

**Los Angeles Spread Spectrum Radio Traffic Signal
Interconnect
Practical Lessons Learned
Evaluation Report**

Final

June 28, 1999

Prepared for:

Federal Highway Administration
California Department of Transportation
City of Los Angeles

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1	Introduction	1
1.1	Background..	1
1.2	Test Partners	2
2	Test Overview	3
2.1	ATSAC System	3
2.2	Spread Spectrum Radio..	5
2.3	Deployment Phases	8
2.4	Test Location	8
2.5	Intersection Deployment Configuration	8
2.6	Operations..	9
3	Evaluation Approach	9
3.1	Evaluation Goals and Objectives..	9
3.2	Evaluation Methodology	10
4	Evaluation Findings	12
4.1	Transferability	12
4.2	Time Effectiveness	23
4.3	Cost Effectiveness	26
5	Conclusions	29
5.1	Lessons Learned..	29
5.2	Recommendations..	31
6	References	32

1 Introduction

The Los Angeles Spread Spectrum Radio (SSR) Traffic Signal Interconnect Field Operational Test (FOT) investigated the feasibility of using wireless communications as an alternative to traditional hard-wire interconnection, to extend the coverage of centralized traffic control systems. While other tests used SSR as a component, e.g., Mobile Surveillance in Orange County, CA, this FOT was the only one with SSR as its focus.

This report captures the practical lessons learned by the test partners during the conduct of the FOT. It also summarizes how the primary partner, the City of Los Angeles Department of Transportation (LADOT) has moved forward subsequent to the completion of the test. The report is divided into five sections: this Introduction, which describes the background to the test and introduces the test partners, followed by sections covering Test Overview, Evaluation Approach, Evaluation Findings, and Conclusions.

This report is primarily intended for management level staff in state and local agencies, who may be considering the appropriateness of SSR for their individual circumstances. The report does not engage in detailed technical discussion about traffic control systems or SSR, except as necessary to help the reader understand the lessons learned. It is recommended that readers requiring a deeper understanding of the technical details of the FOT contact Sean Skehan or An Nguyen at LADOT.

Booz.Allen & Hamilton acknowledges the cooperation and guidance of the Test Partners, without which this report would not have been possible. Particular appreciation is expressed to Sean Skehan and An Nguyen at LADOT, Pheobe Cofer at Transcore, Dave Ragle, Jason Erickson, and Jerry Hempe at Hughes, and Richard Macaluso at Caltrans.

7.7 Background

Prior to the selection of the FOT, the City of Los Angeles had been seeking an alternative to traditional hard-wire interconnection between field equipment and the Los Angeles Automated Traffic Surveillance and Control (ATSAC) system. ATSAC is the centralized traffic control system for Los Angeles. The cost of deploying the physical communications infrastructure using traditional methods was, and still is, a limitation to the rate of expansion of the coverage of ATSAC. In addition, physical constraints may prevent expansion of ATSAC using traditional hard-wire interconnection.

The concept of radio frequency (RF) interconnect had been explored previously by LADOT in the late 1980s and early 1990s. Internal resources, and the technology available at that time, limited the extent to which RF could be meaningfully explored. Nonetheless, LADOT was convinced RF offered potential, and was worthy of further research.

The Federal Highway Administration's (FHWA) ITS Field Operational Test Program offered the opportunity to investigate RF in greater depth. At around the same time as this program was kicking off in 1993, major defense contractors were investigating the potential for their military products in the civilian transportation field. One such firm, the locally-based Hughes Aircraft Corporation, had an RF product which seemed to offer the potential to meet LADOT's needs.

The test officially commenced in September 1994.

1.2 Test Partners

The primary partner for the FOT is the City of Los Angeles Department of Transportation (LADOT). LADOT made available a wide range of management and technical expertise to the project, as well as providing human and physical resources to operations and maintenance.

JHK and Associates (subsequently Transcore) is the private sector partner. JHK had a long term support services contract with LADOT in respect of the ATSAC system, and was uniquely positioned to integrate the FOT into the existing ATSAC system. In turn, JHK brought in Hughes Aircraft Corporation (subsequently Raytheon), as the specialist in Spread Spectrum Radio networks. Although a sub-contractor, Hughes' committed resources to test also.

FHWA and the California Department of Transportation (Caltrans) New Technology and Research Program funded the FOT, and provided oversight and direction. Although not a partner, the California Program for Advanced Transit and Highways (PATH) was appointed as Independent Evaluator. The University of Southern California, as a PATH partner, provided evaluation services through its Department of Electrical Engineering.

Booz.Allen & Hamilton (BA&H) first became involved with the FOT through its contract with FHWA to provide operational test and evaluation support services to FHWA's ITS Field Operational Test Program. This program comprised more than 50 FOTs across the nation, including this test.

2 Test Overview

Test partners faced a range of challenges, including technical, deployment, operational, and maintenance issues. The development of the SSR system had no parallel: the SSR units were not commercially available, no design guidelines existed for placing the units in an urban street environment, and the theory of RF 'network' wireless communications had not been tested in a non-military situation. Additionally, the SSR system had to be integrated into one of the nation's largest and foremost traffic control systems, which demanded very high standards for the quality and throughput of data flows from central to field and back to central.

This section provides an overview of the test. It provides a brief description of the Los Angeles Automated Traffic Surveillance and Control (ATSAC) system, and describes the principles of SSR, the deployment phases, test location, the general configuration of deployment at intersections, and summarizes how SSR impacted operations.

2.1 ATSAC System

2.1.1 ATSAC History

The City of Los Angeles has a population of 3.6 million (1996 estimate), making it the nation's second largest city after New York. Los Angeles is one of only ten cities in the United States with a population greater than 1 million, and is by far the largest city in California.

The city operates ATSAC, which is an Urban Traffic Control System (UTCS). Originally installed in Los Angeles in 1984, ATSAC now controls approximately half of the 4,000 traffic signal intersections in the City of Los Angeles. ATSAC has approximately 20 management, maintenance, and operations personnel. It is important that readers of this report understand that an undertaking of this magnitude provides a level of resource, in terms of both quantity and quality, normally available to only the largest of cities. Without these resources, few cities could have even contemplated this FOT. Further details about ATSAC can be found online at:

<http://itsdeployment.ed.ornl.gov/scripts/foxweb.exe/c:/InetPub/wwwroot/iti98/trafficdetails?356>

2.1.2 ATSAC System Architecture (Physical)

Central

Located in the basement of City Hall East in downtown Los Angeles, ATSAC has a hierarchical physical architecture comprising a supervisory computer connected to multiple area computers, each of which is in turn connected to a peripheral processing unit (PPU) subsystem.

Central to Remote Communications

The PPU is connected via a centrally located communications multiplexor to a corresponding communications multiplexor in a remote communications hub, one for each area. The centrally located and remote communications multiplexors are connected via a variety of communications media: fiber optic cable, microwave, and leased telephone line.

Remote

ATSAC currently comprises 8 areas, each of which may comprises up to 400 intersections. Each area's communications hub comprises a bank of modems, which communicate with Model 170 traffic signal controllers located at individual intersections. This interface is provided via leased telephone lines, or direct connection using copper twisted pair cabling.

This test used SSR as an alternative media connecting the remote communications hub with the Model 170 controllers. Project partners hypothesized it was faster to extend the coverage of the ATSAC system using SSR, compared to direct connection using copper twisted pair cabling, because SSR obviates the need for trenching and cable-laying. This in turn would reduce the cost of bringing new intersections under central control. In some cases, it was considered that SSR may provide an interconnect where hardwire connection was physically difficult or impossible, e.g. from one side of a canyon to the other.

2.2.3 ATSAC System Architecture (Functional)

Functional architecture comprises four components: supervisory, area systems, PPU, and communications. Each is summarized below.

Supervisory function

This consists of:

- 9 Graphical display of overall system information, including intersection status and video,
- 9 Provision of traffic information data to external systems,
- 9 Operator interface on a system-wide basis.

Area systems function

This consists of:

- 9 Traffic system processing (UTCS),
- 9 Data access and file transfer interface,
- 9 PPU synchronization and control,
- 9 Auxiliary communications processing interface.

PPU function

This consists of:

- 9 PPU to area synchronization,
- 9 Once-per-second communications processing,
- 9 Once-per-second intersection monitoring and control,
- 9 Once-per-second detector processing,
- 9 Auxiliary communications processing,
- 9 PPU monitor processing.

Communications function

This consists of:

- 9 Multiplexing,
- 9 De-multiplexing,
- 9 Data transfer.

2.2 Spread Spectrum Radio

2.2.1 Communications Architecture

Intelligent Transportation Systems (ITS) invariably require a physical architecture which incorporates one or more communications media, providing the means for voice, data, or video transmissions between centers, roadside infrastructure, vehicles, and users. This FOT used SSR as an alternative communications medium for two-way data transmissions between one of the

ATSAC system's remote communications hubs and roadside infrastructure, in the form of traffic signal controllers.

For traditional wireline interconnect, the ATSAC system has a communications capability, comprising:

- 9 Once per second UTCS commands,
- 9 Once per second monitoring of intersection status,
- 9 Upload / download without suspension of above once per second
communications duties

At the outset of the test, consistency with this communications capability was the goal set for the selected RF system. In addition, ATSAC has a stringent reliability target of no more than 12 seconds of missed communication in a 24 hour period. This is equivalent to an acceptable error rate of 0.01% or a reliability rate of 99.9%. Although a target (not a requirement), the same performance was also required of the RF system. This had a significant impact on the design of the RF system networking software and, ultimately, the conduct of the test.

2.2.2 Fundamentals of SSR

The term Spread Spectrum refers to a class of communication that modulates (spreads) information over a wide frequency bandwidth (spectrum). For the purposes of this test, the 902 MHz to 928 MHz band was used, although spread spectrum is also available in higher frequency bands, such as 2.4 GHz and 5.8 GHz.

Two types of spread spectrum technique exist, direct sequence and frequency hopping. These methods suppress or avoid interference respectively, by using the full band available for data transmission, rather than a single frequency within the band. For this FOT, the direct sequence technique was used.

Implementers must trade-off the greater range associated with the lower bands, against the greater reliability and less interference in the higher bands. Federal Communications Commission (FCC) licensing regulations must also be taken account. The 902 MHz to 928 MHz band is generally unlicensed, meaning there are few barriers to entry for a wide range of users. This band is therefore attractive (and less expensive) compared to the higher bands, and attracts a correspondingly higher number of users, and potential for interference, particularly in metropolitan areas.

2.2.3 RF Network

There are three types of RF communication available to ITS applications, point-to-point, broadcast, and network. A network architecture was chosen for this test, meaning that data transmissions could occur between individual radios, rather than between selected radios or from a central broadcast. This approach allowed the use of low-powered radios (less than 1 watt power), capable of relaying data transmissions from one radio to the next. Not only did this obviate the need for high power antennae or repeaters, it avoided the need for FCC licensing (although the radios had to conform to FCC's environmental emissions requirements, referred to as Part 15).

Each intersection was equipped with an SSR unit linked to the intersection's Model 170 traffic signal controller. Intersections were grouped into cells, each of which was allocated a 'headend' radio to act as the interface between the remote communications hub and the other radios in the cell. These were known as 'tailend' radios. Conceptually, it was feasible for the headend radio to transmit data to all tailend radios in the cell. However, the system was designed such that it allowed individual tailend radios to monitor which other tailend radios they were currently connected to, and determine the optimal route for data transmissions. If a link between two radios was momentarily lost, the network could dynamically reconfigure itself to route the data transmission via other SSR units in the cell. This process of data transmission was referred to as 'multi-hopping'.

The requirement for once per second transmission, the 0.01% target acceptable error rate, message size, and the throughput capability of the RF network, dictated the theoretical number of radios per cell. At the outset of the project, it was hoped to have all radios functioning within a single cell. Subsequently, it was estimated that a cell could contain up to 32 radios. While multi-hopping was an important feature of the design of the test, the more hops required to complete the transmission of each data packet, the greater the likelihood that messaging could not be completed in a timely fashion. For radios at the periphery of each cell, this could lead to errors. This had a major impact on the design of the RF network software as the test progressed, and ultimately the configuration of cells.

2.2.4 The Hughes' SSR Product

The Hughes' SSR product was adapted for use in a traffic environment from its original design for use in a battlefield scenario. The product uses a proprietary network protocol which supports command and control capability.

2.3 Deployment Phases

The original intention of this test was to equip 87 traffic signal controlled intersections with SSRs (one per intersection). An Initial Deployment of 20 intersections was operational by early 1996. In effect, this Initial Deployment was a 'Proof of Concept', intended to improve the partners' knowledge of installation challenges, and to learn about RF performance. The Initial Deployment investigated link level performance, i.e. between adjacent SSR units, but did not explore network level performance in any detail. The Full Deployment, ultimately comprising 100 intersections including the Initial Deployment, became operational in early 1998.

2.4 Test Location

The test location was in the general vicinity of Marina del Rey, approximately 15 miles southwest of the ATSAC system center. This area is bounded by Santa Monica to the north, Interstate 405 (the San Diego Freeway) to the east, Los Angeles International Airport to the south, and the Pacific Ocean to the west. The test location was approximately 3 miles long (I-405 to the Pacific Ocean), and approximately 2 miles wide, and was referred to as the Mar Vista area.

The Initial Deployment of 20 intersections was located in a single cell. The Full Deployment of 100 intersections was located in four cells, including the original cell, which became cell 1. The cells contained 26, 27, 22, and 25 SSR units respectively, including the headend radio.

2.5 Intersection Deployment Configuration

For the Initial Deployment, the deployment configuration selected was to mount the radio and antenna together, fixed above street level to existing roadside infrastructure (street lamp posts or traffic signal arms). This configuration is referred to as 'remote radio', as the radio is mounted remotely from the Model 170 traffic signal controller. The antenna was connected directly onto the radio, while the radio was connected to the signal controller using a long length of regular connector cable.

During the Full Deployment, limited use was made of an alternative configuration referred to as remote antenna, where the antenna was again fixed above street level to existing roadside infrastructure, but the radio was mounted inside the Model 170 traffic signal controller cabinet. In this configuration, the antenna was connected to the radio using a long length of co-axial cable, while

the radio was connected to the traffic signal controller using a much shorter length of regular connector cable.

2.6 Operations

When the Full Deployment became operational, traffic operations were no different to the operations using traditional hard-wire interconnection. From the perspective of the operators in the ATSAC system center, the method of interconnection, be it copper twisted pair cabling or SSR, was completely transparent to them.

3 Evaluation Approach

Evaluation of the FOT was divided between the University of Southern California (USC) and Booz.Allen & Hamilton (BA&H). USC focused on a quantitative evaluation of the technical aspects of the test, while BA&H focused on a qualitative assessment of the practical lessons learned. This report represents the BA&H component of the evaluation. This section lists the Evaluation Goals and Objectives, and reviews the evaluation.

3.1 Evaluation Goals and Objectives

Evaluation goals and objectives are stated in the 3/23/95 version of the Evaluation Plan, prepared by the University of Southern California (USC), the Independent Evaluator:

3.1.1 Goals

1. Evaluate the feasibility of store and forward spread spectrum radio networking as a means of extending the control of traffic signals in the City of Los Angeles.
2. Assess the cost effectiveness of radio networking compared with conventional hard-wired interconnection.
3. Assess the time effectiveness of deploying spread spectrum radio network compared with conventional hard-wired interconnection.
4. Provide an assessment of the capabilities of newly developed spread spectrum radio.
5. Transfer test experience, through documentation, for the development and deployment of ITS elsewhere in the country.

3.1.2 Objectives

1. Test the RF network at the individual link level including any differences between uplink and downlink.
2. Test the RF network at the network level (between headend and tail radios) including any differences between uplink and downlink.
3. Verify the ability of the system to support the complete range of ATSAC communications capability.
4. Test the intra-cell reconfiguration feature of the network.
5. Evaluate the cost effectiveness of spread spectrum radio networking compared with conventional wireline interconnection technology.
6. Evaluate the time effectiveness of deploying spread spectrum radio networking compared with conventional wireline technology.
7. Transfer test experience for the development and deployment of the SSR network elsewhere in the country.

USC published its draft Evaluation Report, dated April 4, 1998, which addressed objectives 1 through 4 above. Objectives 5 through 7 were not addressed by USC. Collectively, they represent the 'practical lessons learned' from the test, and are the subject of this Booz.Allen & Hamilton (BA&H) Evaluation Report.

3.2 *Evaluation Methodology*

3.2.1 Cost effectiveness

Objective 5:

Assess the cost effectiveness of spread spectrum radio networking compared with conventional wireline interconnection technology.

The evaluation approach compared costs associated with the Full Deployment, to corresponding costs associated with conventional wireline interconnection technology. To the extent possible, greater emphasis was placed on costs (particularly labor costs) related to the Full Deployment, rather than the Initial Deployment, to reflect more streamlined deployment techniques as the Full Deployment progressed. It was important to identify any costs incurred during deployment which:

- will not re-occur in any future system,
- have been incurred because of the nature of the ATSAC system, and would not be applicable elsewhere.

Project costs were studied, supplemented as necessary by interviews with agencies and contractors involved in the test.

3.2.2 Time effectiveness

Objective 6:

Assess the time effectiveness of deploying spread spectrum radio networking compared with conventional wireline technology.

The evaluation approach compared time associated with implementing new components, and modifying existing components for the Full Deployment, to corresponding time associated with conventional wireline interconnection technology. To the extent possible, greater emphasis was placed on time related to the Full Deployment, rather than the Initial Deployment, to reflect more streamlined deployment techniques as the Full Deployment progressed. It was important to identify any time spent during deployment which:

- will not re-occur in any future system,
- has been incurred because of the nature of the ATSAC system, and would not be applicable elsewhere.

Time records associated with project activities were studied, supplemented as necessary by interviews with agencies and contractors involved in the test.

3.2.3 Transferability

Objective 7:

Transfer test experience for the development and deployment of the SSR network elsewhere in the country.

The evaluation approach documented the experiences of all agencies and contractors associated with test, covering institutional, operational, and technical issues. This addressed experiences during the Initial Deployment and the Full Deployment. Data collection will be based on a review of project logs, supplemented as necessary by interviews with agencies and contractors involved in the test. LADOT used its own traffic signal installation and maintenance staff

resources to support the deployment effort associated with the Initial Deployment, whereas it used an external contractor during the Full Deployment. The experiences of both groups were captured during data collection, although many of the lessons learned during the Initial Deployment were factored into the Full Deployment.

4 Evaluation Findings

Evaluation findings are intended to provide an objective assessment of what was learned during the conduct of the test. The evaluation is not an 'audit' of the performance of the SSR system, nor of the staff, agencies, and organizations which participated in the test. It is hoped that the lessons learned will be beneficial to LADOT, Caltrans, and other agencies wishing to extend the coverage of traffic control systems.

This section reports evaluation findings covering transferability, time effectiveness, and cost effectiveness, corresponding to Evaluation Objectives 7, 6, and 5 respectively. This order was selected to provide the reader with a logical reasoning for the evaluation findings.

4.1 Transferability

4.1.1 Technical Issues

This section considers three types of technical issues:

- 9 System design
- 9 RF quality
- 9 Deployment

The USC Evaluation Report examines technical aspects of the test quantitatively, and in some detail. The purpose of this section is to highlight technical issues which need to be considered by potential implementers, based upon the perceptions and opinions of the test participants, without duplicating the USC effort or engaging in detailed numerical analysis.

System Design

Finding #1: LADOT's requirement for once-per-second communications processing with a stringent target of 99.9% reliability resulted in the number of intersections in each cell being reduced to approximately 8 SSR units. Actual reliability achieved was 97% to 99%.

The SSR network architecture was developed to be consistent with ATSAC's requirement for once-per-second communications processing. This means that every second ATSAC must send data to, and receive corresponding data from, each intersection. Part of this data transmission occurs between ATSAC and the remote communications hub. The focus of this test however, is how the SSR network facilitates data transmission between the remote communications hub and the Model 170 controller at each intersection in the test location.

Seven basic types of message are transmitted by the ATSAC center, divided into two primary transaction classes - time critical messages:

- 9 Controller command
- 9 Clock update
- 9 Time Broadcast

and auxiliary messages:

- 9 Upload
- 9 Download
- 9 Standby timing plan download
- 9 Standby event download

The original concept was to intermingle the two data types, with the data being transmitted from and to the headend in each cell. Any time left in the one second polling cycle after time critical messages had been sent would be used for auxiliary messages. The latter can occur over multiple seconds. The original system design allowed for all messages to be sent from each headend to its associated tailends in parallel (i.e. approximately simultaneously), and for the headend to receive responses in the same manner. An early expectation of LADOT was to have all the intersections in a single cell. Subsequently the partners considered it was feasible that a single cell could support up to 32 intersections.

Networking software, developed by Hughes, was loaded into each SSR unit. As described previously, this networking software allowed 'multi-hopping', where individual tailend radios determine the optimal route for data transmissions. If a link between two radios is momentarily lost, the network can dynamically reconfigure itself to route the data transmission via other SSR units in the cell.

By January 1998, problems persisted where each cell would repeatedly shut down after only a few hours of operation, seemingly because the headend radio was unable to receive messages from the tailend radios. The precise reasons for this were not fully determined, but appeared to relate to corruption of location addresses. Reliability was improved by sub-dividing the one second polling cycle

into two 500 millisecond packets, one for time critical messages and one for auxiliary messages. However, this reduced the time available to transmit data to tailend radios, and consequently created pressure to reduce the number of intersections in each cell.

Bad or lack of communication from any intersection for nine consecutive 1 second polling cycles resulted in the intersection reverting to time-of-day control. The intersection was reconnected either manually, or automatically as and when good communication was restored. In general, such problems would not compromise safety, but were sufficiently frequent to result in an overall lack of comfort by LADOT in the readiness of the SSR system to control traffic. Throughout this period, the reliability achieved varied in the range of 70% to 90%, considerably lower than the reliability target of 99.9%. Consequently, all cells remained offline, and functioned in a monitoring mode only, without controlling intersections.

A satisfactory level of performance was achieved at the end of January 1998, by reducing the number of intersections in three cells to approximately 8 SSR units in each cell. The fourth cell was deleted due to persistent reliability problems. Further, LADOT was able to maintain cell size at these reduced levels even after tightening the threshold for bad or lack of communication from nine to three consecutive 1 second polling cycles. Although the 99.9% reliability target was not met, reliability achieved was in the 97% to 99% range.

It is noted by LADOT, Hughes, and JHK that the once per second requirement of the ATSAC system was the greatest technical challenge of the project. Any agency contemplating SSR as an alternative to traditional hard-wire interconnection, but which does not have this requirement, will most likely encounter fewer problems, and may be able to support larger cell sizes.

Finding #2: *The optimal arrangement of radios within each cell was to locate the headend centrally.*

The initial arrangement of radios in cells generally resulted in an off-center headend location within the cell. This was because the headend was located at the edge of ATSAC's existing central coverage, and tailend radios were located on the opposite side of the headend to ATSAC. When cell sizes were reduced, as described above, the tailends furthest from the headend were most affected, representing those radios requiring the most 'hops'. The conclusion drawn from this is that a centrally located headend will maximize the number of tailend radios with which it can be in direct contact (single hop). This will in turn offer the potential to maximize the number of tailend radios which can be reached in a double hop, and so on.

RF Quality

Unlike traditional hard-wire interconnection, the use of RF does not provide an immediate visual understanding of the factors which influence performance. In general, three factors influenced RF quality:

- 9 Line of sight
- 9 Antenna
- 9 Environment

Finding #3: *RF quality was optimized by achieving direct LOS between antennae at adjacent intersections.*

For the 900 MHz spectrum selected for this test, SSR was expected to function up to a distance of 600 meters (1968 feet), provided there was a clear line of sight (LOS) between radios,. LADOT experimented with techniques for achieving optimum LOS, including viewing adjacent intersections with binoculars from a bucket truck, and using strobe lights at night. The overwhelming finding was that RF quality was optimized by achieving direct LOS between antennae at adjacent intersections. In some cases, this meant that the antenna was not optimally located with respect to the Model 170 controller, potentially requiring the extensive cable between the antenna and the radio (remote antenna) or between the radio and the controller (remote radio). Under these circumstances, remote antenna entails extensive use of co-axial cabling.

Finding #4: *Antenna type, positioning, and grounding played an important role in RF quality.*

Extensive experimentation with different types of antennae was undertaken. The project partners concluded that the antenna was more critical to the success of the test than originally envisioned (although it is also noted that this is even more true in the higher frequencies). The type of antenna used was found to have considerable bearing on reliability. A 3dB antenna was used for the Initial Deployment. This was found to be satisfactory, because the radios were in close proximity. For the Full Deployment, cells were larger and communication difficulties were identified for peripheral radios. Consequently, a 6dB antenna was used. Project partners considered that this was one of the most significant contributions made to improving the RF quality of the system.

The antenna is mounted on a ground plane, the function of which is to minimize electrical “noise”. Experience showed that the integrity of the ground plane was important to avoid performance degradation. The alignment of the radio antenna was also found to impact reliability. Under certain circumstances, a

horizontal antenna (referred to as H-Plane) provided better reliability than a vertical antenna (referred to as E-Plane).

Through a combination of practical knowledge and 'on-the-job' experience, the project partners learned the importance of the antenna type, placement, and mounting on performance and reliability.

Finding #5: *The RF environment in the unlicensed 900 MHz spectrum was successfully used for traffic signal control, but concerns remain at the future potential for increasing interference.*

The test demonstrated that the RF environment in the test location was a feasible medium for traffic signal control. The 900 MHz spectrum was selected because it is unlicensed and has minimal entrance barriers. However, power output must be kept below 1 watt-the test used 0.5 watt. Higher outputs are acceptable providing the FCC licensing process has been followed. Higher output users will most likely have better reliability, and will reduce the potential for interference from lower output users.

It is understood that there are many other users in the unlicensed 900 MHz spectrum in the test location, including boat radar, vehicle location systems, public utilities, and wireless telephones. In one case, it is understood that the installation of an electronic hotel room key system disrupted the SSR network. That this is difficult to confirm or reject is indicative of the nature of the difficulties of working in an RF environment.

Other users provide the potential for a volatile RF environment in which interference can vary from hour to hour. While there was never a concern about malicious jamming, or interference leading to safety concerns, the possibility of sub-optimal performance, worsening over time, remains an important concern.

Only a limited range of environmental conditions were encountered during the test. Los Angeles has a generally favorable climate, with no extremes of temperature and precipitation, or lightning. Proximity to the ocean gave rise to some concerns about potentially corrosive sea air conditions (see following Deployment sub-section). Readers must reflect on the applicability of these evaluation findings to their local circumstances.

Deployment

A number of lessons were learned during deployment. While these may have impacted RF quality, their inclusion in this section is primarily intended to capture practical experiences which are potentially relevant to future implementers. Lessons fall into three categories:

- 9 Installation deployment configuration
- 9 Mounting on existing street furniture
- 9 Cable connectors

Finding #6: *The remote radio configuration simplified deployment, while the remote antenna configuration facilitated maintenance and upgrades.*

The remote radio configuration was used at approximately 80% of intersections, with the remote antenna configuration used at the remaining 20%. Each of these configurations offered advantages and disadvantages. The advantage of remote radio was that the required length of co-axial cable (antenna to radio) was kept to a minimum. However, any enhancements to the radio, or replacement in the event of radio failure, required a bucket truck and driver to retrieve the unit.

Conversely, the advantage of remote antenna was that the radio could be easily accessed in the Model 170 controller cabinet. However this required a considerable length of co-axial cable to be pulled from the antenna to the radio, frequently through already congested cable conduits. In some cases, these cable runs were in excess of 100 feet, depending on the selected location of the antenna, and the location of the Model 170 traffic signal controller. Remote antenna tended to be used where intersections were closer together, offsetting the anticipated signal degradation which was believed to occur with the longer lengths of co-axial cable. This degradation was somewhat mitigated as the test progressed, through the use of low loss co-axial cable.

There was general agreement among those involved with installation that the remote radio configuration was easier, as it did not require long lengths of co-axial cable to be pulled. Comments were made that co-axial cable is less flexible than regular connector cable, it cannot easily be bent through more than a 90° angle, and it has a tendency to “stick” to surfaces with which it comes into contact. One engineer suggested that power losses occurred on tight bends, another suggested dedicated conduits for the co-axial cable were required. Among those involved with radio maintenance/swapping-out and enhancements, the convenience of a controller mounted radio were acknowledged.

Finding #7: *Existing street furniture provided an adequate means of mounting antenna and radios.*

LADOT avoided elaborate mounting hardware by using stock items to fix antenna and radios to existing street furniture, such as camera poles, traffic signal mast arms and light standards. These provided a readily available source of electricity, and allowed LADOT to use existing design standards. LADOT staff installed the SSR network for the Initial Deployment, and two contractors

were used during the Full Deployment (one for intersections in the City of Los Angeles, and the other for 12 radios installed at intersections in Culver City).

Finding #8: *Deployment was facilitated by using cables with pre-attached connectors.*

Typically, the co-axial cable link between the antenna and the radio was straightforward.

The link between the radio and the Model 170 controller required a greater number of connections. With the remote radio configuration, this presented particular challenges, because of the distance between the two devices. For the Initial Deployment, connecting cable was cut on-site, pulled into position, and then connected. However the individual wires within the cable were not clearly marked, greatly complicating the process of connection. For the Full Deployment, specially marked wires were used to simplify this process. However, this cable was expensive, and it is understood that some wastage occurred inadvertently. The ultimate solution was to use cable with pre-attached connectors, known as 'pig-tails'.

Hughes provided a specialized tool to facilitate the process of cable connections between the radio and the Model 170 controller, which extracted and inserted pins in the connectors. Hughes also provided training, including on the job training, for field engineers. This method of using pig-tails was believed to provide a more waterproof solution, compared to connections made in the field. LADOT staff used heat shrink tubing to waterproof the connectors and liquid tape to waterproof the antenna ports.

4.1.2 Operational Issues

Finding #9: *The Spread Spectrum Radio network operated successfully when the number of radios was reduced to eight per cell.*

In general, the method of communication between the ATSAC center and individual intersections in the SSR network is transparent to ATSAC's centralized control function. With the exception of slightly lower reliability, traffic signals in the test location operated as if they were linked to ATSAC via traditional hard-wire interconnection. The reduced number of intersections (average 8 per cell) which remained in the SSR network, operated successfully.

While the traffic signal intersections performed no better than if they had used traditional hard-wire interconnection, without the SSR network these intersections could not have operated under centralized control until such time as traditional hard-wire interconnection was available.

It must be remembered that the characteristics of the RF network can lead to variable performance, much more so than traditional hard-wire interconnection. The extent to which impacts operation will emerge as LADOT learns from practical experience in the future.

4.1.3 Maintenance issues

Although the test has not had much opportunity to gather maintenance experiences in a fully operational mode, during its 4 year development period a number of maintenance related findings have come to light:

- 9 Equipment
- 9 Maintenance procedures
- 9 Maintenance agreement

Equipment

Finding #10: *Insufficient data exist to draw firm conclusions regarding reliability.*

SSR units for the Initial Deployment were procured and installed by September 1995. Thereafter, the units for the Full Deployment were progressively procured and installed through mid 1997. By the time the Full Deployment became operational at the end of January 1998, the radios had been in use for between six months and 2½ years.

In an August 1997 failure report prepared by Hughes, 20 radios (from a total stock of 100 radios) were listed as currently experiencing a failure of some kind:

- 9 Nine of the failures were miscellaneous faults,
- 9 Five of the failures were related to the radios' transceiver cards. It was suspected that these failures were related to accidental damage caused by inappropriate power on/off actions in the field, for which equipment handling guidelines were subsequently prepared,
- 9 For six of the failures it had not been possible to verify the nature of the fault. It was speculated that a data communications problem had been incorrectly diagnosed as a radio failure.

It is understood that all radios were repaired and returned to the field. All radios were functioning satisfactorily by the time the Full Deployment reached operational status at the end of January 1998.

At the end of the test, LADOT removed all radios from the original four cells, and re-deployed more than a quarter of them to other locations. In June 1999, 27 radios were deployed in three separate cells:

- 9 Huntington Drive, approximately 10 miles northwest of ATSAC (13 radios)
- 9 Figueroa Street, approximately 12 miles northwest of ATSAC (8 radios)
- 9 Long Beach Avenue, approximately 5 miles southeast of ATSAC (6 radios)

Most of the remaining radios were in stock, although 20 radios were inoperative. Reasons cited for the 20 inoperative radios include:

- 9 Failure of a serial communications chip - this was the predominant reason for failure,
- 9 Wear and tear,
- 9 Mishandling,
- 9 Vehicle collision (with traffic pole).

These data are inconclusive for calculating mean time between failure (MTBF). Notwithstanding this, approximately 15% of the total radio stock had one failure in the previous 14 months, although it is not known when these radios were originally procured and installed. Assuming a commencement of service date of March 1997, 15% of radios failed in two years. Consequently, the current stock of 50 radios provides the equivalent of more than six years backup to currently operational radios, without recourse to repair services. This will provide breathing space for LADOT to gather further information on reliability, during which time the commercial market place may mature sufficiently for other radio options to become available.

It is noted that, by comparison, the MTBF for traditional hard-wire interconnection is close to infinity. In other words, cable rarely fails after it has been laid, except when disrupted by subsequent construction.

Maintenance Procedures

Finding #11: *LADOT swaps out defective units and replaces them from stock.*

During the course of the test, this radio maintenance services were provided by the same firm which supplied the radios for the Full Deployment, a Hughes subsidiary called EEMSA, located in Mexico. In the event of a radio failure, LADOT swaps out the defective unit and returns it to EEMSA. The typical turn around time is 2 to 3 weeks.

Maintenance Agreement

Finding #12: *No formal maintenance agreement is in place.*

The radios used for this are a special delivery, and are not commercially available. LADOT recognizes it does not have the in-house capability to repair radios. However, at the time the test moved into its operational phase at the end of January 1998, no formal maintenance agreement was in place, nor was any planned.

One of the LADOT engineers dedicated to the test has been assigned to ensure that failed radios are replaced expeditiously. The same engineer will train LADOT maintenance staff to replace failed radios.

4.1.4 Other Factors

Evaluation findings related to the technical, operational, and maintenance issues described in the preceding sections will be valuable to agencies contemplating using SSR as an alternative to traditional hard-wire interconnection. Other factors worthy of consideration are described below:

- 9 Skills required
- 9 Barriers to deployment

Skills Required

Finding #13: *A wide range of skills are required for a successful SSR deployment.*

In addition to traffic engineering, the skill set required for this test included system engineering, and wireless communications, including the concepts of SSR, and product knowledge (radio and antenna).

Understanding of a system engineering approach is important in transitioning from user needs, through concept of operation and maintenance plan, functional requirements, understanding interfaces between subsystem components, design, implementation, and integration. For this test, LADOT's user needs included once per second communications as an important requirement for consistency with the rest of ATSAC. This proved to be key decision which had a profound impact on the design of the SSR network. Had LADOT chosen a less stringent requirement, this would have inevitably resulted in a different design.

Knowledge of wireless communications is important for planning radio locations and understanding the impact of line of sight on performance.

Product knowledge, e.g., SSR units and antennae, is essential to ensure optimal performance of the selected devices.

In addition to these technical resources, human and capital resources to support deployment, operations, and maintenance are essential.

Specialized technical resources were provided by JHK and Hughes during the conduct of the test. Additionally, LADOT had access to signal systems resources in its Western Yard, comprising staff with considerable electrical engineering, communications, and traffic signal installation and maintenance experience. LADOT also made available its specialists in the ATSAC center, to provide oversight and supervision services. The ATSAC center has laboratory facilities which were used to for system and radio testing. LADOT also developed its own software to monitor the dynamic reconfiguration feature of the SSR network. LADOT provided a full time engineer, dedicated to this test.

Any agency contemplating a similar SSR deployment must give careful consideration to the resources required for the project, and whether these will be provided internally or externally. LADOT is somewhat unique at the resources it was able to commit to this test, both in terms of the quality and quantity of those resources. While only a few cities have the potential to deliver a test of this complexity, market maturity may lead to a greater range of commercially available products in the coming years.

Barriers to Deployment

Finding #14: *Few barriers exist to future deployment of SSR units by the City of Los Angeles.*

With the experience gained during this test, LADOT appears to have reached a critical mass of knowledge, and has appropriate internal resources. Provided suitable areas exist with a headend connected to the ATSAC system, the only practical barrier to future deployment is the current availability of radios. However it is again noted that many staff involved in the project expressed concerns that the spectrum selected for this test will continue to attract new users and become increasingly congested. This may impact the reliability of the SSR network at some point in the future, unless the power output of the radios is increased beyond 0.5 watts.

Finding #15: *Many barriers exist to future deployment of SSR units by other agencies.*

No other agency has the experience gained by LADOT during this test, nor do they have the same critical mass of knowledge. A few large agencies may have similar internal resources, or access to equivalent external resources, but none

have access to similar radios. The Hughes product is one of a kind and is not commercially available. Until such time as a commercial market develops for SSR network development and support, it appears unlikely that any other agency will follow the lead of the City of Los Angeles.

4.2 Time Effectiveness

4.2.1 Factors influencing time effectiveness

The data on which the evaluation of time effectiveness is based are derived from the perceptions of staff involved in the deployment of SSR units and traditional hard-wire interconnection. For the purposes of this evaluation, a comparison is made against traditional hard-wire interconnection.

Time effectiveness of deployment changed over time, for a number of reasons, including:

- 9 experiences with deployment were gained, e.g. remote radio versus remote antenna
- 9 new techniques evolved, pre-connected cables
- 9 guidelines were developed by LADOT for mounting, etc.
- 9 a contractor was used for the Full Deployment

This evaluation of time effectiveness is focused on deploying radios with the benefit of all the above experiences. It assumes that the learning curve of the test partners has been adequately captured, and is incorporated into future deployments. New agencies contemplating an SSR network deployment will not have to repeat much, if any, of the test partners' learning curve, enabling such agencies to deploy an SSR network in much the same time as it would take LADOT to deploy a corresponding network.

In practice, each deployment will need to be tailored to suit local circumstances, such as size of network (number of cells and radios per cell), data processing requirements, (e.g., once per second communications), reliability targets, and the deployment considerations (remote radio, remote antenna, line of sight, etc.). Further, time effectiveness may be influenced by the procurement process used by new agencies (this is discussed further below). This evaluation of time effectiveness should be used as a guide only.

4.2.2 Comparison of time effectiveness

Following the conclusion of the test, LADOT's first new SSR cell (Long Beach Avenue) contained one headend and five tailends. Exhibit 1 compares the labor effort required to bring this cell to operational status for traditional hard-wire interconnection and spread spectrum radio network.

Exhibit 1: Comparison of time effectiveness for traditional hard-wire interconnection and spread spectrum radio network

Deployment Stage	Traditional Hard-Wire Interconnection	Spread Spectrum Radio Network
Design	6 person days (includes interconnect drawing not required for SSR network) Development of Plans, Specifications, and Estimates (PS&E) by in-house staff or through consultant services contract	5 person days Development of Plans, Specifications, and Estimates (PS&E) by in-house staff or through consultant services contract
Bid (Preparation of bid package, advertisement, selection, and contract execution)	Generally the same for both approaches, typically 40 elapsed days	Generally the same for both approaches, typically 40 elapsed days (see notes 1 and 2)
Build	15 elapsed days Trenching is the major effort	5 elapsed days Installation by electrician (see notes 3 and 4)
Total	61 days	50 days

Notes:

- 1) Currently LADOT holds sufficient equipment, and has access to suitably qualified and experienced internal staff, for the Bid Stage to be unnecessary.
- 2) Deployment of the SSR network lends itself to Design-Build or Systems Manager procurement options (discussed in 4.2.4 below).
- 3) LADOT estimated radios can be installed at the rate of two per day. In terms of scheduling, arrangements had to be made by ATSAC for electricians to be made available for installation.
- 4) LADOT has sufficient radios and cables in stock, so no lead time is required to procure equipment. Currently, no equivalent commercial off-the-shelf systems exist.

4.2.3 Discussion on time effectiveness

Exhibit 1 indicates that, using LADOT's post-test six intersection cell as an example, SSR offers the potential for new agencies to improve time effectiveness by 11 days when extending the coverage of an existing traffic signal deployment. Most of this improvement is directly related to the avoidance of trenching. For larger deployments of SSR, the improvements will be proportionately larger.

In practice, LADOT actually improved time effectiveness by 51 days, as the entire Bid Stage was unnecessary.- LADOT will continue to secure similar improvements while it maintains a stock of radios and cables, and has access to suitably qualified internal staff.

In some cases, e.g., river crossings, and canyons, it may be very difficult to use traditional hard-wire interconnection. Spread spectrum radio network may offer an alternative means of extending the coverage of an existing traffic signal deployment. Time effectiveness can be expected to be considerably greater in these cases.

4.2.4 Influence of procurement method on time effectiveness

Note 2 of Exhibit 1 refers to the possible use of Design-Build or Systems Manager procurement options. Traditionally, transportation agencies use a Design-Bid-Build procurement option installing traffic signals. However, this may not be best suited for a SSR network installation, because of the increased use of technology, and the extent of system development and integration required. ITS deployments have a less clear demarcation between the design and construction phases, compared to traditional traffic signal projects.

Design-Build is a procurement option in which a single entity designs and constructs the project under a single contract. It is best suited for:

- Projects that can be defined by functional or performance based specifications,
- Projects which have the propensity to significantly benefit from innovative design and construction solutions,
- Projects containing complex systems and subsystems,
- Projects with deployment time constraints.

The Design-Build procurement option may require new legislation to change the requirements of State competitive bidding statutes. The absence of enabling legislation may even preclude some agencies from using this technique.

Systems Manager is a procurement option where project design and interface functions are performed by a consultant, and all construction activities are performed by one or more contractors under various construction contracts. The System Manager (sometimes called “System Integrator-System Manager” or “System Integrator”) is responsible for developing project sequencing across design and construction phases, and coordination of design, preparation of PS&E, inspection, testing, and integration. The System Manager is a single point of authority for system design and integration, and provides such services to the agency. However, the agency maintains direct management, administration, and control authority over the contractors.

System Manager is a procurement option best suited for:

- Projects that involve complex electronic systems, communications, software, and computer hardware, and require system integration,
- Projects containing integration of legacy systems or support system expansion,
- Projects constrained by time pressure.

Individual agencies must decide which procurement options are acceptable, and appropriate to their circumstances. FHWA has produced a guide to procurement options: ***FHWA Federal-Aid ITS Procurement Regulations and Contracting Options***, October 1997. The document can be downloaded at:

<http://www.its.fhwa.dot.gov/scripts/cyber2/GetDoc.exe?docnumber=3029>

4.3 Cost Effectiveness

4.3.1 Factors influencing cost effectiveness

The original goal of the test was to investigate whether SSR provided a feasible means to reducing the cost of deploying the physical communications infrastructure associated with expansion of the coverage of ATSAC. For the purposes of this evaluation, a comparison is made against traditional hard-wire interconnection. The data on which the evaluation of cost effectiveness is based are derived from

- Actual cost data for the test,
- Perceptions of the test partners as to the potential for cost reduction through product streamlining and commercialization,
- Actual cost data associated with traditional hard-wire interconnection.

Cost effectiveness of deployment during the test was influenced by a number of factors, including:

- Time effectiveness of the deployment of SSR, as described in section 4.2 above,
- Battlefield nature of the design of the SSR units used for the test,
- Operations and maintenance costs.

To the extent possible, any one-off costs associated with the test must be separately identified to provide a meaningful cost comparison for agencies contemplating a similar SSR network deployment.

4.3.2 Comparison of cost effectiveness

Concurrent with the Full Deployment phase of the test, but under a separate contract, LADOT brought 88 intersections in the same general area as the test location under ATSAC control using traditional hard-wire interconnection. This provided the opportunity to compare the cost of traditional hard-wire interconnection and spread spectrum radio network on an equivalent basis, e.g. similar physical locations, similar time base for costs.

Exhibit 2 compares the costs incurred to achieve operational status for traditional hard-wire interconnection and spread spectrum radio network. The deployment cost is estimated to be \$14,485 less per intersection for spread spectrum radio network compared to traditional hard-wire interconnection.

Exhibit 2: Comparison of cost effectiveness for traditional hard-wire interconnection and spread spectrum radio network (per intersection)

Deployment Stage	Traditional Hard-Wire Interconnection	Spread Spectrum Radio Network (see note 5)
Equipment (see note 1)	N/a	Radio: \$6,500
		Communications: \$1,000
Labor (see notes 1, 2, and 3)	Design \$800	Design \$670
		Installation: \$875
		Inspection: \$270
Combined Equipment and Labor (see notes 1 and 4)	\$23,000	N/a
Total per intersection	\$23,800	\$9,315

Notes:

- 1) Excludes cost of traffic signals, controllers, detectors, conduit, and associated labor costs.
- 2) Based on rates per Exhibit 1, at \$100 per hour per person:
 - 9 Design takes one engineer 40 hours for 6 intersections,
 - 9 Build takes two engineers 4 hours each per intersection, plus a bucket truck at \$75 per intersection (equivalent to \$150 per day)
 - 9 Inspection takes one engineer 16 hours for 6 intersections
- 3) Excludes inspection cost for traffic signals, controllers, and detectors, but includes inspection cost for SSR.
- 4) Based on separate LADOT contract costs.
- 5) Excludes communication hub costs incurred by LADOT, consulting costs incurred by Hughes and JHK, and evaluation costs incurred by USC and BA&H.

As with the evaluation of time effectiveness, this evaluation of cost effectiveness assumes that the learning curve of the test partners has been adequately captured, and is incorporated into future deployments. New agencies contemplating an SSR network deployment will have wait until a commercial off-the-shelf SSR network is available. By that time the SSR unit cost is estimated to reduce from \$6,500 to \$3,500, increasing the estimated deployment cost saving for spread spectrum radio network to \$17,485 per intersection, compared to traditional hard-wire interconnection.

In practice, each deployment will need to be tailored to suit local circumstances, such as size of network (number of cells and radios per cell), data processing requirements, (e.g., once per second communications), reliability targets, and the

deployment considerations (remote radio, remote antenna, line of sight, etc.). This evaluation of cost effectiveness should be used as a guide only.

4.3.3 Discussion on cost effectiveness

Exhibit 2 indicates that SSR offers the potential for new agencies to reduce the cost effectiveness of extending the coverage of an existing traffic signal deployment by approximately 60%. With future enhancements from product commercialization, this saving could increase to approximately 75%. As with time effectiveness, this is directly related to the avoidance of trenching..

It is important that prospective new users of SSR understand that the operations and maintenance costs of SSR may somewhat higher than traditional hard-wire interconnection. This is because of the greater sophistication of the technology, and expectation that failure rates will be greater than traditional hard-wire interconnection. Typically, the only failure mode for traditional hard-wire interconnection is inadvertent disruption due to excavation. For SSR, the likely failure mode is a defective radio. Even so, with the identified deployment cost saving, defective radios could be replaced several times before life cycle costs are equalized.

5 Conclusions

This test was a success by any definition of the word. The test successfully explored the potential for SSR as an alternative to traditional hard-wire interconnection. Not only did it advance the state of the nation's knowledge on a subject which is potentially relevant to any agency with jurisdiction over traffic signal control, it also achieved a level of performance which persuaded LADOT to retain and expand the system after the test ended. That this success was achieved is due in no small part to the commitment of the participating agencies and firms, and to the dedication and technical expertise of their respective staff. This test is an excellent example of what can be achieved when an ITS vision is championed over an extended period to a conclusion.

This section interprets the evaluation findings, and summarizes the key lessons learned. This is followed by a list of recommendations.

5.1 *Lessons Learned*

The test has demonstrated that a SSR network is a practical and viable alternative to traditional hard-wire interconnection. The project partners worked through a

range of technical, operational, and maintenance issues to reach a an outcome where centralized traffic signal control was achieved with similar reliability to that achieved by the rest of the ATSAC system.

Perhaps the greatest testament to the success of the test is its legacy: LADOT continues to use 270 operational radios deployed in three separate cells. LADOT has concluded that the system is ideal for circumstances where small groups of intersections require centralized control but for which funding, physical, or technical factors prevent immediate deployment using traditional hard-wire interconnection.

Benefits cited for SSR include:

- Lower implementation costs
- Quick and easy to install, with minimal traffic disruption. SSR provides a convenient option to spend “use it or lose it” funding and still have a beneficial impact.
- Installation of SSR is more predictable as it is less prone to construction delay.
- SSR is less vulnerable to street digging, one of the major causes of failure of traditional hard-wire interconnection.
- Dynamic network re-configuration means that if an intersection goes down, other intersections remain on line. Traditional hard-wire interconnection does not have this redundancy.
- Although not tested, major earthquakes are expected to be survivable by SSR.
- Do not have to use existing conduits, which are often full, for cable runs.

Conversely, the dis-benefits of SSR include:

- SSR requires a higher level of technical knowledge on the client side. It needs engineering support, including a different approach to planning and design, and cannot be simply purchased like a consumer product. This in turn may lead to procurement issues, including consideration of design/build contract mechanisms.
- SSR will require long term support. SSR units are expected to have a shorter life expectancy than traditional hard-wire interconnection.
- Traditional hard-wire interconnection does not require preventative maintenance, while SSR units are expected to require regular diagnostic checks.
- Potential for damage during installation.
- SSR is susceptible to electronic interference.
- Although rare, SSR units are susceptible to lightning strikes.

- Currently, the SSR units are not commercially available, and no maintenance agreement exists. It is understood that Hughes have held informal discussions with at least one private sector partner, with a view to making certain rights available to that partner so that a commercial product can be brought to the market. No information is available on the outcome of these, and any other, discussions.

5.2 Recommendations

5.2.1 Spectrum Allocation

Evaluation findings related to the technical, operational, and maintenance issues. Consistently, project partners have expressed concern at the notion of controlling traffic signals as an unlicensed user in the 902 MHz to 928 MHz band. Their expectation is that this band will continue to attract more and more users, with a consequence risk to the reliability of the SSR network. If wireless communications is considered to be the way forward, it is recommended that users consider the following three options:

- Increase the power output of the SSR units from 0.5 watts, to up to 1 watt. The SSR units may need to be tested for conformance with FCC Part 15, for environmental emissions, but they will still be considered as an unlicensed user.
- Increase the power output above 1 watt. FCC licensing will be required, with associated time, and cost impacts on the applicant.
- Lobby for a dedicated band, reserved for specific users or uses. This is akin to the ITS America request to FCC in June 1997, for a spectrum allocation of 75 MHz in the 5.85-5.925 GHz band for ITS use. This request is intended to support dedicated short range communications (DSRC) for applications between vehicles and roadside systems, such as electronic toll collection. Interestingly, DSRC applications are currently in the 902 MHz to 928 MHz band. FCC announced a notice of proposed rule-making in June 1998, for which the comment period closed in September 1998.

5.2.2 Once per Second Communications

The single greatest technical challenge which the test faced was the ability to achieve once per second communications. Agencies contemplating the use of an SSR network system must give high consideration to the need, or otherwise, for once per second communication. The test proved it was feasible, but had to

reduce average cell size to achieve. For agencies where this is not a critical requirement, the potential exists for a less demanding software environment, which will result in larger average cell size. This in turn will most likely reduce costs associated with headends, as there will, on average, be less of them.

5.2.3 Commercialization

The hardware and software used for this test was adapted from other applications. Having proved that the concept of the SSR network is viable, it is recommended that for subsequent deployments, the SSR system will need to be 'repackaged' to create a commercially attractive product. In many cases, this may lead to a more competitively priced product also.

Associated with this repackaging, it will be necessary for vendors to provide appropriate warranties and maintenance support options.

6 References

1. JHK & Associates, Spread Spectrum Network Radio Implementation, Preliminary Design Report, March 1996
2. ARINC, Spectrum Requirements for Dedicated Short Range Communications (DSRC), July 1996
3. FHWA, Federal-Aid ITS Procurement Regulations and Contracting Options, October 1997