, centralized versus distributed), varying levels of user services and increasing functionality over time (3).

3.1.1 FHWA Sponsored National IVHS Architecture Project

In cooperation with IVHS AMERICA recommendations, FHWA initiated a formal systems architecture design process funded by the U.S. DOT (4). This architecture development process was solicited in March 1993 (5). From this solicitation four consortia were selected to develop different, competing architecture concepts (6). The lead agencies on the four teams are: Hughes Aircraft, IBM, Rockwell International and Westinghouse Electric. The start date for this work was September 15, 1993.

The schedule for the work includes a 12 month Phase I technical effort, followed by a 3 month "down-select" where the number of proposed architectures is reduced to one or two. Phase I will produce subsystem descriptions and associated data flows. Deliverables from Phase I include:

- initial architecture definition (including mission, logical and physical architecture components),
- traceability matrix,
- definition of simulation parameters,
- analysis of data loading requirements,
- initial cost analysis, and
- a proposed architecture evaluation plan.

Phase II will involve detailed analysis and systems modeling to evaluate the candidate IVHS architectures. Phase II is expected to last 16 months. Deliverables are anticipated to include: detailed architecture definition (including mission, logical and physical architecture components), traceability matrix updates, simulation study results, evolutionary deployment strategy, cost analysis and a performance / benefit summary.

Associated with this National IVHS Architecture project is a consensus building effort involving "key stakeholders." A goal of the study is to develop an architecture that is regarded as the consensus best architecture by key stakeholders. As a part of the consensus process, a Regional Architecture Forum will be held in the Dallas area on May 6, 1994. It will provide an opportunity to gather local responses to the architecture alternatives. Figure 3-1 illustrates the program management and organizational relationships between the entities involved in the project.

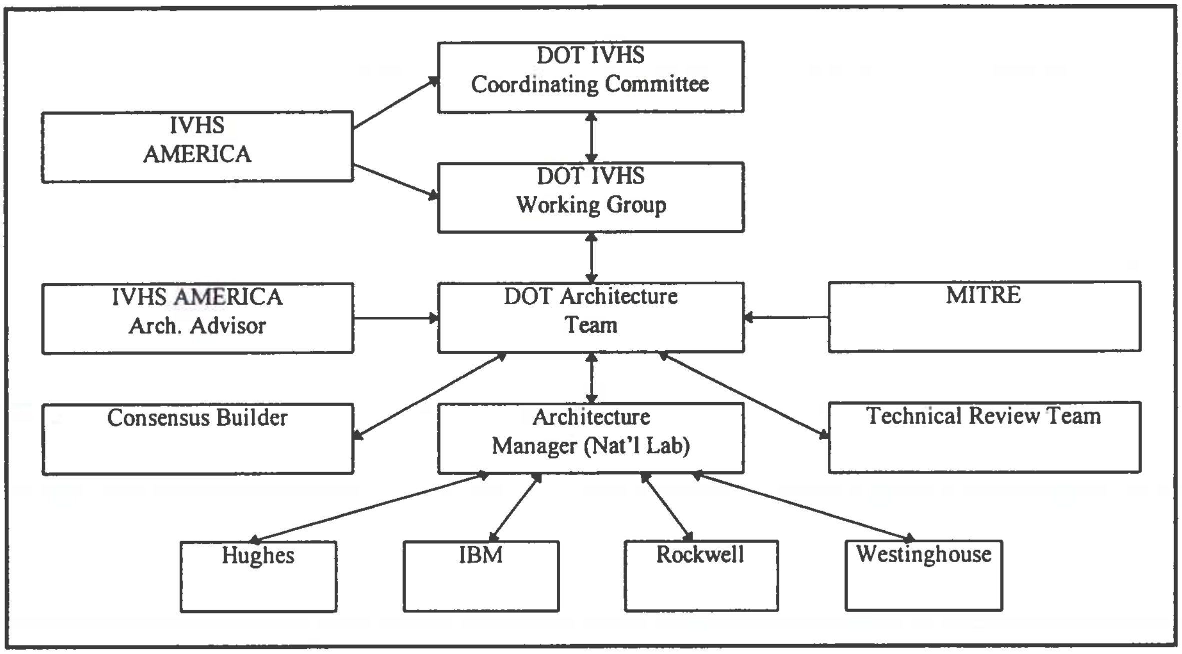

Figure 3-1 National Architecture Program Management

3.1.2 NEMA National Traffic Control / IVHS Communications Protocol (NTCIP)

3.1.2.1 Background

Communications protocols are a key element in implementing IVHS user services. In the traffic signal local controller technology arena, there currently does not exist a common set of protocols for communications. Therefore, it is difficult to develop an integrated system that provides inter-operability between manufacturer's products. Further, there is a desire by customers to view local controllers as "field processors" acting as a communications and control node performing more than traffic duties (7). These additional functions could include: changeable message sign displays, surveillance camera control, sprinkler system control and air quality monitoring.

NEMA traffic control equipment manufacturers began to formulate a National Traffic Control / IVHS Communications Protocol (NTCIP) shortly after finalizing the TS-2 traffic control hardware standard in 1992. Among other considerations, TS-2 Standards addressed communications between equipment components within the cabinet (8). However, it did not pertain to communications protocols between traffic signal local controllers and other devices external to the cabinet.

As NEMA's discussions proceeded, the FHWA sponsored a Signal Manufacturers Symposium in Washington, D.C. in May 1993. The participants included NEMA members, the FHWA, states, cities and other industry representatives. The conclusion of the Symposium was to identify five priority issues for action (9). They were as follows.

- Development of a communications standard
- Designation of the local controller as a "field processor" for various control applications
- Simplified operations and maintenance of traffic signal control equipment
- Improved procurement practices
- Deployment options with identified funding

These issues were consistent with published objectives for IVHS and also consistent with prior FHWA reports on the following related topics.

- Report on *Operation and Maintenance of Traffic Control Systems* (10)
- Expert panel report on *Traffic Control Systems Operations and Maintenance* (11)
- Report on *Traffic Control Systems Operations and Maintenance - A Plan of Action* (12)

Specific issues relevant to communications standards that have been emphasized by NEMA in their NTCIP design efforts are (13).

- Develop a design that is fully documented and that could serve as an "open standard"
- Keep communications separate from applications
- Define a protocol that can be implemented
- Allow multiple vendor's products use of same communications path (connectivity)
- Share common functions between like products (interoperability)
- Enable development of "field processors" that are communications and control nodes in an IVHS network (not just local controllers)

3.1.2.2 NTCIP Design Approach

The NTCIP design approach is based upon network models that have been designed for other non-transportation systems. Therefore, it is a goal for the protocol to conform to existing network methods and standards. The standards that have been chosen are.

- HDLC - High Level Link Data Control (ISO 3309 and ISO 4335) at the link level (14) (15)
- X.25 - (ISO 8208 and ISO 8878) at the network level (16) (17)

The NEMA Traffic Control Systems Section chose these models because (18):

> . . . models were chosen because the communications requirements for traffic control and traffic management generally fall into two levels. These are referred to as *link level* and *network level* communications. At the link level, a communication protocol must

deal with passing data between directly connected devices such as a traffic controller connected to an arterial master. At the network level, a protocol must deal with end-to-end oriented communications where data may have to pass through several intervening devices to reach its destination. For example, a telephone conversation passes through several switching stations before reaching the destination party. In a traffic control application, the scenario might be a central computer downloading a controller database through an arterial master.

Both of these standards are based on the seven layer ISO (International Organization for Standardization) network model. (19) The seven layers of the ISO model are: physical, data link, network, transport, session, presentation and applications.

3.1.2.3 February 1994 Status

Since May 1993, NEMA's NTCIP effort has been structured around week long meetings every two months with member organizations and interested agencies (including FHWA, states and cities). Their time table is to produce a draft for general review by mid 1994. Upcoming meetings are the week of March 21, 1994 in Chicago and the first week in May 1994 in Washington, D.C.

In order to facilitate the protocol work, FHWA has agreed to hire a consultant to evaluate the proposed NTCIP in the spring of 1994. Further, a Steering Committee organized as a result of the May 1993 Signal Manufacturers Symposium is in the process of recommending that FHWA fund the development of computer code implementing the NTCIP after review by the consultant. This software would be written in a portable code (probably C) that could be implemented on a variety of devices and would be in the public domain.

3.2 Vehicle to and from Infrastructure

IVHS technologies and concepts will greatly improve the level of communications between the vehicle and the traffic management infrastructure. Under IVHS, transportation managers will need to communicate information about road and weather conditions, traffic information, and control strategies directly to motorists in their vehicle. Technologies in this category will permit not only traffic information and safety advisories to be broadcast from the traffic management center to the vehicle, but also link transit times and requests for assistance to be broadcast from the vehicle to the traffic management center. Therefore, two-way communication will be an integral part of future IVHS systems.

Spread spectrum transmits over a very wide bandwidth so that the power per unit bandwidth (watts per hertz) is minimized (20). The use of spread spectrum broadcasting techniques permits information to be superimposed over existing communication signals without degrading the quality of either the individual signal or the host signal (21). Regardless of the type of technology used to broadcast information (i.e., beacons, wide-area radio, cellular telephone, or satellite communications), using spread spectrum broadcasting techniques will permit greater amounts of information to be used by both travelers and transportation officials alike. All of the technologies discussed below are capable of using spread spectrum broadcasting techniques.

Table compares some of the characteristics of systems for communicating between the vehicle and the infrastructure.

Table 3-3 Comparison of Communications Media Characteristics

Type	*Incremental Infrastructure Cost for IVHS*	*Vehicle Cost*	*Throughput Capacity*	*One-or Two-Way Communication*	*Geographic Coverage*	*Other Pros/Cons*
Infrared or RF	High	Low	High	Two-way	Small per beacon	Provides position calibration
FM sideband	Low	Low	Very Low	One-way	Limited	Function added to radio
Mobile satellite services	Low	High	High	Two-way	Very wide	Too wide-multiple cities, too
Cellular	Low	Medium (requires phone in vehicle)	Medium/ limited by phone use	Two-way	Limited	Integrates phone with IVHS
RF data Network	Low	Medium	Medium/ increasing	Two-way	Complete	Allows for IVHS growth

3.2.1 Local-Area Broadcast (HAR/AHAR)

Local-area broadcast, commonly referred to as Highway Advisory Radio (HAR), is one means of providing one-way communication to motorists (20, 22). Information is relayed to travelers through their existing AM radio receiver in their vehicle. Users are instructed to tune their vehicle radio to a specific frequency via roadside or overhead signs. Usually, information is relayed to the motorists through a pre-recorded message, although live messages can be used. HAR systems can be used to provide information about existing travel conditions, construction activities, routes to and from special events, incident and congestion conditions, and alternate routes.

Most HAR systems broadcast on special AM frequencies (either 530 or 1610 KHz); however, any frequency can be used as long as a low power level is used and a local AM station does not interfere. Information is broadcast from low-powered transmitters located along or under the roadway. Therefore, the range of most HAR systems is limited to a few miles.

One of the primary disadvantages of this type of system is that the driver is required to manually tune the car radio to the HAR frequency. However, efforts are underway to develop an automated HAR (AHAR) system (23). With AHAR, the radio monitors for special transmissions, and automatically tunes to the AHAR frequency and mutes the car radio for the duration of the AHAR message.

3.2.2 Subcarrier (One-Way)

3.2.2.1 FM Subcarrier

These systems employ the empty space that acts as a buffer between commercial radio stations to provide control information to a network of receivers or users (24). These systems superimpose data on an existing FM broadcast radio transmission. Subcarrier networks can be used to develop a radio-based system "dedicated" to providing continuous information to travelers.

Two types of FM Subcarrier systems are available. The traditional subcarrier (termed RDS) operates in the 88 - 108 MHz frequency range using a bandwidth of 10kHz. Although data transmission rates are on the order of 1,185 bps, the throughput transmission rate is substantially less because data cannot be transmitted continuously (28). The second type of FM subcarrier (High Data Rate) operates in the 88 - 108 MHz frequency range using a bandwidth of 20 kHz. Information capacity on this subcarrier configuration is 8 kps.

By using a synthesized voice format, detailed verbal information can be provided to travelers both at work and in their personal vehicle (20). It is also possible to use FM subcarriers to transmit text information to transit passengers. In the Dallas Area, DART installed LED signs in buses that use FM subcarrier transmission to convey transit information, news and ads (25). Data transmission rates in the DART system are 4,800 bps.

The cost of these systems is relatively low since existing commercial broadcast transmitting equipment is used. A special receiver is required in the vehicle to process the information. Only one-way communication is possible with this type of system and coverage is limited to hose areas covered by FM radio broadcast stations (28). Other disadvantages include the following (20):

- Most existing subcarrier systems are privately owned and operated (although a public agency could fund and operate its own subcarrier network as a public service).
- Although unnoticeable to most listeners, subcarrier systems degrade the quality of voice transmissions on adjacent radio stations (this problem is more pronounced with low powered radio stations).

3.2.2.2 AM Subcarrier

In addition to FM subcarrier transmissions, there is some ongoing research in establishing subcarrier communication using AM transmissions (26). Advantages of this approach include: larger transmission area than FM signals (especially useful in rural applications where daytime coverage may include a 250 mile radius) and the inexpensive nature of AM radios. Disadvantages include: data transmission is low speed (perhaps as low as 100 bps and AM signal skip over vast distances. Preliminary testing of this technology could begin as early as spring 1994.

3.2.3 Beacons -- Infrared and Microwave (Two-Way)

Beacon systems are one way of providing localized communications between the infrastructure and vehicles (27 , 28 ,29). Beacon systems permit data to be transferred to and from the vehicle at relatively high speeds. Data transfer rates can range between 400 kbps and 1 Mbps. In order to minimize the problems caused by multiple vehicles contending for the same uplink channel to the communication system, the coverage area by a single beacon is typically limited to less than 100 feet. Therefore, most systems that use this type of technology locate beacons at intersections and other key decision points. This placement also allows intersection-specific information to be broadcast to the vehicle.

While most beacon systems are used with Advance Traveler Information Systems (ATIS), they can also be used to support electronic toll collection (ETC) and other regulatory functions such as weigh-in-motion (WIM) and automatic vehicle classification. Because these systems can only broadcast information to vehicles in the immediate vicinity of the beacon, they are not well-suited for providing advance warning of accidents or congestion on specific routes (27).

Beacons systems are currently being used by the ALI-SCOUT system in Germany (29) and the Road Automobile Communication System (RACS) in Japan (30).

3.2.4 Wide-Area Radio System (Two-Way)

Wide-area radio systems offer the potential for two-way communication between the traffic management center and a large number of vehicles over a wide geographic region (such as a metropolitan area) (27). These types of systems can be used to broadcast traffic and other travel information to vehicles, or to transmit route selection and guidance information to specific vehicles from a central control facility. They can also be used by vehicles to transmit link travel times, incident reports, and requests for assistance back to the control system. Currently, most of the wide-area radio systems in operations today use a separate RF data radio in the vehicle (as opposed to the normal radio in the vehicle).

Unlike HAR and AHAR systems which are used to broadcast only localized information, wide-area systems are generally used to cover a large geographic region. They can be used to transmit common information or data over a single channel to all vehicles in a broadcast area. Equipment in the vehicle could then be used to filter out specific information that is relevant to vehicles in a region. These systems could also be used to provide vehicle-specific information (such as route information or acknowledgment to requests for assistance by individual vehicles).

Two-way wide-area radio systems were used in both the PATHFINDER and the TRAVTEK operational test projects. In both of these cases, an FM RF data radio was installed in the vehicle. These radio systems were used to provide probe reports from the vehicle to the traffic management center, and to transmit traffic and travel information from the traffic management center to the vehicle.

3.2.5 Cellular Radio Services

An alternative to wide-area radio systems is cellular radio (21). Through cellular radio systems, information can be provided to select vehicles within specific cells of the system. This would allow information to be tailored to meet the needs of travelers in a specific region or radio cell. With this type of system, information can be geo-filtered so that only information relevant to vehicles traveling in a particular cell or region is provided. This would greatly reduce the amount of redundant or irrelevant information that is broadcast to travelers in a specific region.

Cellular radio systems offer great growth potential as well. As systems convert from analog to digital, other means of providing information (other than voice) are expected to become available, including graphical displays. However, there is concern that the newer digital equipment may still not be able to accommodate the data transfer demands of developing IVHS systems (28).

3.2.6 Commercial Radio

Many commercial radio stations include traffic reports as part of their regular programming during rush hour and other periods of the day (31). The primary advantage of this approach of providing traffic information is that large segments of the driving population can be reached with little or no additional cost to the public agency for specialized in-vehicle equipment. However, the timeliness and accuracy of the information broadcast on commercial radio is sometimes not very good. Because commercial radio has goals other than reporting traffic information, traffic reports are often transmitted only when normal scheduling permits. This may cause considerable time delays from when an incident occurs to when it is reported by the media. Often, many incidents go unreported or are cleared by the time they are reported on the radio. The accuracy of the information provided by commercial radio stations is a function of the time between the broadcaster's last communication with the incident reporting source and the number of incidents that have occurred and/or have been cleared during that time (32 ,33).

One way to improve the accuracy of the information is to allow commercial radio stations and traffic reporting services direct access to the traffic information and surveillance video from the traffic control center. In Chicago, more than 30 public and media users have their own direct transmit/receive terminals to the Illinois Department of Transportation's surveillance computer, which provides real-time congestion and travel time information reports (34). In Minneapolis, broadcasts are made by a commercial traffic reporting service directly for the surveillance and control center so that up-to-date information is always available to the motoring public (35), as well as to commercial broadcasters. In Dallas and Houston, as well as other urban areas, Metro Traffic, a commercial service, provides traffic information to local broadcasters.

3.2.7 Satellite (Two-Way) Communications

Dedicated satellite radio channels can be used to provide nationwide coverage for certain types of vehicle-infrastructure communication services (27). Currently, satellite communication services are used to allow specific commercial vehicle operators anywhere in the United States to communicate with company dispatchers from the cabs of their trucks. Because of the large area that can be covered by satellite systems, the greatest potential for satellite communications appears to be for rural and interstate applications. Furthermore, since satellite systems are line-of-sight, the potential to lose transmissions in densely-developed CBD's is high.

There are some satellite communication systems that are generally used for commercial trucking applications. These systems are typically vendor-operated. They provide non-verbal messages from fleet dispatchers to heavy vehicles anywhere on the road in the United States (36). Hardware in the vehicle usually comes with a series of pre-formatted messages stored in memory; however, drivers can compose free-form messages using a keypad. Besides simple messages and positioning reports, some systems can also provide value-add services such as trailer monitoring (position, status, and activity logs); remote engine monitoring; anti-theft systems; temperature monitoring for refrigerated units; and wireless downloading of information about driver logs, on/off loading of freight, and other data stored in on-board recorders.

3.2.8 Meteor Burst Communications

Meteor burst technology is based upon reflecting communication signals off the trails of meteors as they travel through the atmosphere (37). No definitive opinion has yet emerged pertaining to this technology.

3.3 Within- Infrastructure Communication

Communications among all of the individual elements is another critical component of an Advanced Traffic Management System. These systems will be required to perform the following functions:

- Connecting the traffic management center (TMC) with the various sensors, signals, signs, and ramp meters.
- Providing communication between the TMC and the communication infrastructure that supports the vehicle to/from infrastructure interface.
- Interconnecting TMCs operated by various organizations and agencies that provide area-wide transportation services (such as traffic enforcement and regulatory agencies, construction and maintenance organizations, EMS, fire, and road service organizations) or interagency TMCs in a multi-jurisdictional environment.

Several options are available for connecting all of the various elements of a traffic management system, including the following:

- Landlines
- Microwave
- Wide-area Radio
- Two-way Satellite Communications

Table summarizes some of the attributes of potential technologies for communicating within the infrastructure.

Table 3-4 Communications Media for Traffic Control Systems

Media	Current Use	Information Capabilities	Applications	Connection	Repeater Distance
Twisted Pair	Widespread	Data, Voice, Limited Video	Central to multiple field drops	Physical (Owned or Leased)	8-12 mi
Coax	Numerous	Data, Voice, Video	Central to multiple field drops	Physical	1/3 - 1 mi
CATV (Cable)	Few	Data, Voice, Video	Central to multiple field drops	Physical (leased)	N/A
Fiber	Limited	Data, Voice, Video	Point-to-Point Central to multiple field drops Trunking	Physical	3-10 mi
Microwave	Very Limited	Data, Voice, Video	Point-to-Point Trunking	Air-Path (FCC)	1-20 mi
Radio	Limited	Data, Voice	Central to Multiple field drops	Air-Path (FCC)	10-20 mi

3.3.1 Landlines

Landlines are the backbone for communicating between infrastructure elements of most existing traffic management systems as well as emerging IVHS systems. Three types of communications mediums can be classified as being landline systems: twisted pair wire, coaxial cable, and fiber optic systems (20, 38).

Twisted pair wire is most widely used in traffic signal control and loop detector systems. A twisted pair cable consists of sets of two wires that are wrapped around each other and covered with a metallic shield. The twisting of the wires minimizes interference from external sources that could corrupt the information being transmitted. When used for traffic management purposes, twisted pair cable is usually voice grade, although digital systems can also be used. For the most part, a single twisted pair cable is not used to carry information from several devices to a control center because of the greater capacity requirements of a trunk line system. Twisted pair cable can be either owned by the traffic management agency or leased from local communication systems.

Coaxial cable is the technology most commonly associated with cable television. As with twisted pair wire, it is commonly used to connect numerous traffic control devices with the center control facility. Coaxial cable is suited for transmitting voice, digital, and video data. One problem with this medium is the need for amplification and system maintenance with longer distances. The medium is also susceptible to outside interference from other electrical sources. Like twisted pair cable, a coaxial cable can be either installed by a local traffic management agency or shared with a local CATV network.

Fiber optics communication systems use pulsating light waves to transmit data digitally. Because transmissions are free from electrical interference commonly associated with cable systems, fiber optic cable can be used to provide a high quality transmission of video, data, and voice data. Fiber optics also allows transmission of much higher data volumes and more video images than other mediums. Because of the cost of these installing fiber optics cable, the medium appears to be best suited for long distance trunk applications.

3.3.2 Microwave

An alternative to landline communications is microwave (21, 38, 39). Microwaves are radio frequencies in the range above 1 GHz. High data transfer rates are possible with microwave communication technologies. This makes it ideal for carrying voice, data, and/or video information. Also, because radio waves at frequency greater than 1 GHz have many of the characteristics of light energy, it is possible to provide a direct point-to-point link that can be used to communicate with a concentrated group of remote signals or video cameras. This makes microwave technology a viable alternative for trunking applications and for connecting other major system nodes to the traffic management center in areas where landlines are too costly.

With microwave, signals are broadcast from an antenna through the atmosphere along a line-of-sight path (38, 39). Therefore, no physical connection between the transmitter and the receiver is required. This makes microwave ideal in areas where there is little or no space available for conduit or aerial cables. It can also be used in areas where natural barriers (such as large bodies of water) prevent a physical connection from being made. However, because a direct line-of-sight between the transmitter and the receiver is required, its use in rolling terrain or in densely developed urban areas may not be practical without installing repeater stations. Furthermore, it can be very difficult to obtain a microwave frequency allocation in some urban areas because frequencies must be unique not only in an area but also in a direction to prevent interference from other microwave transmissions. Most available frequencies are usually in the higher frequency bands.

Because microwaves radiation is uni-directional, separate inbound and outbound facilities are needed to achieve two-way communications (38). Furthermore, microwave transmissions can be affected by atmospheric conditions, with the greatest amount of degradation occurring at high frequencies. Rain and fog can also severely affect microwave transmissions.

3.3.3 Wide-Area Radio

Wide-area radio systems can also be used to communicate between various elements of the infrastructure (38). Although radio frequencies range from the hundreds of KHz all the way to 1 GHz, only a few have potential for applications in traffic control communications. The most likely frequencies for wide-area broadcasts appear to be in the 928/952 MHz bands. In these bands, radio wave propagation is essentially line-of-sight. Unfortunately, like microwave, frequencies along a particular transmission path must be unique to prevent interference. Therefore, there may be limited frequencies available in some urban areas. In those areas where it is available, the maximum range of this communication medium is on the order of 15 to 30 miles (subject to any obstacles to the line-of-sight transmission paths) without installing repeater stations. Data transfer rates up to 9600 bps and higher can be supported over a single 25 kHz channel with this media.

Wide-area radio can be used to connect the traffic management center to remote traffic control devices (such as isolated changeable message signs or traffic signal locations) or to traffic management centers in other jurisdictions in multi-jurisdictional areas. This type of communication technology is most applicable in rural or mountainous areas where the cost of installing landlines would be prohibitive (27). Wide-area radio systems can also be used to interconnect up to 40 traffic signal controllers (on a single channel) in an urban area (38).

3.3.4 Satellite (Two-Way) Communications

Satellite communication systems can also be used to link remote traffic control or communication devices to the central control facility. Satellites permit two-way communication between the control center and the remote elements of the infrastructure. Like wide-area radio systems, satellite communications appear to be most feasible where the cost of installing landlines is prohibitively expensive (27).

3.4 Vehicle-to-Vehicle

As IVHS systems mature, particularly Advanced Vehicle Control Systems, the need for vehicle-to-vehicle communications will greatly increase. Inter-vehicle communications will support advanced vehicle control functions such as coordinating vehicle platooning and headway control. Vehicle-to-vehicle communications could also be used to relay safety and warning information on non-automated highways.

Currently, two types of communication media appear to be most feasible to provide inter-vehicle communications: microwave and wide-area radio (27). Microwave technology can be used to provide an effective single channel communications link for closely spaced vehicles where direct line-of-sight can be maintained. Wide-area radio and mobile radio systems can be used to communicate between vehicles that are widely dispersed (such as in rural or nighttime operations).

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4. TRAVELER INTERFACE

The traveler interface is the device that allows the traveler to interact and retrieve needed or requested information from various elements (such as the traffic management center or the information databases) of an IVHS system. Interface devices permit travelers to obtain specific information tailored to their needs, including updates of travel conditions (i.e., traffic and weather) from the traffic management center; input origin and destinations on route guidance and navigation devices; request location of specific user services (such as restaurants, hotels, etc.); receive route guidance and navigation instructions; and request roadside assistance from emergency services. These devices can be located either at home or work, along the roadside, or in the vehicle.

4.1 Input Devices

Several types of technologies are in use or being developed to input requests and instructions from travelers.

4.1.1 Touch Screen

A touch screen provides a convenient means for users to select necessary input screens and to enter data in on-board systems. With these types of systems, the driver enters information and selects desired function by directly touching the display device (1). An infrared light grid is overlaid on the display screen. When the user points to an item on the display screen, the overlaying light grid is broken. By using this system, the position of the finger on the device indicates the function which the driver wishes to invoke. This type of entry device was used in the TravTek system (2).

4.1.2 Key Pad/Key Board

Another common way in which drivers can enter information on-vehicle communication devices is through key pads or key boards. These input devices are especially useful for navigation and routing selection systems where the driver is required to enter a desired destination or a series of destinations or roadway type preference data. These devices can also be used to request a variety of traveler services and yellow pages information. Specific keys can be reserved for special functions, such as requesting emergency assistance from police or a traffic management center.

4.1.3 Voice Recognition

An emerging technology that has potential application as a driver input device is voice recognition (1). With voice recognition, the driver can enter instructions or ask for information directly from a computer in the vehicle without taking his or her hands off the steering wheel. Microphones in the vehicle are used to pick up driver's verbal instructions. The instructions are processed by a speech recognition module. The module could be attached to computers in the vehicle that serve other functions or could be part of an autonomous voice recognition/driver interface system.

4.2 Display Devices

Devices are currently being developed that will permit information to be displayed to drivers directly in their vehicle. A number of technologies are being developed that use one or more of the following display outputs:

4.2.1 Voice Output

While some auditory displays, such as warning or alert electronic tones, have been used in automobiles for some time, recent advances in electronics have greatly expanded the potential range of auditory (or voice) messages that can be presented to drivers. Technological advances in speech synthesis and digitized voice recordings are primarily responsible for expanding the range and flexibility of auditory display systems. Potential applications of speech technology in the vehicle include the following (3):

- Fuel and vehicle status information;
- Traffic, terrain, and weather advisories;
- Navigation and route guidance instructions;
- Feedback to control inputs; and
- Answers to user queries.

Auditory displays possess a number of characteristics that may improve the efficiency by which information can be relayed to the driver (3). First, auditory displays can be used to alert drivers to the presence of potential hazards or conditions much faster than visual displays. Alerting drivers to upcoming potential turns and changing traffic conditions is also a logical extension of auditory displays in an ATIS environment. Furthermore, they can also be used to present specific instructions and cues without requiring drivers to take their eyes from the roadway.

However, auditory displays have specific limitations that may reduce their effectiveness as an on-board communication device. (3). By their nature, auditory displays are intrusive and distracting, and could disrupt, potentially, a driver's concentration at a critical moment in the driving task. Since there is a wide range of noises and sounds in the automobile, voice messages have to compete with other auditory devices in the vehicle (such as the radio, other passengers, general road and vehicle noise, etc.) for the driver's attention. This may lead to auditory clutter within the vehicle. Another major limitation of voice message devices is that they may interfere with the driver's ability to hear external emergency warnings and alerts (such as at railroad grade crossings and when emergency vehicles are on the roadway).

The complexity of the information that can be presented using voice messages alone is another limitation. While warnings and alerts can be communicated relatively easily, more complex information, such as navigation and route guidance information, is more difficult to provide using voice messages alone. Typically, drivers do not comprehend the meaning of a voice message until it has been transmitted in its entirety (4). Furthermore, very long messages, such as those used to alert drivers of route changes or incident conditions, have to be repeated several times before a driver can fully comprehend and remember the message (3, 4).

4.2.2 Visual Display

One potential method of providing drivers with complex navigation and route guidance information is through visual displays mounted in (or on) the dashboard of a vehicle (4). A few systems are under various stages of development or in prototype form (5 , 2, 6 , 7). Most of these systems will be used to provide motorists with route guidance and navigational information, although, other types of information (such as congestion and traffic information, weather updates, or "yellow pages" information) can be presented using these devices.

In-vehicle visual displays offer a number of advantages over other available technologies in providing information to motorists while driving (4, 8). The first obvious advantage is that information is more readily accessible to the driver. With visual displays, a driver can be provided with constant and continuous access to positioning, routing, and navigational information. Furthermore, in-vehicle visual displays provide great flexibility in the way in which information can be presented. With these types of devices, information can be displayed in text, graphics, or a combination of both. This will permit information to be better organized so as to reduce processing time and effort by the driver. Color can also be added to these displays to assist motorists in processing information more quickly and efficiently.

As with other communication devices, however, there are also a number of limitations to in-vehicle visual displays (4, 8). Perhaps the greatest limitation and concern with this technology is that drivers will have to take their eyes off the roadway in order to obtain the information. Concerns also exist that, because of the great flexibility of these devices, vehicle designers and traffic agencies will be tempted to design maps and displays that are too complex for a driver to comprehend in short glances; thereby, allowing drivers to become potentially overloaded with too much information. Also, there is concern that in-vehicle visual displays will add visual clutter to the already existing instrument panel inside the vehicle.

4.2.3 Heads Up Display

As technology continues to develop, the Head-up display (HUD) is an obvious alternative to in-vehicle video display terminals for presenting visual navigational and route guidance information to motorists (9). Although originally developed for the aviation industry, several automobile manufacturers are beginning to develop HUDs for presenting vehicle status and navigation information to drivers.

HUDs can be used to display a wide variety of information. Through the use of icons and alpha-numeric text, navigation and route guidance information can be projected directly into the driver's field of view (3). This permits information that is normally provided via instruments embedded in the dashboard to be available without requiring the driver to take his or her eyes off the roadway ahead. HUDs are believed to provide drivers with the following two benefits over traditional internal navigational and vehicle status displays (3, 10):

- Because navigation and vehicle status information is projected into the driver's field of view, the need for visual scanning between two information sources (i.e., the inside instrument panel and the outside roadway environment) is reduced.
- Through optical techniques, information can be presented at the same apparent distance as the outside environment. This can potentially reduce the time drivers need to accommodate their vision as they scan the visual horizon.

However, there are numerous concerns regarding the safety and applicability of using HUDs in the driving environment (3). Currently, most HUDs being used in automobiles provide drivers with relatively simple information (such as an indication of vehicle speed) only. Furthermore, unlike an aircraft, the visual background in the driving environment is constantly changing and complex. The background is also rich with color contrast which may obscure the displayed information. The projection of additional information in the driver's view may also create visual clutter for some drivers. Significantly more research into the interaction between HUD format, optical and attention variables, and task performance is required in order to determine whether or not HUDs are superior to in-vehicle video or auditory displays.

4.2.4 Variable Message Signs

Variable Message Signs (VMSs), also referred to as Changeable Message Signs (CMSs), have been utilized to communicate with motorists for over 30 years (11). They are frequently used by transportation agencies for warning, regulation, routing, and traffic management purposes. The CMS is the primary real-time device used by transportation agencies to communicate directly to motorists in many urban areas. A recent inventory (12) identified 57 freeway operations centers in North America that either use or plan to use CMSs to communicate with motorists.

Early CMS were quite limited in terms of the amount of information they could display and the ease with which displays could be changed. However, advancements in computer and communications technologies in the 1970s and 1980s produced CMSs that could be changed relatively quickly and easily. Currently, nearly any type of message that can physically fit onto a CMS can be displayed, including graphic displays, although human factors for legibility, information loading, etc. must be considered.

A synthesis of available CMS hardware and technology has recently been completed (11). At present, CMSs can be light-emitting, light-reflecting, or a combination of both. New light-emitting hardware such as fiber-optics and super-bright light-emitting diodes (LEDs) are also being applied to CMS designs. Research also continues into more futuristic technologies such as holographic signs, dynamic graphic display boards, etc. Given the significant interest and investment in the technology nationally, CMSs are likely to remain an integral part of urban traffic management systems for the foreseeable future.

CMSs have several advantages for communicating with motorists in real-time. First of all, the technology is proven and is being utilized extensively nationwide. Also, CMS operations are generally incorporated into the overall traffic management system of the freeway, corridor, or roadway network. In this way, transportation agencies have direct control over the amount and accuracy of information presented to motorists.

However, CMSs also suffer from several limitations. First of all, the location of the devices is fixed, which limits where and when motorists are able to access information. Furthermore, motorists can see any given sign for only a small amount of time, which constricts the amount of information that can be presented to the motorist. Also, the visibility of CMSs can be affected by external conditions, such as weather or a high percentage of trucks. Finally, the information that is presented cannot be easily tailored to the needs of an individual driver. As a result, much of the information that is presented may not be relevant to the needs of a given motorist.

4.3 Chapter 4 References

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5. CONTROL STRATEGIES

With the improved level of communication between the infrastructure and the vehicle, and with the enhanced ability to obtain better and more timely information about traffic conditions in the transportation network, traffic and transportation agencies will greatly improve their ability to implement control strategies to help control demand and ensure travel safety and mobility in the transportation network. These control strategies are focused at improving mobility and enhancing safety on the entire transportation network, including both the freeways and the surface streets. Some control strategies (such as adaptive traffic signal control, freeway ramp metering systems, and HOV lanes) are focused at improving capacity in the systems, while other control strategies (such as road pricing and parking management) are demand management techniques. Still other control strategies will permit management centers to respond to incidents and other events by shifting demand to alternative modes of transportation. Potential control strategies that can be implemented using the improved computing, communication, and control systems possible in an IVHS system are summarized below.

5.1 Ramp Metering

Ramp metering involves the use of traffic signals to regulate the number of vehicles entering a freeway at the entrance ramps. Ramp metering controls the flow of entering traffic so that the combined freeway and ramp traffic does not exceed the capacity of the freeway. With ramp metering, the time interval between the entry of vehicles into the freeway main lanes is controlled. Ramp metering tends to promote smoother operations on the freeway main lanes by reducing the impact of merging traffic on the freeway traffic. By releasing one vehicle at a time at a ramp signal, the main lane vehicles can more easily adjust their speeds and positions in the outside lane to accommodate the merge of entering vehicles (1).

Several different timing strategies have been developed for ramp metering systems (2). Pre-timed metering, where the ramp signal operates with a constant cycle, is the simplest strategy. With a pre-timed metering strategy, the ramp signal can be timed to permit either only one vehicle or a small platoon of vehicles to enter the freeway each green interval. In contrast to pre-timed metering, traffic responsive metering is directly influenced by the mainline and ramp traffic conditions during the metering period. The metering rates are selected on the basis of real-time measurements of traffic variables indicating the current relationship between upstream demand and downstream capacity. Common strategies employed with traffic responsive ramp metering involve balancing upstream volumes with downstream capacities (demand-capacity control) and metering based on current occupancy levels (occupancy control). A final common ramp metering strategy is gap-acceptance merge control. With this strategy, freeway main lane traffic is monitored for acceptable gaps. The arrival of the gap at the downstream entrance ramp is then anticipated. Vehicles are then released in sufficient time to accelerate and merge into the moving gap.

Ramp metering systems have been installed in numerous locations in the United States, including Los Angeles, California; Minneapolis, Minnesota; Chicago, Illinois, and Long Island, New York. The Texas Department of Transportation is making provisions for ramp metering systems for most of the surveillance and control systems in the major metropolitan areas in Texas.

5.2 HOV Restriction

The primary purpose of High Occupancy Vehicle (HOV) facilities is to increase the people-moving (as opposed to the vehicle-moving) capacity of a roadway. HOV facilities are exclusive lanes or facilities dedicated to the movement of vehicles carrying a high number occupants. Since use of the lane is restricted to vehicles with high occupancy levels, HOV facilities are generally less congested than a typical freeway. Because of their guaranteed time savings over regular lanes of traffic, HOV facilities are often attractive alternatives to many commuters travelling in peak periods. Traditionally, occupancy levels of 3 or more people per vehicle are defined as high-occupancy vehicles; however, some locations (such as Houston, and Dallas,Texas) permit vehicles carrying as few as two occupants to use their HOV facilities.

Several types of HOV facilities that can be implemented on a freeway or arterial street, including the following (3):

- An exclusive facility in a separate right-of-way and dedicated for the full-time use of high-occupancy vehicles,
- An exclusive facility dedicated for the full-time use of high-occupancy vehicles, but contained within the right-of-way,
- A concurrent flow lane where a normal freeway lane is dedicated for the use of high-occupancy vehicles for at least a portion of the day (usually the peak period), and
- A contraflow lane where a normal travel lane in the *off-peak direction* is dedicated for the use of high-occupancy vehicles for at least a portion of the day. The lane is typically separated from the off-peak direction travel lanes by insertable plastic posts or pylons.

Although typically associated with freeways, HOV facilities have also been successfully implemented on arterial streets in many major metropolitan areas, including New York City; Pittsburgh, Pennsylvania; Chicago, Illinois; and Houston, Texas. Other types of priority treatment of high-occupancy vehicles on arterial streets include the following:

- Exclusive transit streets,
- Priority signals for HOV's, particularly buses,
- Priority parking spaces for HOV's, and
- Priority parking rates for HOV's.

IVHS technologies can help enhance operation of these facilities by improving the quality of surveillance so that incidents can be quickly removed from these facilities. IVHS technologies also open the potential to implementing automated enforcement systems to ensure that only authorized vehicles, or vehicles with a sufficient number of occupants enter an HOV facility. In addition to monitoring the use of the HOV facilities, advanced computer and communication technologies will permit automated access control to the facility through lane use control signals, automated gates, and advanced traveler information systems.

5.3 Traffic Signal Control

Significant improvements in mobility, air quality, and fuel savings can be achieved by improving the level of progression and control of traffic on the arterial street network. A significant portion of the traffic signals in the United States are in need of major improvements to both the equipment and signal timings (4). Therefore, providing better traffic signal control and modernizing equipment can significantly reduce the level of congestion on arterial streets. Fortunately in the Dallas urban area, significant improvements in signal operations have been effected through TXDOT's oil overcharge funding and the Dallas County bond program for signal improvements.

A number of basic improvement strategies that can produce significant improvements to traffic flow on the arterial street system (3) are as follows:

- *Equipment Upgrades* -- Upgrading or modernizing existing traffic signal equipment would permit more advanced traffic signal timing and control strategies to be implemented at particular intersections.

- *Timing Plan Improvements* -- Retiming traffic signals so that the timings correspond to current traffic flows and patterns can reduce unnecessary delays and congestion at some locations.

- *Interconnecting Signals* -- Interconnecting two or more traffic signals can improve progression in an arterial or network of arterials. Traffic signal systems can designed to provide pre-timed control (in situations where traffic patterns remain relatively constant) or adaptive control (in situations where traffic demands are constantly changing).

- *Removal of Traffic Signals* --- Removing unwarranted or unneeded traffic signals can produce reductions in vehicle delays and unnecessary stops.

With IVHS, the degree to which these basic traffic signal engineering improvements will enhance traffic operations and safety will expand. As computer technology improves, sophisticated traffic controllers that provide better control features can be implemented as intersections are upgraded. With better controllers, better and more efficient timing plans and control strategies can be implemented. Advanced communication systems will greately enhance a traffic managment agencies' capability to provide coordination between isolated intersections.

In addition to these basic improvements, implementing more advanced control strategies can further improve operations and flow on the arterial street system. With improved communications and computer technology, traffic signal systems can be implemented to that are adaptive to current traffic patterns (5). Adaptive control systems (such as SCOOT and SCAT) use real-time data collected by advanced sensor and surveillance systems to perform short-term estimates of flow condition. Using the estimates, traffic signal timings are developed and implemented (in real-time) that will improve overall efficiency in the transportation network. Fully adaptive traffic signal systems may produce the greatest benefits in locations where congestion is high, and where flow patterns are complex and vary by time of day.

5.3.1 OPAC

OPAC (Optimization Polices for Adaptive Control) is a traffic signal control concept which determines whether to extend a phase by examination of a delay-based control function (6). The optimization technique used to achieve this goal is to minimize total intersection delay by minimizing the area between the cumulative arrival and cumulative departure curves (7). This technique has been evaluated through a private sector contract to FHWA (8) and is currently be field tested in the following locations.

- New Jersey along Route 18 near New Brunswick at 16 signals.
- Seattle, Washington at two separate isolated intersections.

5.3.2 SCATS

SCATS is an acronym for the Sydney Co-Odinated Adaptive Traffic System. The objective of the master controller is to select the phase splits which most closely match demand, to select the cycle length which maximizes the efficiency of the intersection and to select approporiate offfsets (9 . The strategies used to achieve this set of objectives are:

- When demand is heavy, maximize throughpu (vehs/hr) to avoid queue build-up.
- When demand is moderate, minimize delay within the system while avoiding excessive delay.
- When demand is low, minimize the number of stops in the system.

5.4 Parking Restriction

Prohibiting on-street parking is one method of improving traffic operations and increasing capacity on urban arterial streets, particularly at signalized intersections. By removing roadside parking, traffic flow and safety can be improved by permitting additional or wider travel lanes to be installed, by removing conflicts between parking and through traffic movements, and by eliminating potential sight distance restrictions.

Parking management programs are often implemented with different objectives in mind. In some cases, parking management programs have been implemented to provide sufficient parking for residential, commercial, and retail activities. As an IVHS control strategy, comprehensive parking management programs could be implemented not only to improve traffic flow and safety, but also to enhance the air quality, to encourage shifting to different modes of transportation, and to preserve sufficient access for local residents.

IVHS technologies can be used to dynamically manage and implement parking control strategies in a corridor or area. With improved surveillance and monitoring capabilities, parking restrictions can be implemented automatically in response to changing traffic patterns or in response to incident conditions. Advances in vehicle identification technologies will also help with developing and enforcing residential and special-use parking restrictions. As with automatic toll collection, IVHS technologies will also make it possible to collect parking and enforcement fees automatically.

5.5 Ramp/Lane Closures

Another strategy for improving traffic flow, particularly on freeways that operate at or near capacity, is to close selected entrance or exit ramps (1,3). Weaving areas caused by traffic entering and exiting the freeway can create turbulence in the main lanes of the freeway. This can reduce the capacity of that section of freeway. Closing the ramp and making provisions for directing traffic to other ramps and surface streets helps maintain traffic flow on the freeway. However, because of its restrictive nature, closing freeway entrance and exit ramps can be controversial, meeting with considerable public opposition in some cases.

Closing a freeway ramp is typically employed when other control strategies, such as ramp metering, have failed to maintain the desired quality of flow on the freeway. Two prime conditions where closing a ramp may prove to be beneficial include the following:

- When adequate storage is not available at an entrance ramp to prevent queues of vehicles waiting to enter the freeway from interfering with surface street traffic.
- When traffic demand on the freeway immediately upstream of an entrance ramp is at capacity, but there is adequate capacity on adjacent alternate routes.

In both cases, closing the ramp forces traffic demand to other locations. Careful analysis is required to ensure that alternative ramps and arterial streets can accommodate diverted traffic demand.

Similarly, closing a lane on a freeway can also be used as a control strategy for improving traffic flow. Examples where closing the freeway main lanes may be appropriate include the following:

- As an advance warning of a blockage (either caused by an incident or a scheduled maintenance activity).
- To improve the merging operations associated with critical or high-volume entrance ramps.
- To divert traffic from the main lanes of a freeway to alternate routes during peak flow periods.
- As a means of controlling the number of vehicles entering a bottleneck area such as a tunnel facility.

IVHS technologies make implementing these control strategies more practical and feasible than in the past. Advanced surveillance and communication technologies will permit greater and more precise monitoring and predicting of traffic conditions that might warrant the closing of a freeway ramp or lane. In-vehicle communications and route-guidance systems can automatically alert drivers of locations where ramps or freeway lanes have been closed and can divert traffic around these areas automatically.

5.6 Road Use Pricing

Road use pricing (or Congestion Pricing) is a travel demand management technique designed to discourage use of certain facilities during high demand or "premium" periods. The concept of road use pricing is to charge motorists a fee for using a freeway or arterial street that is in high demand (3, 10 , 11). The fee is intended to reflect the incremental cost that the individual motorist has on cost of operations (in terms of added delay, fuel consumption, and air quality). For example, an additional car wanting to use a congested highway adds delay to all of the users of that road. Under a road use pricing strategy, this vehicle is assessed a fee equivalent to its costs. By charging motorists a fee to use the facility, the intent is to "price" the highway or arterial street so that a sufficient supply of capacity is provided for those who are willing to pay for it. It is considered a traffic demand management technique because it is believed that those who are not willing to pay will: 1) adopt other modes of transportation, 2) go a different route, or 3) forego the trip altogether.

Traditionally, one of the biggest impediments to implementing an area-wide road use system has been the ability to monitor vehicle use of certain facilities (11). However, advancements in AVI and other IVHS monitoring technologies has made implementing a road use pricing system more feasible than in the past. One cost of implementing a road use pricing strategy would be the installation of devices for monitoring vehicle use of select facilities. Another implementation cost would be that associated with creating an administrative / enforcement structure for collecting revenues generated by the control strategy.

The most difficult aspect of implementing a road use pricing system appears to be political (12). Although toll facilities are common in most parts of the United States, implementing an area-wide road use pricing system may be viewed as another form of taxation and may not be widely accepted by the general population (3). Equity issues are also a consideration.

5.7 Reversible Lanes

The intent of a reversible lane system is to take advantage of unused capacity in the direction of lighter traffic flow by making one or more of those lanes available for the dominant direction of traffic (3). With a reversible lane system, one or more lanes are designated for movement one-way during part of the day and in the opposite direction during another part of the day. Reversible lane systems are particularly effective on bridges and in tunnels where the cost of providing additional capacity through construction is expensive or impossible. Reversible lane systems can also be established by reversing the flow of an entire street during peak periods or by making a two-way street operate one-way during peak periods.

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6. NAVIGATION / GUIDANCE

One of the goals of IVHS is to improve the efficiency of travel in the network by providing travelers with better navigation and route guidance information. On-board navigation and guidance systems will assist the traveler in planning and following routes. Typically, different technologies and display formats are used depending upon whether navigation, route guidance, or both are going to be displayed to the traveler. Furthermore, the quality of the information is dependent upon the accuracy and completeness of the map database from which the information is derived. Accurately locating where the vehicle is in the network is also a critical issue in providing travelers with accurate navigation and guidance information. All of these issues can affect user acceptance and utility of navigation and route guidance technologies.

6.1 Display Techniques

Information is displayed to the traveler through numerous technologies, including video display terminals mounted in the vehicle, heads-up images displayed on the windshield, auditory messages, and dashboard signals. These technologies can be used to provide two important displays to the traveler:

- The location (or position) of the vehicle in the transportation network, and
- Guidance instructions on how to reach a traveler's intended destination.

Displays can be generated using either real-time or historical information.

6.1.1 Position Displays

Position displays provide information on the driver's current position in the transportation network. Frequently, the vehicle's position is overlaid on a map of the surrounding street network. The vehicle's location can be determined using several techniques, including dead reckoning, and radio triangulation techniques. An example of the type of display is shown in Figure . (The large arrowhead on Orange Street represents the vehicle.) The TravelPilot system, which was used in the PATHFINDER project, uses this type of information display (1).

The primary advantage of this type of display is that the actual road network is displayed to the driver (2). Since the driver's position is displayed on a map, the driver can obtain a global perspective of all the available routes. Map displays also provide supplemental information, such as the distance between intersections and surrounding landmarks, that cannot be presented using others types of displays. However, position displays only show the driver where he or she is in relation to their intended destination. Typically, position displays by themselves do not give advice on the best route to an intended destination.

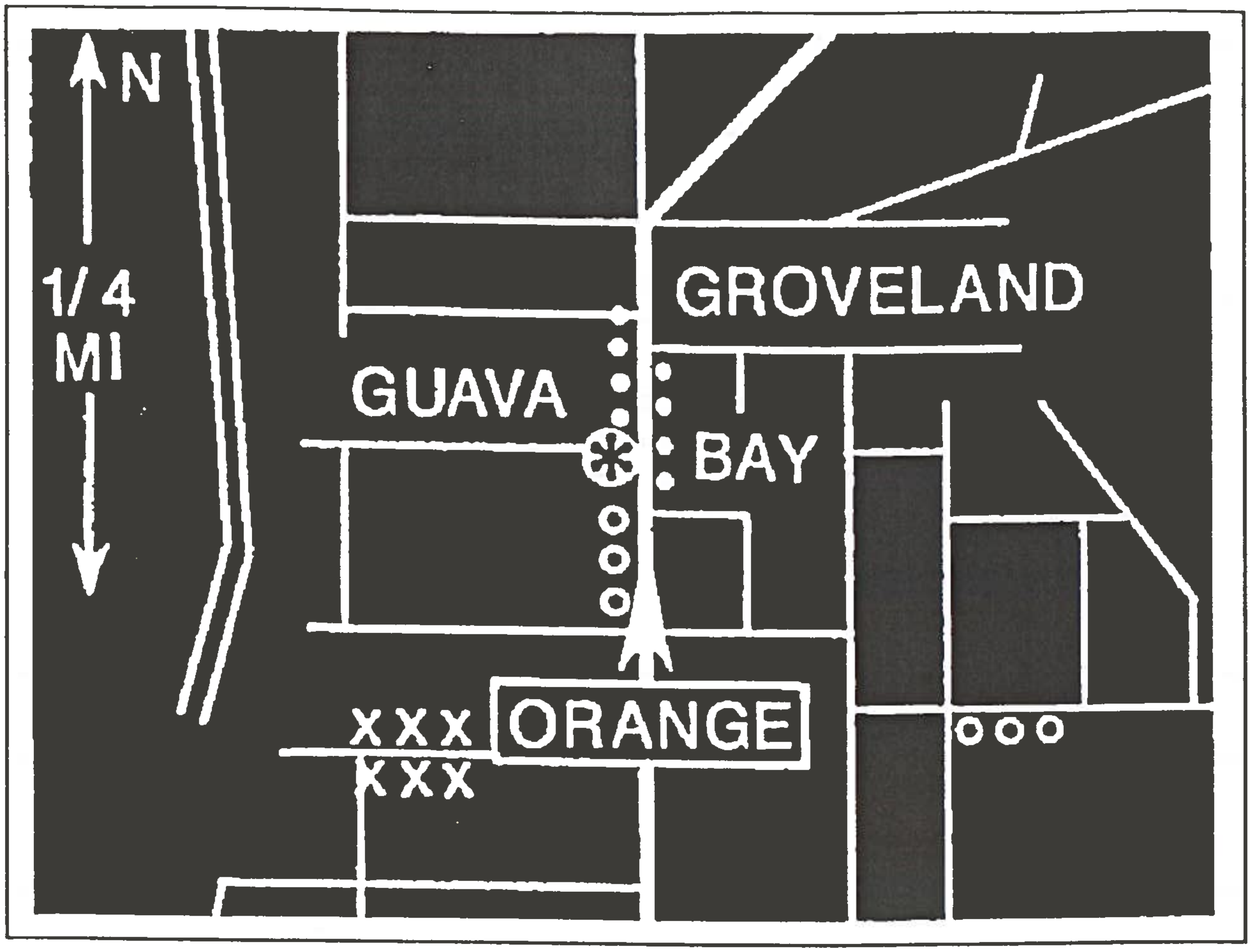

Figure 6-1 Example of the Position Display Used in the TravTek System

6.1.2 Guidance Displays

Guidance displays are intended to provide motorists with turn-by-turn instructions to their ultimate destination. These types of display use simplified street diagrams, turn arrows, and/or text instructions to provide motorists with directions on how to reach a specific destination. The type of information usually presented with guidance displays includes lane change and turning instructions, updates on distances to next maneuver, and possible intermediate landmarks. New instructions are issued in advance of and at the location where the driver is required to execute a maneuver.

Three methods are typically used to provide drivers with guidance information. With the first type of display, the driver's route is overlaid on a map of the transportation network. The recommended route can be highlighted so that the driver is aware of the route he or she is supposed to be following. An example of this type of display is shown in Figure . A second method of providing guidance information to motorists is with simplified graphic and text messages. This type of display is illustrated in Figure 6-3. The ALI-SCOUT in Germany and the AUTOGUIDE system in England use similar types of displays as these for presenting guidance information. Finally, guidance information can also be presented using either digitized or synthesized voice commands. Many systems, such as the TravTek system in Orlando, use all three forms of providing guidance information and permit the driver to select the forms most suitable to his or her individual preferences (3).

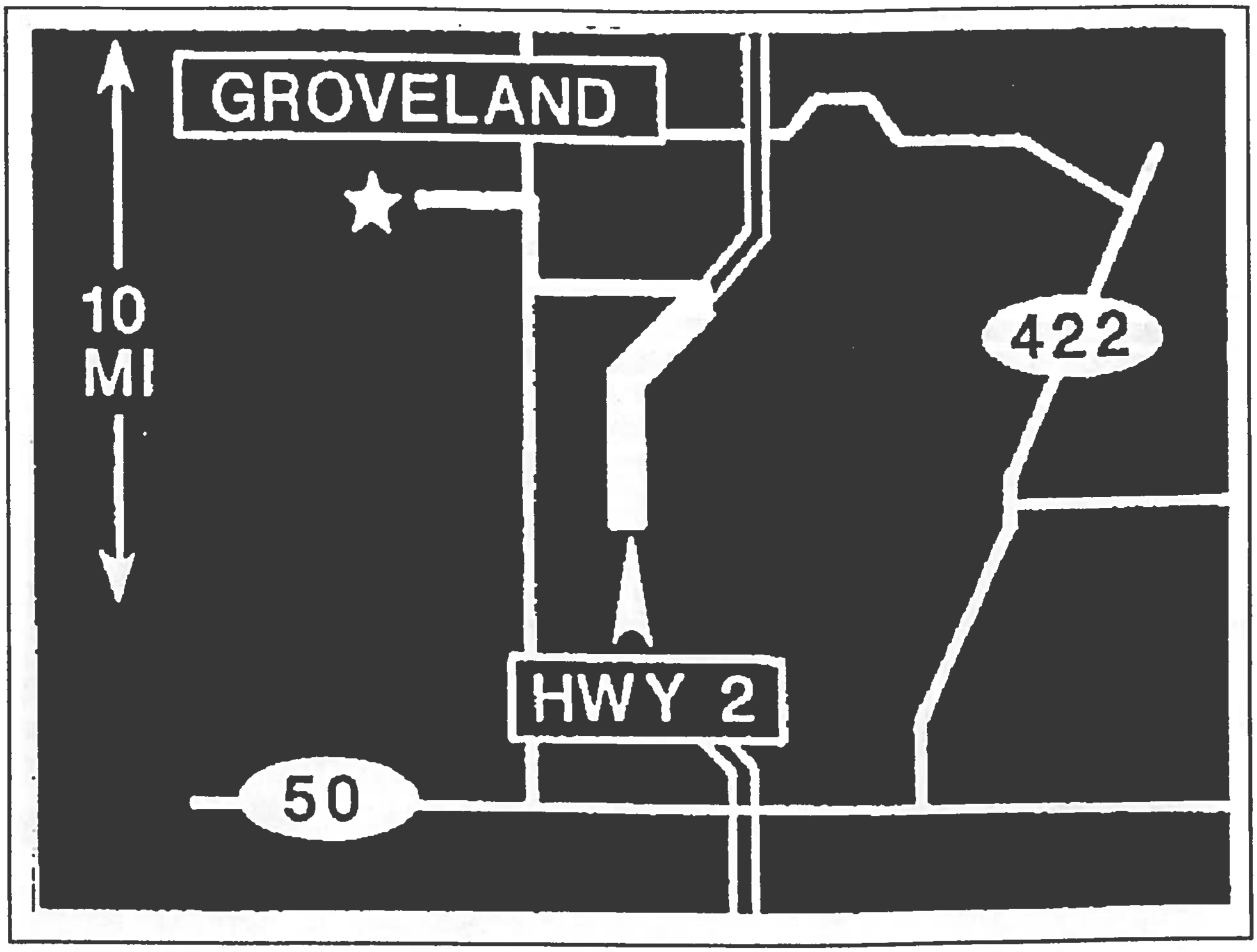

Figure 6-2 Example a Highlighted Route Overlaid on a Map Display Used in the TravTek System.

6.2 Map Database

An accurate and reliable map database is an essential element of the route guidance and navigation systems to be developed under IVHS (4). The databases include the coordinates and other descriptors of the road network for a metropolitan or regional area. In addition, more detailed information about the physical characteristics and functional classification of each roadway must also be contained in these databases. Furthermore, locations where roadways overlap but do not intersect (such as bridges, underpasses, tunnels, etc.) must also be included if the database is to be used for navigational and route guidance purposes. The database should also contain accurate descriptions of the street names (including alternate names) and block numbers. Even more importantly, the database must also contain a complete and accurate listing of important navigation restrictions such as isolated turn restrictions, physical dividers, one-way streets, time-of-day restrictions, flow restricted roadways (e.g., HOV lanes), etc. Typical sources that can be used to build an accurate map database are as follows:

- USGS Quadrangle Sheets
- Census Bureau Topologically Integrated Geographic Encoding and Referencing (TIGER) files
- Postal Service Zip Code Data
- Aerial Photographs
- State, County, and Local Governmental Agencies.

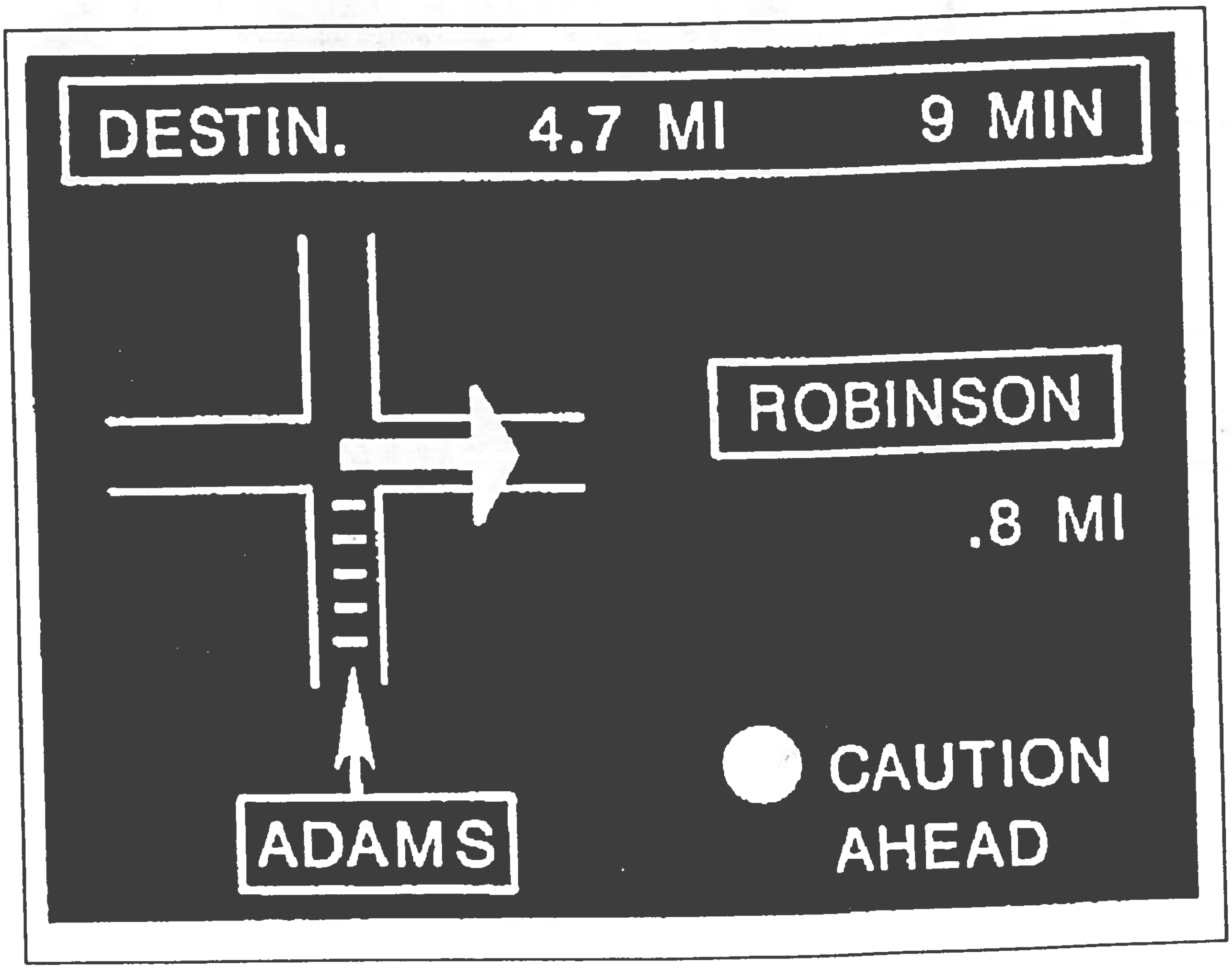

Figure 6-3 Example of a Simplified Route Guidance Display Used in TravTek System.

In the past several years, digital map databases have been produced for many locations in the United States. These database are now becoming commercially available for use in in-vehicle route guidance and navigation systems.

6.3 Vehicle Locating Techniques

Accurately locating the vehicle in the transportation network is critical to providing drivers with position and guidance information. Vehicle position information is required to perform many function in Advanced Traffic Management and Advanced Traveler Information Systems. Dead reckoning, LORAN radio navigation systems, global positions systems (GPS), and map-matching techniques are used by many IVHS technologies for accurately determining a vehicle's position in the transportation network.

6.3.1 Dead Reckoning

Dead reckoning is a technique that is used by many IVHS related technologies for determining the current position of the vehicle. Dead reckoning uses distance and speed measurements to compute the vehicle's progress from a known starting location (5). Sensors in the vehicle, such a magnetometers, gyroscopes, differential odometers, and optical road sensors, are used to sense changes in the direction of the vehicle. Other sensors connected to the odometer cable or the wheels are used to measure distances traveled in a particular direction. By accumulating these measurements for the duration of a trip, the position of the vehicle can be determined.

One problem with dead reckoning systems is that errors tend to accumulate as the distance traveled increases (6). The accuracy of most dead reckoning systems is around 2% of the total distance traveled. To maintain accuracy, most systems must be periodically reinitiated. This can be accomplished using several techniques including map-matching, roadside proximity beacons, manual correction procedures, or global positioning systems.

6.3.2 LORAN

LORAN (LOng RAnge Navigation) is a long-range radio navigation system. Multiple transmitters are used to plot hyperbolic lines of position. A receiver in a vehicle can determine its position by analyzing the time intervals between pulses of two or more radio transmitters. Since the position of the radio transmitter is known, triangulation techniques can be used to locate the vehicle.

Since LORAN was initially developed for maritime use, most of the LORAN transmitters are located along the coast and the navigable waterways (such as the Mississippi River and the Great Lakes). This has created a gap in the coverage area in the middle of the United States (including the Dallas area) (6). Also, problems may exist in receiving LORAN transmissions in urban areas because of multi-path reflections and signal disruptions caused by tall buildings and varying terrain.

6.3.3 Global Positioning Systems

With Global Positions Systems (GPS), a vehicle's location is determined using radio signals broadcast from satellites orbiting the earth (7). Pseudo-random code (called pseudo-random code because they are a set of very complicated digital codes sequenced so that they repeat every millisecond) are broadcast by each satellite. Triangulation techniques are used to determine the vehicle's location using the radio signals from three satellites. Because the satellites are in very high orbits, their exact location is constantly known. Minor variations are measured constantly by the Department of Defense and correction messages are transmitted from the satellites themselves.

These systems can locate a vehicle in the transportation network with a high degree of accuracy. In order to get an accurate reading on the vehicles, the receiver in the vehicle must receive transmissions from three satellites. In the standard positioning mode, a vehicle's location can be determined with a degree of accuracy of 350 feet (100 meters). With the precise positioning service in operation, a position of a vehicle can be accurately determined to within 60 to 100 feet (10 to 30 meters).

Currently, GPS receivers are complex and costly. Furthermore, the signal from the satellites can be disrupted by tall buildings, tunnels, bridges, etc. which can lead to discontinuities when monitoring a vehicle's location, especially in built-up urban areas. To adjust for this problem, it is often necessary to augment some GPS-based systems with other positioning technologies (such as dead reckoning).

One potential means of correcting for "blackout" problems and improving the accuracy of the position calculations is to use Differential GPS. With Differential GPS, a ground-mounted GPS transmitter is used in addition to the satellite transmitters. The ground-mounted transmitters acts as a static reference point Because the exact location of the ground-mounted transmitter is known, it can be used to transmit error correction messages to any GPS receiver in the area. The other GPS receivers then use the message to correct the position solution for the vehicle.

6.3.4 Map Matching

Map matching is a navigation technique that is often used to enhance and correct in-vehicle dead-reckoning navigation technique (8 ,5). Computer software follows the progress of the vehicle through an on-board digital map. As the vehicle turns, the map matching software matches the dead-reckoning estimate of the current position to the closest point on the map. This is done to correct for accumulated errors in the vehicle sensors. Because the vehicle's position is being matched to a map, an extensive digital map database is required for a highly accurate system. Currently, most route guidance and navigation aides being developed in the United States are using a combination of dead reckoning and map matching techniques.

6.4 Chapter 6 References

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7. DATA PROCESSING

The processing of data in a timely manner is one of the key elements of any IVHS system, particularly Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS). Most ATMS and ATIS will rely on information obtained from multiple sources. Algorithms are required to process this information and implement appropriate navigation, route guidance, and control strategies in a timely and efficient manner.

7.1 Coupled Route Selection and Traffic Control

These algorithms adjust both the issued route guidance instructions to the vehicles and the traffic control systems (i.e., traffic signal systems) on the arterials to meet current travel demands (1). These types of algorithms attempt to achieve maximum efficiency in the transportation network by optimizing both capacity and demand. In order for the algorithms to be effective, careful monitoring of the transportation network is needed.

7.2 Database - Static

Static databases are needed with most ATMS and ATIS systems. They provide historical information about traffic conditions throughout the network (1). Examples of static databases include the following:

- Traffic volume and travel time information throughout the network by time-of-day and day-of-week;
- The type and location of traffic control devices in the network;
- Transit schedules and stop locations; and
- The locations and cost of parking facilities.

Typically, these databases change little over time; however, periodic adjustments are needed in order to keep them accurate.

These types of databases have a number of applications in an ATMS/ATIS environment. First of all, they can be used as surrogate or alternative information sources when real-time data are not available. Second, they provide a means of comparing real-time data to determine when conditions on the roadway are "out of the ordinary" and require special attention (such as in the case of incident conditions). Finally, these types of databases also provide the backbone for predicting future traffic conditions and making appropriate traffic management decisions.

7.3 Database -- Dynamic

Dynamic databases are those that constantly update in response to current conditions on the network (1). They typically include real-time data that describe an event as it happens. Examples of the type of data contained in dynamic databases include the following:

- Loop detector data from a freeway surveillance system or traffic signal system,
- Current location and travel time of individual transit vehicles,
- Current location and travel time of probe vehicles, and
- Current availability of parking at specific parking facilities.

It is the dynamic databases that permit the real-time management of traffic. Dynamic databases are used in numerous ATMS and ATIS applications including the real-time routing of vehicles, adaptive traffic signal control, and dynamic management of transit vehicles. These databases can also be used to periodically update static databases as well. Because the traffic conditions on the network are constantly changing, the dynamic databases are also constantly changing. Therefore, it is critical that good database management techniques are used to ensure that the quality of the data is maintained.

7.4 Route Selection Algorithms

Route selection algorithms are used to determine the optimum route from a driver's origin to a destination (1). Algorithms in vehicle instrumentation or contained at a control center can develop optimum routes minimizing travel time, minimizing travel distance, or providing the driver with the most scenic route to a destination. Routing decisions can be based on historical information, or in response to real-time information. Route algorithms could be also set up to achieve individual driver's needs or driving preferences. For example, in the TravTek system in Orlando, Florida, the driver could select one of three options (fastest, avoid toll roads, or avoid freeways) for routing the vehicle (2).

Two types of route selection philosophies have been provided with most ATIS/ATMS systems (3). With the first type, the central control agency determines which routes individual vehicles should follow. Route guidance information is then transmitted to the individual vehicles by the central control center. Since individual vehicles can be assigned to particular routes, a centralized routing system would permit traffic management agencies to optimize traffic flow and minimize traffic congestion throughout the network (i.e., system optimum). However, numerous social and legal issues may prevent full scale implementation of this type of route selection/control strategy.

The general trend of most ATMS/ATIS systems being developed in the United States is toward the second philosophy where the route selection process occurs at the vehicle level. Algorithms contained in the vehicle would permit individual drivers to determine the best available route which satisfies his or her individual needs or desires. This type of system generally results in the selection of routes which optimize the benefits to the individual driver (i.e., user optimum).

7.5 Driver/Vehicle/Cargo Scheduling

Another potential benefit of IVHS is the development of algorithms that will permit drivers, vehicles, and cargo to be dynamically matched to achieve better and more efficient fleet dispatching (1,4). Using vehicles equipped with AVI/ AVL technology, fleet dispatchers can monitor traffic situations and dispatch nearby fleet vehicles that are already on the road to pick up the cargo. The algorithms will allow for intelligent dispatching (i.e., scheduling small stops in real-time) or just-in-time deliveries. These algorithms will make use of information obtained from other IVHS systems, such as real-time travel and traffic information systems, so that fleet dispatchers have the most current and accurate information available.

7.6 Real-Time Traffic Prediction

Because of the dynamic nature of traffic, algorithms need to be developed to provide accurate short-term prediction of future traffic conditions in the network (5). These algorithms would use real-time origin-destination data obtained from vehicles equipped with an in-vehicle device and two-way communications capability to predict where and when congestion will occur. This information can then be integrated with traffic control and management strategies to provide accurate information on predicted traffic conditions and the best routes and modes to take to avoid areas of congestion. Research efforts are currently underway to develop real-time traffic-predictive algorithms that can be used in predicting traffic flows, queue lengths, and delays based on current measurements of volume and speed.

7.7 Assignment Algorithms

Real-time traffic assignment algorithms could theoretically be used to optimize operations in a network or corridor (1). Based on entered origin and destination information, these algorithm would assign traffic to specific routes in a network. By using traffic data obtained from roadway detector and vehicle probes, these algorithms could be used to predict traffic loads and link times in the network. Microscopic algorithms could be developed that predict the routes of individual vehicles based on entered origin/destination information and existing network conditions. Once these future travel demands have been predicted, control strategies could be developed to ensure smooth and efficient operations. These types of algorithms would attempt to minimize the total delay in the system .

7.8 Route Guidance Algorithms

Route guidance algorithms take the information from the route selection algorithm process and develop simple instructions to aid the drivers in navigating to their desired destination. These instructions can be in the form of simple turn-by-turn instructions, highlighted street overlays on a video map display, or a combination of both. Both diagrammatical and verbal instructions are used to provide drivers with route guidance information. Route guidance information is then displayed to motorists using guidance displays and/or verbal messages.

7.9 Data Fusion Techniques

Data fusion is the process by which information from numerous sources is combined and assimilated to provide an accurate and timely representation of current traffic conditions in the network (5). Through the data fusion process, information from several sources is compared to develop real-time estimates of traffic volumes, speeds, or travel time on each link of the transportation network. Data fusion techniques can also be used to assimilate incident information from different data sources (such as police, traffic reporting services, probe vehicles, etc.).

Similar data fusion techniques were used in both the PATHFINDER demonstration project in California and the TravTek project in Florida (5). In these systems, several different sources of travel time information were available on most of the links in the network, including the computerized traffic management system, the freeway surveillance system, probe vehicles, historical databases, computer models, and the operators. Fuzzy set logic was used to assess the quality and the timeliness of the data from the various sources and develop an estimate of the travel time on each individual link. (Fuzzy set logic, a type of artificial intelligence, provides rules that permit inexact or imprecise data that are "close to" a decision threshold to be used in making a decision.)

7.10 Optimal Control Strategies

These algorithms monitor incoming traffic data and implement optimal control strategies that would maximize traffic flow and efficiency in the network. For examples, algorithms have been proposed that would permit the dynamic routing of transit vehicles to adjust for short-term changes in demand. These algorithms would rely heavily on other IVHS-related technologies (such a probe data, data from vehicle locating and positioning systems, etc.) to provide accurate and timely information about traffic conditions in the transportation network.

7.11 Incident Detection Algorithms

In past years, several algorithms have been proposed for automatically detecting incidents using freeway detector data (6). Some are comparative algorithms (or pattern recognition algorithms) that compare measured traffic conditions to pre-established thresholds. Others use statistical procedures to detect significant changes in traffic patterns over time. Still others use complex theoretical models to predict future traffic conditions using traffic measures and historical trends. The structure of an algorithm affects its performance in terms of detection rate, false alarm rate, and detection time. Alternative techniques, such as video image processing and algorithms using artificial intelligence techniques, may improve incident detection capabilities on freeways.

Unfortunately, most of the research has focused on developing incident detection algorithms for freeway systems. Currently, there are no algorithms designed to detect incidents on surface arterial streets. FHWA is scheduled to release an RFP for a research study to examine the issue of incident detection on surface streets later in FY '94.

7.12 Chapter 7 References

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8. IN-VEHICLE SENSORS

Much of the information to be used either by computers in the vehicle or by external traffic management agencies will come from sensors in the vehicle. These sensors will be provide information not only about the vehicle itself but can also be used to develop information about the external environment in which the vehicle operates.

8.1 Equipment Status Sensors

Many automobile manufacturers are installing equipment to monitor the status and performance of the vehicle. Some of this equipment can be used to store and/or display information that can be used to help better manage traffic on the transportation network. They can record engine diagnostics which, if communicated directly to a traffic management center, could assist in dispatching appropriate roadside emergency services in response to incident conditions or requests for assistance. They can also be used to continuously record operating information such as speeds and acceleration/deceleration, and time and distance traveled (1). Engine diagnostic information could also assist in providing information on vehicle emissions and fuel consumption.

From a fleet operator's perspective, these types of sensors can help monitor performance of fleet vehicles (2). These systems can collect real-time vehicle-related information (such as engine rpm, road speed, distance traveled, and time) and communicate this information back to a dispatching center. A keyboard and a display can also be provided so that drivers can input log-related information such as his or her ID, state line crossings, and trip expenses. Information can be stored in on-board recorders and transferred later to a computer for analysis or it can be downloaded using a two-way radio or cellular phones from a remote location.

8.2 Vehicle Headway Sensors

Coupled with intelligent cruise and variable speed controls, automatic vehicle headway sensors can be used to maintain a constant headway or gap between vehicles (3). A vehicle equipped with this technology would automatically slow when approaching another vehicle, and remain at a safe distance until such time as it would be appropriate to resume its original cruising speed. This type of technology has been proposed as a means of increasing capacity on urban freeways (4). Research is being conducted on using this technology as a collision avoidance system as well (5).

Much of the technology in this area is still experimental. While much of the current research has focused on using radar and video-image processing systems (3), other forms of technologies such as infrared and laser could also be used to monitor headways between vehicles.

8.3 Odometers

With the emergence of autonomous route guidance and navigation systems, the odometer has become an increasingly important element in the vehicle. Many route guidance and navigation systems, particularly with those systems that use dead-reckoning/map-matching techniques, rely on the odometer to provide accurate distance measurements. Currently manufactured odometers, which use a flexible shaft attached to the drive train and provide distances measurements accurate to the 0.1 mile, are not accurate enough for navigation and vehicle locating purposes. New electronic odometers can accurately measure distances in increments as small as inches (1).

8.4 Electronic Compasses

Like the odometer, an electric compass is an essential components in many navigation and route-guidance systems. The electronic compass consists of two electric coils wound around a highly permeable core material. A third coil carries an alternating current which induces an alternating voltage in coils. The direction of the vehicle is determined by measuring the phase shift in the induced voltage. The magnitude of the phase shift depends upon the orientation of the vehicle in the earth's magnetic field (1).

Electronic compasses in the vehicle are critical to dead-reckoning/map-matching systems. These systems rely on compass readings to accurately determine the heading of the vehicle. This, in combination with the cumulative distance traveled since the last heading change, can be used to determine the position of the vehicle in the transportation network.

8.5 Driver Fatigue and Performance Monitoring

In addition to monitoring traffic and road conditions, in-vehicle systems have been proposed to monitor driver fatigue and performance (1). Sensors in the vehicle would monitor a driver's reaction time and take corrective measures if they are slow or impaired. For example, breathalyzer systems can be installed in a vehicle so that if a driver is intoxicated, he or she would be unable to start the vehicle. Vehicle monitoring systems and enhanced vision systems can aid motorists in perceiving and reacting to hazardous and low visibility conditions. Systems have been proposed that would alert motorists when they become fatigued or drowsy, thereby assisting them to recover before the vehicle leaves the roadway.

8.6 Chapter 8 References

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Dallas Area-Wide IVHS Plan
BACKGROUND

- ISTEA → FHWA
- IVHS PROGRAM
- EARLY DEPLOYMENT
- TxDOT → DALLAS DISTRICT
- TTI

TTI

Dallas Area-Wide IVHS Plan
GOALS

- Coordinate with public & private sector to collect real-time transportation information.
- Optimize transportation system operations and minimize duplication of effort.
- Actively encourage transit and HOV usage.
- Coordinate with commercial vehicle operators to allow mutual data sharing.
- Incorporate emerging IVHS technologies.

TTI

Private Sector

- High Tech Industries
- Traffic Info Services
- Goods Movement Services
- Passenger Services
- Automobile Associations

Plan Development Participants

- Mobility Technical Committee (MTC)
- Private Sector
- Police/Fire/EMS
- DRMC Dallas Regional Mobility Committee

TTI

WORK PLAN & STUDY OBJECTIVES

- Establish broadly-based Steering Committee
- Assess existing transportation management & communications linkages
- Identify institutional & legal barriers
- Produce an implementable integrated, area-wide, multimodal, multi-jurisdictional Plan
- Develop staged implementation plan
- Define projects for implementation and identify funding

Mobility Technical Committee (MTC)

- TxDOT (Dallas District)
- Cities
- Dallas County
- Surrounding Counties
- DART
- NCTCOG
- TTI

POTENTIAL IVHS PLAN PARTICIPANTS

Category	Potential Organizations
Administrative Agencies	FHWA, TxDOT
Lead Study Agency	Texas Transportation Institute
Other Funded IVHS Study Organizations	Dallas County, NCTCOG, Barton-Aschman Associates, others as appropriate.
Cities *	Addison, Balch Springs, Buckingham, Carrollton, Cedar Hill, Coppell, Dallas, De Soto, Duncanville, Farmers Branch, Ferris, Garland, Glen Heights, Grand Prairie, Highland Park, Hutchins, Irving, Lancaster, Lewisville, Mesquite, Murphy, Ovilla, Plano, Red Oak, Richardson, Rockwall, Rowlett, Seagoville, Sunnyville, The Colony, University Park, Wilmer, Wylie
Counties*	Dallas County, Collin County, Denton County, Rockwall County, Kaufman County, Ellis County
Publicly Funded Passenger Transportation Companies	DART, school buses
Privately Funded Passenger Transportation Companies	Such as: shuttle companies (SuperShuttle, etc.), taxi companies (Terminal Cab Company, Yellow Checker Cab, etc.), charter buses, Trailways, etc.

* Includes relevant departments (e.g., Police, Transportation, Fire, Streets), Councils, Commissioners, designated committees (e.g., Dallas City Council Transportation Committee), Coroner, etc.

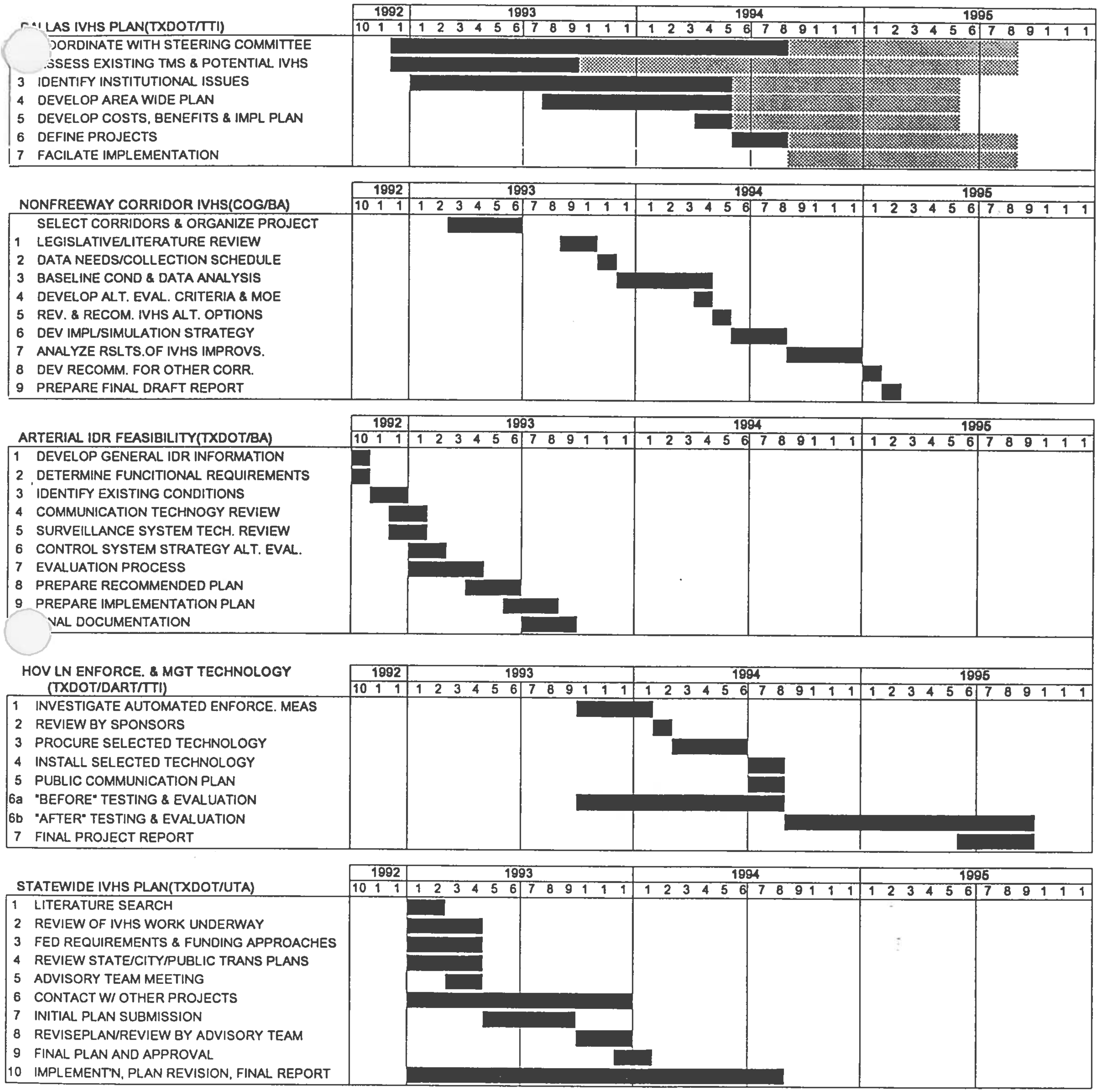
Category	Potential Organizations
Private Sector Technology Sources	Such as: Texas Instruments, Hughes, General Dynamics, E-Systems, LTV, AT&T, GTE, Lockheed, IBM, Motorola, etc.
Vehicle Locator Sources	Such as: Teletrac, Pinpoint, Autotrac, AMTECH, DART, etc.
Commercial Fleet Operators	General delivery fleets (such as: UPS, Dial-a-Messenger, Inc., One Hour Delivery Service, Inc., Federal Express, etc.), Product delivery/pickup fleets (such as: McShan Florist, armored car services, etc.) Service fleets (such as: Xerox, telephone companies, utility companies, etc.)
Public Information Distributors	CATV access companies (such as: TCI Cablevision, etc.), radio stations (such as: WRR, KVIL, etc.), TV stations, newspapers (such as: Dallas Morning News, etc.)
Multi-jurisdictional Committees	Mobility Technical Committee (MTC), Traffic Management Team (TMT), Dallas Regional Mobility Coalition (DRMC), etc.
Automobile Driver	American Automobile Association
Other	Chamber of Commerces, D/FW Airport, Texas Turnpike Authority, etc.

POTENTIAL ROLE						
IVHS Function	ATMS		ATIS	APTS	CVO	AVCS
Goal #	1,5	2,3,4,5	1,5	3,5	4,5	5
Goal	Traffic Data Collection	Operation of ATMS	ATIS Broadcast	Transit & HOV	Shared Route Data	Incorporate Technology
FHWA, NCTCOG, TxDOT	X	X	X	X	X	
TTI	X	X	X	X	X	X
Other Funded IVHS Organizations	X	X				
Cities	X	X	X	X	X	
Counties	X	X		X		
Public Passenger Transportation Companies	X			X	X	
Private Passenger Transportation Companies	X			X	X	
Private Sector Technology Sources				X	X	X
Vehicle Locator Sources	X				X	
Commercial Fleet Operators	X				X	

POTENTIAL ROLE						
IVHS Function	ATMS		ATIS	APTS	CVO	AVCS
Goal #	1,5	2,3,4,5	1,5	3,5	4,5	5
Goal	Traffic Data Collection	Operation of ATMS	ATIS Broadcast	Transit & HOV	Shared Route Data	Incorporate Technology
Public Information Distributors			X	X		
Multi-jurisdictional Committees				X		
Automobile Driver			X			
Other (Chamber of Commerces, D/FW Airport, Texas Turnpike Authority)				X	X	

LATED ONGOING IVHS PROJECTS
DALLAS IVHS PLAN

8/4/93
Revised 8/25/93



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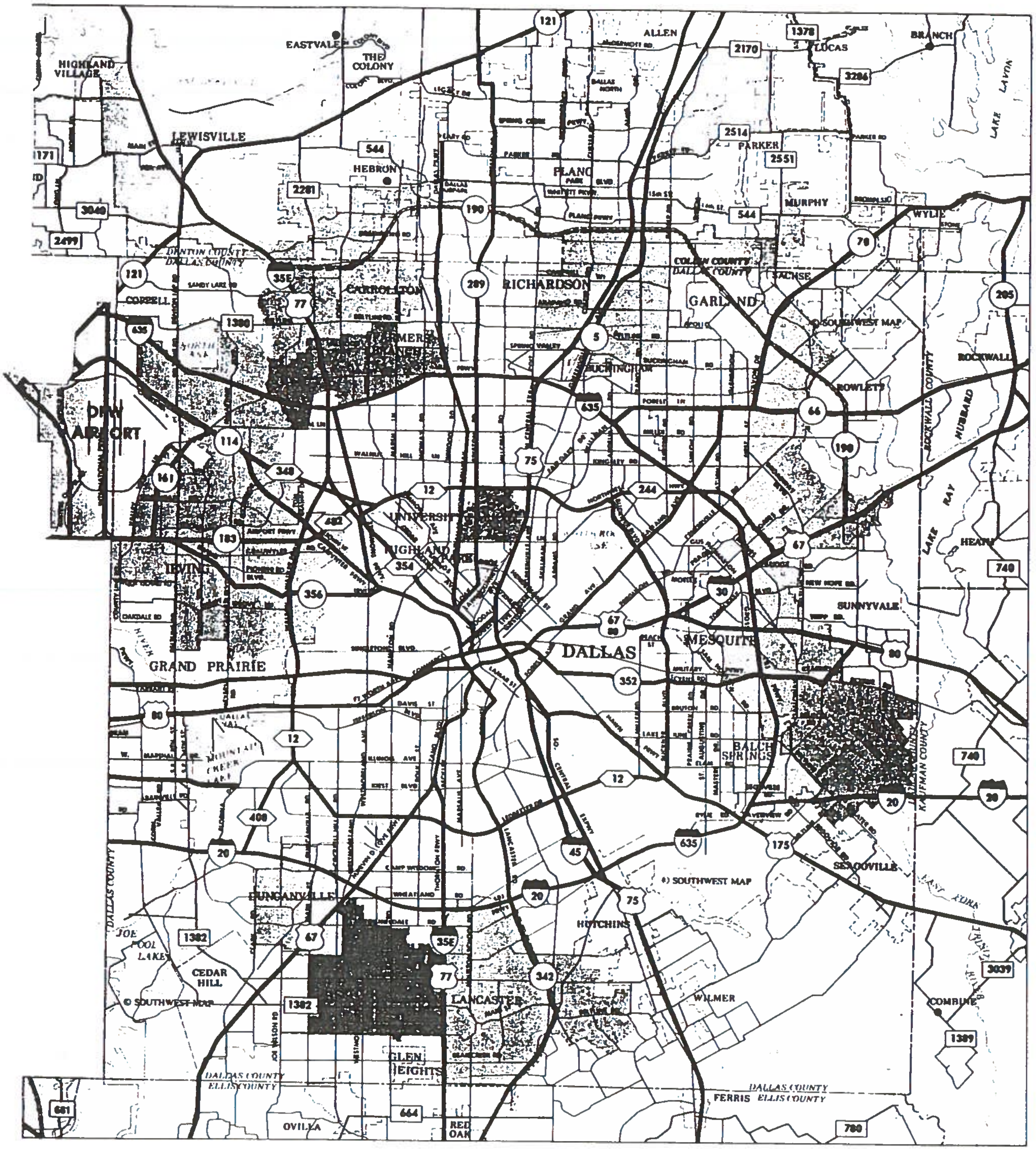

FIGURE 1. DALLAS IVHS PLANNING REGION.

POPULATION AND FREEWAY MILEAGE FACTORS
DALLAS AREA IVHS PLAN

RANK	POPULATION(K)	
1	DALLAS	1000
2	GARLAND	180
3	IRVING	155
4	PLANO	129
5	MESQUITE	101
6	GRAND PRAIRIE	100
7	CARROLLTON	82
8	RICHARDSON	75
9	LEWISVILLE	47
10	DUNCANVILLE	36
11	PARK CITIES	31
12	DESOTO	31
13	FARMERS BRANCH	24
14	ROWLETT	23
15	LANCASTER	22
16	CEDAR HILL	20
17	ALLEN	18
18	BALCH SPRINGS	17
19	ROCKWALL	10
20	ADDISON	9
21	SEAGOVILLE	9
30	WYLIE	8
22	SACHSE	5
23	GLEN HEIGHTS	5
24	COCKRELL HILL	4
25	HUTCHINS	3
26	RED OAK	3
27	FERRIS	2
28	SUNNYVALE	2
29	WILMER	2

RANK	FREEWAY MILEAGE	
1	DALLAS	123
2	IRVING	29
3	MESQUITE	20
4	GRAND PRAIRIE	11
5	GARLAND	9
6	LEWISVILLE	9
7	LANCASTER	8
8	BALCH SPRINGS	7
9	RICHARDSON	6
10	HUTCHINS	6
11	ALLEN	6
12	CEDAR HILL	6
13	PLANO	5
14	SEAGOVILLE	5
15	ROCKWALL	5
16	CARROLLTON	5
17	GLEN HEIGHTS	5
18	DUNCANVILLE	5
19	DESOTO	5
20	SUNNYVALE	4
21	FARMERS BRANCH	3
22	WILMER	3
23	FERRIS	2
24	RED OAK	2
25	ADDISON	1
26	COCKRELL HILL	1
27	SACHSE	1
28	ROWLETT	1
29	PARK CITIES	1
30	WYLIE	1

RANK	FREEWAY MILES X POPULATION(K)	
1	DALLAS	123000
2	IRVING	4495
3	MESQUITE	2020
4	GARLAND	1620
5	GRAND PRAIRIE	1100
6	PLANO	645
7	RICHARDSON	450
8	LEWISVILLE	423
9	CARROLLTON	410
10	DUNCANVILLE	180
11	LANCASTER	176
12	DESOTO	155
13	CEDAR HILL	120
14	BALCH SPRINGS	119
15	ALLEN	108
16	FARMERS BRANCH	72
17	ROCKWALL	50
18	SEAGOVILLE	45
19	PARK CITIES	31
20	GLEN HEIGHTS	25
21	ROWLETT	23
22	HUTCHINS	18
23	ADDISON	9
24	SUNNYVALE	8
25	WYLIE	8
26	RED OAK	6
27	WILMER	6
28	SACHSE	5
29	FERRIS	4
30	COCKRELL HILL	4

NO FREEWAYS — ASSUME 1 MI.

1980 WORKING PAPERS

APPLICATION OF IVHS USER SERVICES IN THE DALLAS URBAN AREA

Fax Completed Sheet To TTI at 691-8172or mail to: TTI, 8150 N. Central Expy Ste 815 Dallas, TX 75206

IVHS USER SERVICES	EAR TERM 1-5 YRS				MEDIUM TERM 10 YRS				COMMENTS
	YES	NO	MAY-BE	NEED MORE INFO	YES	NO	MAY-BE	NEED MORE INFO	
TRAVELER INFORMATION									
Traveler Advisory									
Traveler Service Information									
Trip Planning									
Location Determination & Display									
Route Selection									
In-Vehicle Signing									
TRAFFIC MANAGEMENT									
Incident Detection and Management									
Demand Management									
Traffic Network Monitoring									
Traffic Control(adaptive strategy)									
Parking Management									
Construction Management									
Electronic Toll Collection									
PUBLIC TRANSPORT AND									
EMERGENCY VEHICLE MGT									
Planning and Scheduling Systems									
Signal Preemption Traffic Control									
Automatic Payment(Flexible Fares)									
Dynamic Ridesharing									
Prediction of Arrivals									
Emergency Services Management									
FREIGHT AND FLEET MANAGEMENT									
Inter-modal Transportation Planning									
Route Planning and Scheduling									
Hazmat Monitoring and Tracking									
Vehicle and Cargo Monitoring									
Law Enorcement									
Regulatory Support									
RELATED TO ALL GROUPS ABOVE									
Traveler Safety/Security									
MAYDAY Transmissions									
DRIVER-ASSISTED									
VEHICLE CONTROL									
Collision Alert Warning									
Collision Avoidance Control									
Driver Condition and Performance									
Intersection Hazard Warning									
Vision Enhancement									
Vehicle Condition and performance									
AUTOMATED HIGHWAY SYSTEM									
Automated Check-In									
Automated Check-Out									
Longitudinal Control									
Lateral Control									
Malfunction Control									
Traffic Regulation									

AGENCY________________________ RESPONDENT________________________

ADDITIONAL COMMENTS:

TECHNICAL MEMORANDUM 1980-7

TRAFFIC SIGNAL CONTROL DURING INCIDENT CONDITIONS

Dallas IVHS Planning Region

June 1994

OVERVIEW

The purpose of this memorandum is to document a proposed approach to traffic signal control during incident conditions on freeways or other major regional roadways. Coordinated control of traffic signals where multiple jurisdictions are involved, as is often the case in the Dallas IVHS Planning Region, is addressed.

AREA PROFILE

Although the Dallas urban area is not precisely defined and seems to be continually changing, for purposes of this project it is taken to be Dallas County and the municipalities which directly abut the county to the north, south, and east of the county boundaries. The Dallas urban area comprises approximately 1,000 square miles with a population exceeding two million. The City of Dallas itself has a population of approximately one million. There are 33 incorporated cities in Dallas County. The City of Dallas has contiguous boundaries with 15 of these cities, five of which have populations greater than 100,000 and three of which have populations between 50,000 and 100,000. There are over 300 miles of freeway in the Dallas urban area, with approximately 125 miles in Dallas and the remaining mileage distributed among 24 other cities.

EXISTING TRANSPORTATION MANAGEMENT SYSTEMS

Working with area operating agencies, an inventory of existing traffic management systems and transportation facilities was compiled. Previous Technical Memorandums have documented these inventories. A brief overview of the findings are presented below.

- ***Traffic Signal Systems*** - There are over 2,000 traffic signals in the Dallas urban area, with approximately 60 percent being in the City of Dallas. Of the signals in the urban area, 78 percent are timed for coordination. Of the total number of signals in the urban area, 22 percent are in some type of computer based system, either closed loop or central mainframe.

- ***Traffic Control Centers*** - Nine of cities have office areas devoted to computer based traffic signal control centers. TxDOT has a traffic management center which houses radio communications, CCTV monitors, CMS operations, motorist assistance and patrol dispatch for the North Central Expressway (US 75) and a portion of IH 635 (LBJ Freeway).
- *CCTV* - Closed circuit television systems are installed in Garland and Richardson for traffic monitoring via their CATV systems. Other cities are in conversation with their cable franchisers for similar capability. TxDOT will shortly install 16 cameras along North Central Expressway as part of the freeway reconstruction project.
- *CMS* - TxDOT operates over 20 changeable message signs, mostly in the vicinity of the North Central Expressway Corridor. At the present time these signs are used to convey information on known construction operations and closures but will display real time traffic information as detection systems are available.

EXISTING INCIDENT MANAGEMENT PROCEDURES

Thirty of the cities in the study area were surveyed to determine incident management procedures and to identify particular problems or needs . Any perceived jurisdictional problems were also investigated since incidents on freeways are handled by the police and emergency medical service of the city within which the incident occurred. The incident management procedures were documented in terms of notification and response, on-site procedures, and documentation. It was generally agreed that jurisdictional problems between abutting cities were minimal and in fact a high degree of cooperation exists. Within particular cities there appeared to be some conflict of purpose between the desire of the enforcement authorities to investigate and secure the scene and the desire of traffic engineers to restore capacity expeditiously and minimize backup contributing to secondary accidents.

TRAFFIC SIGNAL CONTROL DURING INCIDENT CONDITIONS

There are generally no pre-planned traffic signal control schemes for response to incidents. In general, police officers manually control traffic at critical intersections at or near incident sites as the need and available personnel exist. For an incident of protracted duration, such as a large spill or multiple vehicle accident requiring extended time to clear the roadway, individual cities may implement special timing plans from their central control facility if one exists, or manually at the field intersection, if no such central capability is possible.

A workshop was held to examine any potential institutional issues which might be barriers to area-wide traffic management, particularly under incident conditions. Two divergent approaches to traffic signal control in a multi-jurisdictional environment were proposed for initial discussion.

- ***Unilateral Centralized Management*** - Under this concept, one agency, presumably TxDOT, would control and manage traffic signals in and around incident scenes and along alternate routes. Cities would continue to operate signals on other streets not defined as incident responsive routes. Several barriers to such an operation were apparent. First, cities were reluctant to have another agency operating their signals, whether it be the State or another city. The legal implications were a concern and, furthermore, signal operating philosophy varies from city to city. Finally, funding for the State to serve in such a role would be a problem even if it were legally feasible.
- ***Multilateral Decentralized Management*** - Under this concept, all operation of signals under incident or non-incident conditions would rest with each individual city. Response to incident conditions would be through the city's traffic control system either by advanced traffic responsive adaptive control or some type of manual override. Cities would retain autonomous control of their signals but not all cities have, nor in the case of smaller cities, do they anticipate having an advanced traffic signal system capable of such response.

It was generally agreed that a regional concept was essential, but not necessarily as a regional **control** center. The cities still want to have control of traffic signals within their particular jurisdiction but are open to cooperative operation for incident conditions across city limit lines. A consensus model evolved which is described as follows.

The Consensus Model

Under incident conditions, predetermined, jointly developed signal timing plans would be called for from a regional traffic management center (RTMC). This center would most likely be the TxDOT freeway management center, which would have freeway CCTV and detector monitoring capability. With direct, two-way communication to the cities' control centers, specific timing plans could be called for in response to incident characteristics. Each city would have the responsibility to implement the timing plan. As the operational relationships mature, more direct control may be possible, such as when a city's control center is not staffed. In any event, it is likely that only predetermined timing plans would be implemented and then only through the cities' own system. Briefly described, those cities with central traffic signal

management capability would implement the recommended incident condition plan. For signals where such capability does not exist, the RTMC would have capability to directly address the local controller and call for a locally stored incident timing plan, overriding the plan in effect.

TRAFFIC SIGNAL CONTROL SCENARIOS UNDER INCIDENT CONDITIONS

Seven scenarios were developed as a function of where and when an incident is detected and the response of various affected agencies.

Time of Occurrence

Two general time period of incident occurrence were identified:

Prime Time on a freeway, regional arterial, or local street, and

Non-Prime Time on a freeway, regional arterial, or local street.

Prime time is defined as the portion of the day when a city with central traffic management capability has staff available in that center, typically on a weekday during daylight hours.

Incident Location

- **Freeway**-Freeway Facilities
- **Regional**- Major Non-Freeway Routes of regional significance
- **Local**-Local City Streets without significant regional significance

Response Agencies

Each scenario is developed to reflect response service agencies and the recommended response of those agencies depending on the type of facility on which the incident occurs. Service or responding agencies are delineated as follows:

- **Emergency Services**

  Police, Fire, EMS, Streets, Wreckers, Hazmat
- **Transportation Services**

  TxDOT, Counties, Tollroad Authority, DART

  Cities: Tier 1-Cities with central computer traffic signal control capability

Tier 2-Cities with more than 15 signals without central traffic signal control capability

Tier 3-Cities with less than 15 signals without central computer traffic signal control capability

Tier 4-Cities with no traffic signals

Private Sector (Traffic information providers)

Responses

Depending on the time and location of incident occurrence, the various agencies will initiate a predetermined response.

- **Emergency services**-Police, fire, EMS, wreckers, and hazmat would respond to incidents as they normally do, responding to location and type of incident during all times of day, primetime and non-primetime.
- **TxDOT**-TxDOT would operate a Regional Traffic Management Center (RTMC) during much of the day and possibly during weekends for special circumstances. During incident conditions on freeways or frontage roads, TxDOT would operate the CMS, ATIS, Ramp Control, HAR, and other incident management services (such as provision of sanding, heavy equipment, signing, or barriers). During incidents occurring off-freeways on regional roadways, the RTMC would operate the CMS, ATIS, Ramp Control, and HAR as appropriate to the location of the incident. .In addition, the RTMC would recommend predetermined, incident responsive signal timing plans to those cities which have capability to implement plans remotely (Tier 1 cities). For cities without such capability, the RTMC would remotely command locally stored incident responsive signal timing plans at local intersections, primarily at frontage roads and crossing arterials. The RTMC would also notify the affected cities, DART, and the private sector information providers.
- **Tollroad Authority**- During incident conditions on the tollroad, the Tollroad authority would operate the CMS, ATIS, Ramp Control, HAR, and other incident management services as provided in their operating policies. They would notify the emergency services and the RTMC of incidents.
- **DART**- In response to notification by the RTMC, DART would have the opportunity to reroute certain transit vehicles to avoid delay at or near incident locations. DART would also notify the RTMC of any incidents reported by their vehicle operators.

- **Counties-** The counties may play a role in future traffic incident management but probably not in the operation of traffic signals since they operate only a limited number of signals. For critical intersections, the RTMC could override and operate the signals as described above.
- **Cities-** During primetime, cities with central control capability (Tier 1) would implement and operate the timing plans (predetermined and mutually developed) recommended by the RTMC in response to incident conditions. During non-primetime, Tier 1 cities would either implement the plans automatically or after notification to the on-call signal department representative. For cities without central control capability, the RTMC would operate the appropriate signals directly, as described for primetime operation. It will be important for cities to communicate with the RTMC the location of incidents or special situations so that appropriate action may be taken and affected agencies may be notified.
- **Private Sector-**Private sector as considered here is defined as those entities such as MetroTraffic, Shadow Traffic, and news media providing traffic information to the traveling public. RTMC , as the central information clearing agency, would notify the private sector of traffic occurrences. In turn, those private sector entities would provide information to the RTMC for appropriate response.

Communications

Underlying all scenarios is the absolute need to communicate incident and incident-related conditions among agencies. The RTMC will serve as the information receiving and distribution center. Two way communication of relevant traffic conditions is essential.

Summary

Figures 1 through 7 provide a tabular summary of the relevant agencies and their responses under various incident locations and time of occurrence.

CLOSURE

A plan for multijurisdictional operation of traffic signal coordination during incident conditions has been described above. The plan is feasible under current available IVHS technology. The plan requires a high degree of cooperation and communication among the area agencies responsible for traffic