TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 462.6		

4. TITLE AND SUBTITLE	5. REPORT DATE
SWIFT: Seattle Wide-area Information for Travelers Evaluation Summary	January 5, 1999
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) William Perez and Bruce Wetherby	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Science Applications International Corporation 7927 Jones Branch Drive, Suite 200 McLean, Virginia 22102	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. Y-5908
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Olympia, Washington 98504-7370	13. TYPE OF REPORT AND PERIOD COVERED Summary 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

The SWIFT (Seattle Wide-area Information for Travelers) project was a field operational test of a wide area ITS communications system using a flexible FM sub-carrier High Speed Data System (HSDS). The test was conducted in a public/private partnership with WSDOT, King County Metro Transit, Delco Electronics, Etak Inc., IBM, Seiko Communications Systems, Metro Traffic Control and the Federal Highway Administration.

Three devices were used, by the public, to receive the traveler information: a Delco car radio (capable of providing vector navigation in addition to personal paging and the SWIFT messages); a Seiko wrist watch pager; and a portable computer (capable of providing graphic displays of traffic advisories and bus positions).

After the 15-month test, interviews with the 600 Seattle commuters/participants were conducted to assess user acceptance. A communications study evaluated the adequacy of the HSDS system to disseminate traveler information. An architecture study assessed the effectiveness of the various components to carry out SWIFT operations. An institutional issues study documented the history of the project and assessed the institutional issues confronted. A deployment cost study investigated the cost of deployment of a SWIFT system and assessment of potential profitability.

The first five reports in this series detail individual aspects of the project.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
ITS, High Speed Data System, FM subcarrier, traveler information, system architecture, operational test, deployment, FOT	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	37	

Research Report
Research Project Y-5908
Seattle Wide-area Information For Travelers

SWIFT: Seattle Wide-area Information For Travelers Evaluation Summary

by

William Perez, Ph.D. Bruce Wetherby, Ph.D.

Science Applications International Corporation
7927 Jones Branch Drive, Suite 200
McLean, Virginia 22102

Prepared for

Washington State Transportation Center (TRAC)
University of Washington, Box 354802
University District Building
1107 NE 45th Street, Suite 535
Seattle, Washington 98105-4631

Washington State Department of Transportation
Technical Monitor
Larry Senn

Washington State Transportation Commission
Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

January 1999

EXECUTIVE SUMMARY

On September 8, 1993, the Federal Highway Administration (FHWA) published a request for ITS FOTs. The concept for the SWIFT project was submitted in response to this request on January 6, 1994 by the SWIFT Project Team. The SWIFT Project Team proposed to partner with the FHWA to perform an operational test of a wide-area ITS communications system in the Seattle area. The proposed system incorporated a flexible FM sub-carrier High Speed Data System (HSDS) that had been developed and commercially deployed in the Seattle area by one of the SWIFT Project Team members. The HSDS would be used to transmit traveler information to three receiving devices provided by other SWIFT Project Team members. It was anticipated that the SWIFT Operational Test would provide valuable information regarding the viability of these devices for traveler information systems. SWIFT Project Team members included:

- Delco Electronics Corp., a subsidiary of General Motors Corporation (Delco)
- Etak, Inc. (Etak)
- Federal Highway Administration (FHWA)
- International Business Machines, Inc. (IBM)
- King County Department of Metropolitan Services (Metro Transit)
- Metro Traffic Control, Inc. (Metro Traffic Control)
- Seiko Communications Systems, Inc. (Seiko)
- Washington State Department of Transportation (WSDOT).

SWIFT System Description

An overview of the SWIFT system is shown in Figure 1, while Table 1 lists the primary types of information that were delivered by SWIFT. Each SWIFT receiving device regularly scanned the FM airwaves to identify, retrieve and display the information/messages intended for it.

The SWIFT system was divided into five (5) data components:

- Generation— gathering of the information to be transmitted
- Processing— formatting of the information to be transmitted
- Transmission— broadcast of the information to travelers
- Reception— receipt of the transmitted information by SWIFT devices
- Interpretation— use of the transmitted information by operational test participants.

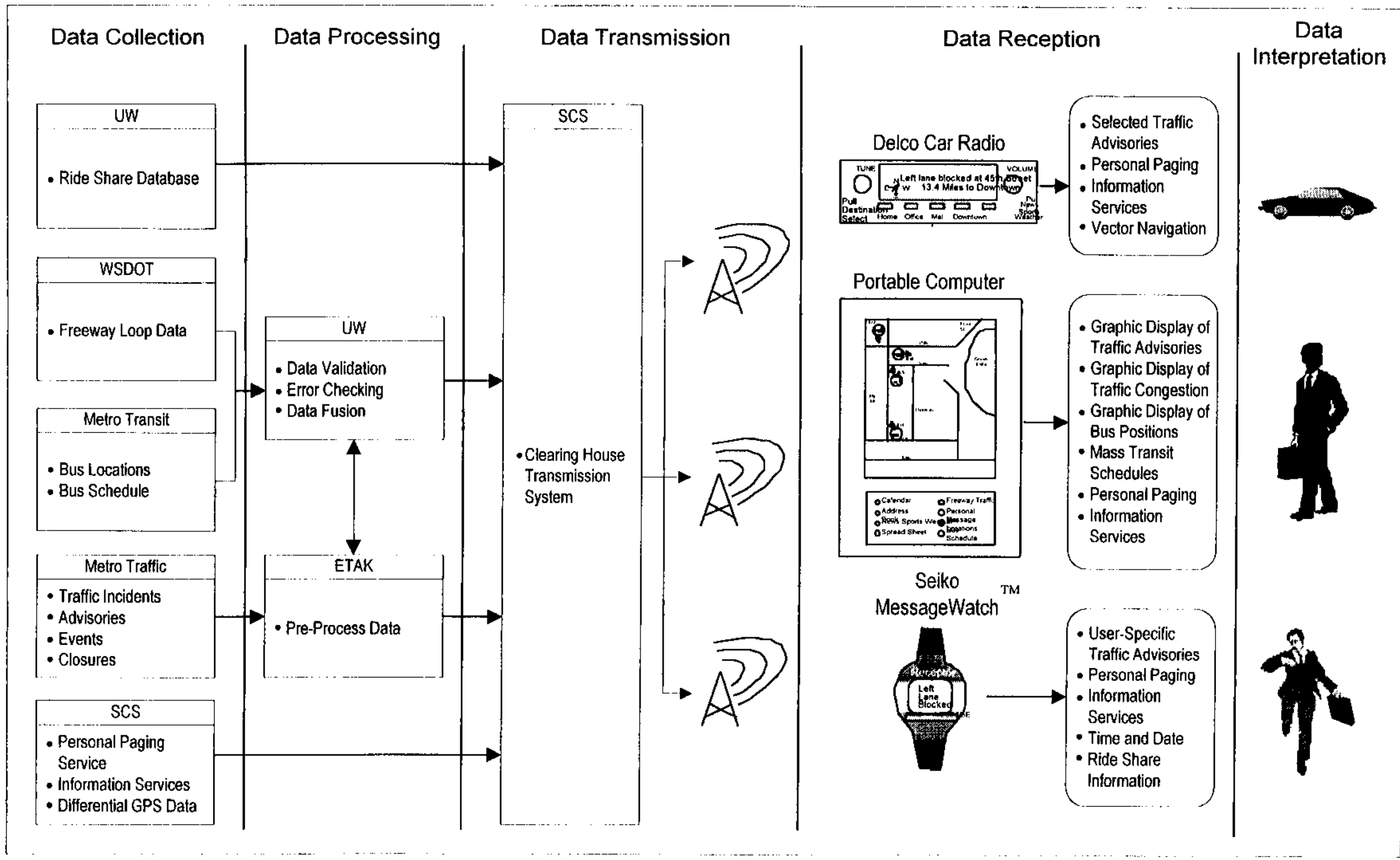

Figure 1. SWIFT System Description.

Table 1. Information Delivered by SWIFT.

Device/Information Received	Traffic Incidents, Advisories, Scheduled Events and Road Closures	Route Guidance	Traveler-Service Information	Freeway Loop-Sensor Information	Bus Locations and Schedules	Time and Date, Personal Paging and General Information Messages
Seiko MessageWatch	Yes	--	--	--	--	Yes
Delco In-vehicle Navigation Device	Yes	Yes	Yes	--	--	Yes
SWIFT Portable Computer	Yes	--	Yes	Yes	Yes	Yes

HSDS-Capable Receivers

Three types of HSDS-capable receiver devices, each developed and manufactured by private entities through consultation with their SWIFT team members, provided SWIFT FOT participants with incident information, traffic speed/congestion information, bus information, informational messages (e.g., forecast weather, sports scores, stock-market information) and personal pages, depending upon the device. The devices were:

- Seiko MessageWatch
- Delco In-Vehicle Navigation Device
- SWIFT Portable Computer

Seiko MessageWatch

These devices are commercially available and widely used in the Seattle area to deliver personal-paging services and "information service" messages. Current information-service messages include weather forecasts, financial market summaries, local sports scores and winning lotto numbers. SWIFT traffic messages were featured as an added information service.

SWIFT test participants who used the Seiko MessageWatch supplied information to the Evaluator about the usual routes, directions, days and times of the day they traveled. Traffic messages indicating the location and severity of traffic problems that the user might encounter were sent based on the resulting travel profile. Because the Seiko MessageWatch stored eight messages, only traffic problems that resulted in substantial delays were sent.

Delco In-Vehicle Navigation Device

This device incorporated a route-guidance component, GIS, GPS receiver and the speakers of a radio/compact disc player to present real-time traffic information to users. The whole package was placed into one of four vehicle types: 1995 or newer Buick Regals, Oldsmobile Cutlass Supremes and Saturns, and GMC Rally Vans.

The Delco device included the capability to select destinations from a "Yellow Pages" directory of local landmarks, hotels, restaurants, businesses and street corners selected by the user. The GPS provided the current location of the vehicle and a directional display associated with the route guidance system indicated the direction (relative to the vehicle) and distance to the selected destination. The stereo speakers were used to announce received messages.

Real-time traffic-incident information was transmitted over the Seiko HSDS. The HSDS receiver was built into the Delco in-vehicle navigation unit filtered out any messages that were outside a user-defined distance (the user could set the radius) from the current location of the vehicle. The navigation unit also decoded upon demand the SWIFT traffic messages from text into a "voice" that provided incident details to the driver. Although messages were retransmitted every minute, only new or modified messages were announced to the driver.

SWIFT Portable Computer

The SWIFT project primarily used IBM Thinkpad and Toshiba Satellite portable computers. Some Dauphin sub-notebook computers were distributed before they were discontinued due to negative user feedback. The Thinkpads were 486 machines, used Windows 3.1, had a built-in, "butterfly" keyboard and presented information on an active matrix, SVGA color display. The Satellites were Pentium 100 machines, used Windows 95 and also presented information on SVGA color displays.

A separate HSDS receiver unit was attached to the SWIFT portable computer's serial port. This unit had approximately the same footprint as the portable computer and was often attached to the portable computer via Velcro tape. Primary SWIFT information presented on the portable computer included real-time traffic incident, speed/congestion and bus-location information.

All of the traveler information for SWIFT portable computers was displayed using Etak Geographical Information System (GIS) software to show the location of each piece of data. The software allowed the user to select the type(s) of information (i.e., traffic incident, speed/congestion or transit-vehicle location) to be displayed on a map of Seattle. A "Yellow Pages" directory was also installed and linked to the GIS software to show the location of a selected business or point of interest. SWIFT portable computers also offered transit schedule information from static database tables inside the computer.

SWIFT Field Operational Test Evaluation

Once the SWIFT system was completed, an FOT was conducted with approximately 690 users who were recruited from the community in order to assess the system. With the majority of the SWIFT system completed by June 30, 1996, the SWIFT FOT evaluation was conducted from July 1, 1996 through September 20, 1997. The goals of the SWIFT FOT evaluation, listed in order of priority, were to evaluate:

1. *Consumer Acceptance, Willingness to Pay and Potential Impact on the Transportation System* – determine user perceptions of the usefulness of the SWIFT receiving devices, how much consumers would be willing to pay for such devices and services and assess how SWIFT-induced changes in users' driving behavior might impact the Seattle transportation network if the SWIFT system was fully deployed.

2. *Effectiveness of the HSDS Transmission Network* – determine how well the SWIFT HSDS communications system functions.

3. *Performance of the System Architecture* – determine how well the various SWIFT components work singularly and together.

4. *Institutional Issues That Affected the Operational Test* – identify how institutional factors associated with the SWIFT public-private partnership affected the FOT, with emphasis on implications for deployment.

5. *Deployment Costs* – estimate how much money it would take to deploy and maintain a SWIFT-like system.

Five evaluation studies were conducted as part of the SWIFT FOT evaluation. These studies paralleled the five SWIFT FOT evaluation goals and were implemented at various times during the 15-month test.

Results

The following represents summary results for the SWIFT FOT. The results are presented for each of the five study areas.

Consumer Acceptance Study Findings

The primary purpose of the *SWIFT Consumer Acceptance Study* evaluation was to assess participant, or end-user, perceptions of the usefulness of the information provided by SWIFT. This was done by using a combination of questionnaires, telephone surveys and focus groups. Findings, broken out by evaluation objective, are summarized below:

- *Importance for travel planning*—the majority of SWIFT users, regardless of device type, indicated that they found traffic incident and congestion information to be very important for making travel decisions

- *Usefulness for travel planning*—most participants, including those receiving the real-time bus-position information, indicated that they found the majority of the information presented by SWIFT to be useful for making travel decisions, such as what road/bus to take, what time to leave, etc.

- *Minimum set of user services and device features*—SWIFT users provided numerous suggestions for how to improve the SWIFT service, including improving message timeliness, providing route-specific messages, improving message accuracy, indicating when an incident occurred and providing messages when the system goes down.

- *Device usefulness*—although improvements in portability were suggested for the portable computers, in particular, the majority of SWIFT participants reported that they found their SWIFT devices to be useful and parsimonious with the intended application.

- *Willingness to pay*— Over two thirds (i.e., 68%) of the SWIFT participants reported that they'd be willing to pay either $5.00 or $10.00 per month for a service that incorporated several improvements to timeliness, accuracy, reliability and convenience.

- *Travel convenience and efficiency*—SWIFT users indicated that information provided by the system primarily helped them to "keep moving," "reduce my stress level" and "reduce my commute time." Others indicated that the information helped them change commute routes, change commute times and saved them time by assisting with the monitoring of bus arrivals.

- *Changes in traffic congestion, air quality, energy consumption and safety*—SWIFT was viewed as assisting, or improving the following: congestion, time utilization, route planning, stress levels and travel time.

- *System reliability*—93% of Seiko MessageWatch users viewed the system as being available 75-100% of the time, while 79% of Delco-in-vehicle-navigation device and 44% of SWIFT portable-computer users made this attribution.

- *System availability*—The majority of SWIFT participants viewed SWIFT as being an available system, but one that was affected by buildings and terrain, particularly for the SWIFT portable computers.

In summary, SWIFT FOT participants generally viewed SWIFT as a beta—or proof of concept—test rather than a test of a finished product. Nonetheless, most indicated that they found the traveler information to be useful, incorporated it to make travel decisions and came to rely on it.

Communications Study Findings

The *SWIFT Communications Study* evaluation focused on assessing the adequacy of the HSDS to disseminate SWIFT traveler information to the end-user devices. This was accomplished by using a combination of user questionnaires and field tests. The field tests, in particular, assessed SWIFT communications coverage effectiveness by testing for Received Signal Level (RSL), Bit Error Rate (BER), Packet Completion Rate (PCR) and the existence of multipath at eight (8) sites pre-selected for their potential ability to highlight deficiencies in communications effectiveness. Therefore, test sites were selected where reception was likely to be poor. Findings, broken out by evaluation objective, are summarized below:

- *Independent HSDS Assessment*—the SWIFT FOT was a success from a communications point of view. Analysis of user-reported problems with receiving messages indicated that the HSDS performed within predicted estimates provided by Seiko. That is, approximately 93% of all users reported that they experienced no problems receiving messages.

- *RSL, BER and PCR Testing*—field measurements of RSL, BER and PCR confirmed that the system performed within specifications, although the receipt of messages in some test locations appeared to be influenced by multi-path factors.

- *Multi-path Interference Testing*—the existence of multi-path degraded the receipt of messages and measured BER and PCR levels at two sites. Nonetheless, the majority of the transmitted SWIFT information was received successfully at these sites.
- *In-building Reception Sensitivity Testing*—in-building receipt of messages was impacted by the distance a SWIFT receiving device was located inside a building. Nonetheless, in-building degradation of message-receipt is a normal performance characteristic of an HSDS and one in which the environmental factors (e.g., building structures, antenna design) contributing to this effect are not completely known.

In summary, the *SWIFT Communications Study* documented the successful performance of an HSDS that was fielded in conjunction with a deployed ATIS in the Seattle, WA area. Message-receipt probability was excellent for the majority of SWIFT participants, and field measurements of RSL, BER and PCR indicated that information transmission was good. Nonetheless, the existence of multi-path at some locations suggested that significant future attention should be given to the analysis of multi-path interference mechanisms.

Architecture Study Findings

The *SWIFT Architecture Study* assessed the effectiveness of the various components of the SWIFT system to carry out, or perform, SWIFT operations. This assessment was accomplished by implementing user questionnaires and focus groups, usability tests, system performance analyses and field tests. The *SWIFT Architecture Study* also assessed system expandability and transferability. Findings, broken out by evaluation objective, are summarized below:

- *System operating as intended from a user's perspective*—SWIFT participants indicated that they found the information disseminated by SWIFT to be both important and useful, and that they used this information to make travel-related decisions, such as what travel routes and times to take. They also perceived the SWIFT devices to be safe and relatively easy to use and highlighted a number of positive operational features for each.
- *System operating as intended from a system's perspective*—Testing of the data throughputs of the SWIFT system indicated that the majority of SWIFT information was successfully transmitted throughout the system, and to SWIFT participants. These transmissions, in particular, were valid, timely and consistent within pre-specified system parameters. This meant that the system was up over 90% of the time for the majority of the users. In addition, the fidelity, or accuracy, of the information disseminated by SWIFT was generally found to fit specifications.
- *System not operating as intended from a user's perspective*—Some SWIFT participants, especially Seiko MessageWatch users, indicated that SWIFT messages were not perceived to be timely. This was due to previously-identified limitations in the message-queuing algorithms for these devices. Otherwise, portable-computer users indicated that not all SWIFT buses were displayed on these devices and some questioned the accuracy of speed/congestion information that was displayed. Finally, Delco in-vehicle navigation device and portable-computer users complained that they did not receive general-information messages and personal-paging services.

- *System not operating as intended from a system's perspective*—Fidelity tests of SWIFT system performance indicated that approximately 30% of the real-time bus position information was not being received by SWIFT devices, thus complicating the intended use of the portable computer devices for transit purposes. In addition, data conversion problems caused incorrect mapping of speed data for locations and/or incorrect interpretation of speed data for given locations. Finally, general-information messages and personal-paging services were not provided to portable computers and in-vehicle navigation devices.
- *System expandability and transferability*—the SWIFT FOT showed that an HSDS was very effective for disseminating traveler information in a large, congested metropolitan area. This included providing real-time incident, speed/congestion and bus-position information very effectively to paging watches, in-vehicle navigation devices and portable computers. Considerations for expanding such a system include the cost of infrastructure improvements (e.g., additional loop detectors) on both arterials and freeways, the number of users expected to use the system and, ultimately, the intended purpose of the system. Otherwise, transferability of the system is good given that many of the ITS architectural subsystems need to implement such a system are already available in many cities throughout the country.

In summary, the *SWIFT Architecture Study* showed that the SWIFT system was very effective in disseminating real-time incident, speed/congestion and bus-position information to Seattle-area travelers. In particular, SWIFT information dissemination processes proved to be both reliable and relatively accurate, although some operational problems were identified by the assessment. The expandability and transferability of the system was also assessed to be excellent.

Institutional Issues Study Findings

The purpose of the *SWIFT Institutional Issues Study* was to document the history of the project; assess the institutional factors that impacted upon the conduct of the SWIFT FOT; identify policy, jurisdictional and other factors impacting the test; and derive lessons learned. The methods for implementing this evaluation with fourteen (14) SWIFT team-member representatives were questionnaires and semi-structured interviews. Findings, broken out by evaluation objective, are summarized below:

- *Project History*—the SWIFT partnership, which was started in 1993, resulted in submission of the SWIFT FOT proposal to the FHWA in January, 1994 and acceptance in April, 1994. The SWIFT teaming agreement served to both form and bind together the SWIFT team members to address the goals and objectives of the FOT. With development activities primarily occurring in 1995 into early 1996, the SWIFT FOT was initiated on July 1, 1996 and proceeded for the next fifteen months. The SWIFT evaluator worked with the project team from 1994 through 1998 to effect the proper assessment of the system. This included the SWIFT Evaluation Plan (1995), five SWIFT test plans (1997) and six SWIFT final reports (1998), including this overall summary report.

- *Issues that impacted the conduct of the FOT*—the primary "issues" that impacted the SWIFT FOT were grouped in the organizational/jurisdictional, financial, regulatory/legal and public acceptance areas. These included confusion over the responsibilities of each organization, role clarity, nature of the public-private partnership, procurement/ acquisition strategies, market certainty, proper contracting/auditing procedures, patent/copy rights, standards/protocols and the role user acceptance plays in system deployment. Other issues, primarily addressing factors commonly found while deploying Information Technology (IT) projects, were identified by SWIFT team-member representatives.
- *Policy, jurisdictional and other factors impacting the test*—SWIFT team-member representatives indicated that the goals of the SWIFT project were relatively clear; the perceived benefits and risks of participating in the FOT varied widely among the team members; WSDOT, Seiko and Etak were most often mentioned as the champions of the project; the majority of the team members agreed that consumer acceptance was crucial to commercial deployment of the system; and that a subscription-based model was best suited for future deployment of the SWIFT system. The historical significance of providing real-time bus information was also cited as a major contribution of the project.
- *Lessons learned*—primary SWIFT lessons learned included the following attributions: responsibilities of the team members need to be clear from the onset; roles of the team members need to be delineated and understood by all; each side of the public/private partnership needs to understand the principles and ideals that govern the other; patent and copyright rules of the Federal government need to be modified to include models for public/private partnerships that address the distribution of patent and copyrights among the team members; ITS standards and protocols should be modified so that both public and private entities agree as to their contents; procurement and acquisition processes need to be better defined so as to facilitate, not hinder, ITS deployments; issues regarding ITS market uncertainty need to be delineated so that development processes will be facilitated; government contracting and auditing requirements need to be clarified for private-sector ITS public/private partnership team members and market research and user-system prototyping should be included in ITS projects to ensure that the system is well received.

In summary, the *SWIFT Institutional Issues Study* evaluation showed that the SWIFT project had historical significance; that the project was conceived, planned and executed with a maximum amount of cooperation among the team members and a minimum amount of delay in terms of implementation; that the SWIFT team members were, for the most part, free in their praise of their partners; that although a number of SWIFT institutional issues were identified, the impact of these variables was minimal; and that a number of lessons learned could be derived from the project for potential application elsewhere. Among the lessons learned from the SWIFT FOT were the need to clearly define the responsibilities and roles of each partner and to anticipate as much as possible the regulatory and legal impacts of the information-technology system that is being built.

Deployment Cost Study Findings

The purpose of the *SWIFT Deployment Cost Study* was to determine the cost of deploying the SWIFT system and to assess whether such a system might be profitable. Methods used to implement this evaluation included the Life-Cycle Cost Estimate (LCCE) and Commercial Viability Analysis (CVA). Findings, broken out by evaluation objective, are summarized below:

- *Analysis of LCCE results*—Life-cycle costs for a deployed SWIFT system were estimated to be \$6.4 million for FOT development, \$1.5 million for commercial development and \$0.8 million for the cost of annual commercial operations, for an initial investment total of \$8.7 million. 34% of the SWIFT FOT development costs were assigned to Seiko, primarily for developing and integrating the SWIFT Radio Receiving Modules (RRMs) for the in-vehicle navigation and portable computer devices, while 46% of SWIFT commercial development costs were assigned to Metro Networks, primarily for the cost of traffic-incident identification operations. The University of Washington's role in SWIFT development for data collection and fusion, although not as costly as Seiko's, was shown to be more labor intensive by consuming more than 60% of the labor hours above Seiko's. The largest single Overhead Direct Cost (ODC) for the SWIFT project was the licensed version of the Seattle Metropolitan area digital map that Etak provided at a cost of \$231,000.
- *Analysis of CVA results*—Analysis of three market-penetration scenarios for SWIFT (i.e., 4%, 12% and 20% of vehicle commuters who drive more than five miles to work each day) indicated that deployment of a "SWIFT-like" system is expected to be a viable commercial enterprise. Even under the most conservative market-penetration scenario (i.e., 4%), which corresponded to likely-to-subscribe information collected by the SWIFT Consumer Acceptance Study, the CVA analysis showed that annual revenues exceeded annual operations costs by a factor of more than three (3) to one (1). Among the lessons learned from the SWIFT CVA were: deployment of a SWIFT-like system in other cities may require the expenditure of up-front "infrastructure" costs (i.e., costs associated with developing the required HSDS hardware and software and integrating it with available FM radio stations); significant FM-subcarrier ATIS deployment costs (i.e., software development, integration and testing) are likely to be encountered during the development phase; operations costs, especially those for information gathering, should be fairly stable; and successful deployment should be based upon the construction of sound market-penetration scenarios.

In summary, the *SWIFT Deployment Cost Study* calculated the costs of developing, deploying and operating the SWIFT system and concluded that future deployment of "SWIFT-like" systems (i.e., those incorporating FM subcarriers as their basis) stand a good chance of being commercially viable.

Conclusions

In conclusion, the SWIFT FOT evaluation indicated that the project was a highly successful ITS test that demonstrated the efficacy of using a High Speed Data System (HSDS), or FM Subcarrier, to disseminate incident, bus and speed/congestion information via three different end-user devices: pager watch, portable computer and in-vehicle navigation device. Six hundred ninety (690) Seattle-area commuters, many with route- or mode-choice options, participated in the FOT and provided user-acceptance evaluations which showed that the system was perceived to be useful for avoiding traffic incidents, traffic congestion and for making transit-related decisions. Other evaluation components examined the operational features of the communications and architectural systems, and showed that the system was operational over 90% of the time and performed as expected. The SWIFT FOT evaluation identified various institutional issues that affected the project—which were minimal in their perceived impact—and determined that the financial bases for future deployment of such ATIS projects were good. Finally, the test results yielded recommendations for the deployment of future traveler information systems.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The United States (U. S.) Congress passed the Inter-modal Surface Transportation Efficiency Act (ISTEA) in 1991. The purpose of this legislation was to re-invigorate the country's transportation infrastructure by providing needed repairs to the highway system, encouraging the development of inter-modal transportation facilities and applying information technology (IT) solutions to transportation problems.

The Intelligent Transportation Systems (ITS) initiative grew out of ISTEA's interests to apply IT solutions to transportation problems. Specifically, the U. S. Department of Transportation (USDOT) developed the *National Program Plan for ITS* (1994) in order to guide the deployment of ITS around the country. The goals of the USDOT ITS program are to:

- Improve the safety of surface transportation
- Increase the capacity and operational efficiency of the surface transportation system
- Enhance personal mobility and the convenience and comfort of the surface transportation system
- Reduce the environmental and energy impacts of surface transportation
- Enhance the present and future productivity of individuals, organizations and the economy as a whole
- Create an environment in which ITS can flourish

Operational tests present opportunities to develop, deploy and evaluate specific implementations of ITS. According to the Federal Highway Administration (FHWA) document, *Generic ITS Operational Test Guidelines* (1993), prepared by The MITRE Corporation, an ITS Field Operational Test (FOT) is a "joint public/private venture, conducted in the real world under live transportation conditions..." that "...serve[s] as [a] transition between Research and Development (R&D) and the full-scale deployment of [ITS] technologies." Thus, FOTs represent a significant step in accelerating the deployment of ITS in North America.

Conducting FOTs results in feedback from the public regarding the viability and perceived usefulness of a specific ITS implementation. This information can be used by the public and private organizations involved to determine the best approach toward full-scale implementation after the FOT is completed. Also, lessons are learned during the conduct of an FOT that will enable the Federal, State and Local governments in partnership with industry and non-profit, academic institutions to bear, conceive, design, develop and deploy an ITS that provides the best possible services to the traveling public.

1.1. SWIFT Project

On September 8, 1993, the Federal Highway Administration (FHWA) published a request for ITS FOTs. The concept for the SWIFT project was submitted in response to this request on January 6, 1994 by the SWIFT Project Team. The SWIFT Project Team proposed to partner with the FHWA to perform an operational test of a wide-area ITS communications system in the

Seattle area. The proposed system incorporated a flexible FM sub-carrier High Speed Data System (HSDS) that had been developed and commercially deployed in the Seattle area by one of the SWIFT Project Team members. The HSDS would be used to transmit traveler information to three receiving devices provided by other SWIFT Project Team members. It was anticipated that the SWIFT Operational Test would provide valuable information regarding the viability of these devices for traveler information systems. SWIFT Project Team members included:

- Delco Electronics Corp., a subsidiary of General Motors Corporation (Delco)
- Etak, Inc. (Etak)
- Federal Highway Administration (FHWA)
- International Business Machines, Inc. (IBM)
- King County Department of Metropolitan Services (Metro Transit)
- Metro Traffic Control, Inc. (Metro Traffic Control)
- Seiko Communications Systems, Inc. (Seiko)
- Washington State Department of Transportation (WSDOT).

On April 6, 1994, the SWIFT proposal was accepted by the FHWA contingent upon the filing of a signed Memorandum of Understanding (MOU) by all SWIFT Project Team members and a Teaming Agreement between the Washington State Department of Transportation (WSDOT) and the FHWA. The SWIFT MOU was signed on October 18, 1994 and the SWIFT Teaming Agreement was completed on January 10, 1995. Following the fulfillment of these requirements by the SWIFT project team, construction of the SWIFT system was initiated.

In addition to guiding the signing of the SWIFT MOU and Teaming Agreements, WSDOT also negotiated separate contracts with the University of Washington (UW) and Science Applications International Corporation (SAIC) to participate in the SWIFT project. The University of Washington was retained to provide data gathering and fusion services for the project, while SAIC was retained as the independent evaluator. In this regard, SAIC signed their contract with WSDOT on September 13, 1994 and UW on November 17, 1994.

As part of the their contract with WSDOT, the University of Washington also developed and demonstrated a dynamic ride-share matching system called Seattle Smart Traveler (SST). SST used the UW Intranet to match ride requests with drivers. Participants registered and requested/offered rides using a web-like page, and riders would be notified of pending rides by email. The project also used 65 SWIFT Seiko MessageWatchs, or pagers, to let riders know where to call to set up a ride. These SST users also participated in SWIFT and received traffic incidents and general-information messages. A separate evaluation of SST was conducted by the Texas Transportation Institute and, thus, the SWIFT evaluation did not address the SST project.

1.2. SWIFT System Description

An overview of the SWIFT system is shown in Figure 1-1, while Table 1-1 lists the primary types of information that were delivered by SWIFT. Each SWIFT receiving device regularly scanned the FM airwaves to identify, retrieve and display the information/messages intended for it.

The SWIFT system was divided into five (5) data components:

- Generation— gathering of the information to be transmitted
- Processing— formatting of the information to be transmitted
- Transmission— broadcast of the information to travelers
- Reception— receipt of the transmitted information by SWIFT devices
- Interpretation— use of the transmitted information by operational test participants.

Each of these are described in the following sections.

Table 1-1. Information Delivered by SWIFT.

Device/Information Received	Traffic Incidents, Advisories, Scheduled Events and Road Closures	Route Guidance	Traveler-Service Information	Freeway Loop-Sensor Information	Bus Locations and Schedules	Time and Date, Personal Paging and General Information Messages
Seiko MessageWatch	Yes	--	--	--	--	Yes
Delco In-vehicle Navigation Device	Yes	Yes	Yes	--	--	Yes
SWIFT Portable Computer	Yes	--	Yes	Yes	Yes	Yes

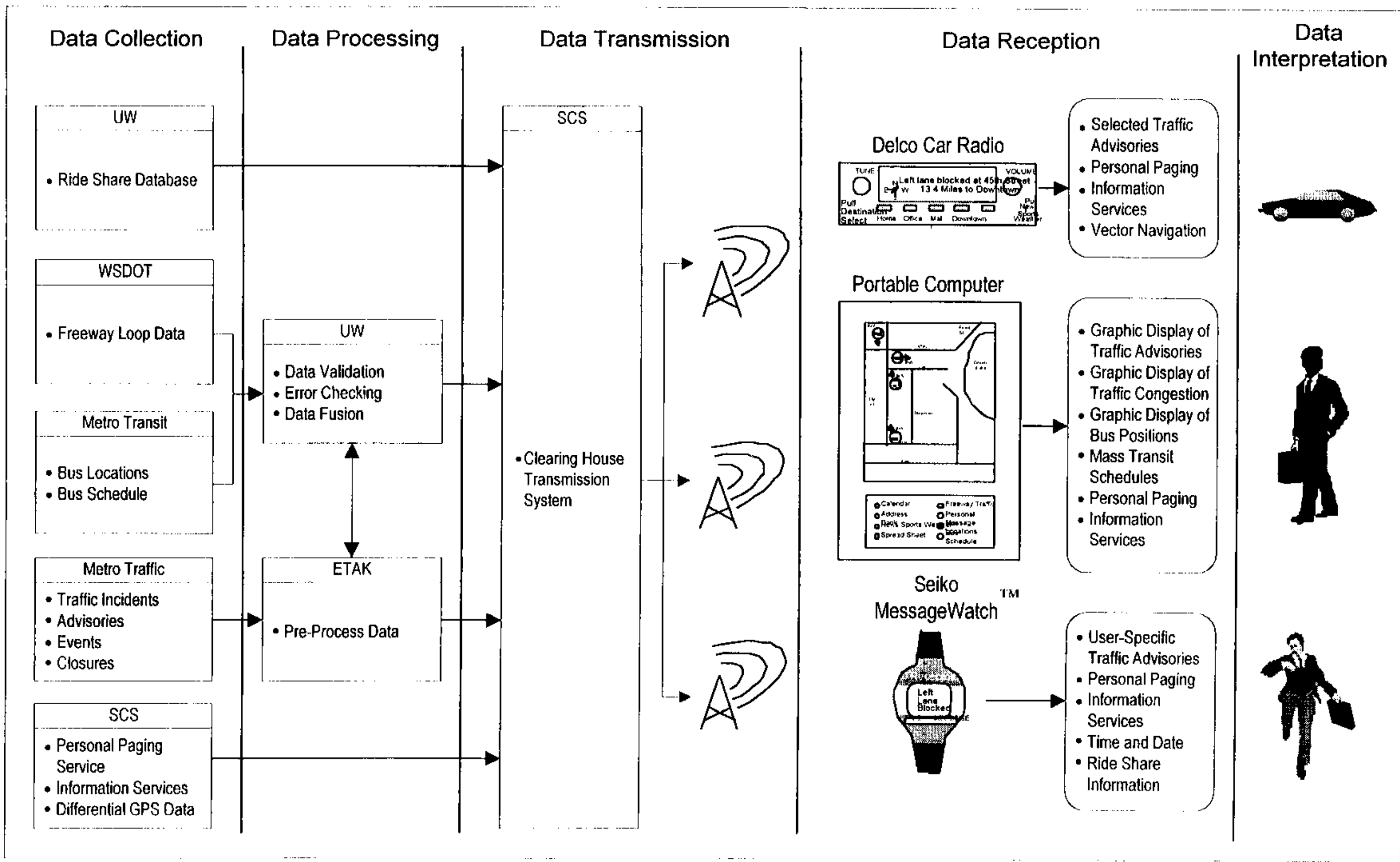

Figure 1-1. SWIFT System Description.

1.2.1. Generation

Table 1-2 provides a listing of the information that was provided to SWIFT FOT participants. This information was generated by Metro Traffic Control, Etak, Delco, WSDOT, Metro Transit and Seiko.

Table 1-2. SWIFT Data Generation.

Data Generator	Data Generated
Metro Traffic Control, Inc.	Traffic Incidents, Advisories, Scheduled Events and Closures
Delco and Etak	Route Guidance
Etak	Traveler-Service Information
WSDOT	Freeway Loop-Sensor Information
Metro Transit	Bus Locations and Schedules
Seiko Communications Systems, Inc.	Time and Date, Personal Paging and General Information Messages

Traffic Incidents, Advisories, Scheduled Events and Closures

This information was generated by Metro Traffic Control personnel who routinely compiled incident information for use in traffic reports delivered to several Seattle-area radio stations. Information, consistent with the International Traveler Information Interchange Standard (ITIS), was entered into a Traffic Work Station (TWS) developed by Etak, Inc. The TWS located the incident and the operator added descriptive information about the incident, such as "truck overturned" or "right lane closed." The TWS then formatted the message for transmission and forwarded it to Seiko.

Route Guidance

As part of the in-vehicle device they developed for the SWIFT project, Delco supplied a route-guidance system that assisted local drivers by providing a directional pointer to pre-selected destinations. This system incorporated a Global Positioning System (GPS) antenna that was placed on the roof of the SWIFT FOT participant's vehicles that participated in this portion of the test, and was tied into a Geographic Information System (GIS) that Etak supplied. Users would select destinations from an "Etak Guide" which contained the latter's geographic coordinates. Users could also enter latitude/longitude coordinates as destinations, save the current positions of their vehicles as destinations and select to receive estimated time of arrival (ETA) information based upon the current speed of their vehicles. The route guidance provided by the directional pointer was static— no turn-by-turn directions were provided, only an arrow pointing in the direction the driver needed to go to reach the destination.

Traveler-Service Information

As indicated, the in-vehicle device for SWIFT provided traveler-service information (i.e., Etak Guide) to its users. This same information was also presented as a "Yellow Pages" directory on the SWIFT portable computers. Users could select the name of local-area businesses or organization by category (e.g., service stations, restaurants, colleges and universities, tourist destinations, etc.) and receive a display of the appropriate address and telephone number in order to guide their travel. Portable computer users could also select to have the locations of their selections presented on the map of Seattle that accompanied the SWIFT application.

Freeway Loop-Sensor Information

Traffic congestion information was derived from the existing WSDOT freeway management system in Seattle. Vehicles were detected with a network of 2,200 standard traffic loops, and UW used the loop information to estimate speeds, which were then expressed as a percentage of the posted speed limit. The speed information was compared to freeway bus speeds to detect any errors. Congestion information was then packaged into a format that could be directly transmitted and sent to Seiko via the Internet.

Bus Locations and Schedules

Bus location and schedule information was provided by King County Metro Transit. Their Automatic Vehicle Location (AVL) system uses small roadside transmitters, wheel (distance) sensors and pattern matching to locate buses in the system. Each location was updated about once every minute and a half. Raw data from Metro Transit's system were sent to UW, where each coach location was converted into latitude and longitude. The UW then generated all of the information including the route and trip number into a format ready for transmission, which was sent to Seiko via the Internet. The SWIFT project included all the fixed routes that Metro Transit operates, or up to 900 buses during peak periods.

Time and Date, Personal Paging and General Information Messages

All SWIFT devices also received and displayed information services currently available to Seiko MessageWatch customers. These included time and date, weather reports, financial-market summaries, sports scores, ski reports and lotto numbers. All SWIFT devices could also function as a personal pager.

1.2.2. Processing

Data generated by WSDOT, Metro Transit, and UW were collated at UW, where it was validated, converted, corrected and fused. Once these activities had taken place, the data were processed into standardized data packets in order to facilitate ultimate transmission over the HSDS. Information provided by Metro Traffic Control was preprocessed on the TWS. All data from UW and Metro Traffic Control were transmitted to Seiko via the Internet.

1.2.3. Transmission

SWIFT data transmission involved sending the processed data to Seiko which formatted the data packets for transmission over the HSDS transmission network. Once formatted by Seiko, the data were transmitted over an FM subcarrier at a rate of 19,000 bytes per second (19 Kbps). In order to increase the certainty of reception by Seiko MessageWatches, double-level error correction and multiple transmissions were used. Otherwise, asynchronous (or broadcast) message sent to the Delco in-vehicle navigation device and the portable computers were sent updated data only once at intervals of 30 to 90 seconds.

Seiko High Speed Data System

The SWIFT project was based upon the HSDS that is currently used to deliver paging and information services to Seiko MessageWatch customers. The HSDS signal is added to standard FM broadcast transmissions in the form of digital data modulated at a frequency 66.5 khz higher than the standard, or "nominal," FM audio signal. No portion of an FM signal, audio or otherwise, is broadcast below the nominal frequency. FM radio signals are usually broadcast in three frequency groups between the nominal frequency and 55 khz above this frequency. Thus, the SWIFT HSDS signal was presented at a frequency that did not interfere with nominal, or standard FM audio, transmissions.

SWIFT HSDS receivers were "frequency agile," which means they could receive messages from any HSDS-equipped FM station. Seven Seattle-area radio stations transmitted the HSDS protocol to SWIFT devices. Consequently, information was sent from all stations in the area which nearly guaranteed reception of important paging messages.

SWIFT information was transmitted three times (once every 1.87 minutes) from each station for the Seiko MessageWatch. Otherwise, for the portable computers and Delco in-vehicle navigation device, congestion information was transmitted every 20 seconds, incident information every 30 seconds and bus information every 90 seconds. This feature of the Seiko HSDS provided information redundancy which further ensured that SWIFT FOT participants were receiving the most current information provided by their receiving device.

SWIFT Message Formats

All SWIFT information was encoded into a version of the International Traveler Information System (ITIS) message-formatting convention. The North American version of ITIS, which was developed by the Enterprise group, is based on message formats used by the European Radio Broadcast Data System (RBDS). The ITIS codes conserve bandwidth by sending incident and congestion information in a compact form. Some customization of the ITIS formats was necessary for SWIFT in order to adjust for HSDS packet size, which is longer than the RBDS packet. Message formats were also developed to send the SWIFT bus location and speed/congestion data, which are not available in the RBDS.

SWIFT traffic-incident information received by the Delco in-vehicle navigation device was integrated with Global Position System (GPS) location and time/date information received by the same device. The latter capability provided the incident-direction/distance information and the current time of day information presented by the Delco in-vehicle navigation device.

Information transmitted to the three receiving devices used in the SWIFT project is presented below:

- Seiko MessageWatch— incident type/direction, roadway affected and closest intersection. Example: A level 3 incident (i.e., accident) on Southbound I-5 is located near the Mercer intersection.
- Delco In-vehicle Navigation Device— incident type/direction, description, roadway/intersection affected, duration and vehicle-reference (in miles) description. Example: An accident blocking the two outside lanes of Northbound I-5, expected to last for the next 15 minutes, is located 16 miles to the Northwest.
- SWIFT Portable Computer— map based icon display/text description (including incident type, roadway affected, direction, closest intersection, backup and duration) of incidents, icon display of real-time bus position, timepoint schedule information, icon display of speed information (i.e., closed, 0-19, 20-34, 35-49, 50+ and no data) and speed icon location description. Example: Vehicles are traveling at 50% of normal speed at the Mercer speed sensor.

1.2.4. Reception

Three types of HSDS-capable receiver devices, each developed and manufactured by private entities through consultation with their SWIFT team members, provided SWIFT FOT participants with incident information, traffic speed/congestion information, bus information, informational messages (e.g., forecast weather, sports scores, stock-market information) and personal pages, depending upon the device. The devices were:

- Seiko MessageWatch
- Delco In-Vehicle Navigation Device
- SWIFT Portable Computer

Figures 1-2, 1-3 and 1-4 show examples of the three receiving devices used for SWIFT. Operational features of each of these devices are described in the following sections.

Seiko MessageWatch

These devices are commercially available and widely used in the Seattle area to deliver personal-paging services and "information service" messages. Current information-service messages include weather forecasts, financial market summaries, local sports scores and winning lotto numbers. SWIFT traffic messages were featured as an added information service.

SWIFT test participants who used the Seiko MessageWatch supplied information to the Evaluator about the usual routes, directions, days and times of the day they traveled. Traffic messages indicating the location and severity of traffic problems that the user might encounter were sent based on the resulting travel profile. Because the Seiko MessageWatch stored eight messages, only traffic problems that resulted in substantial delays were sent.

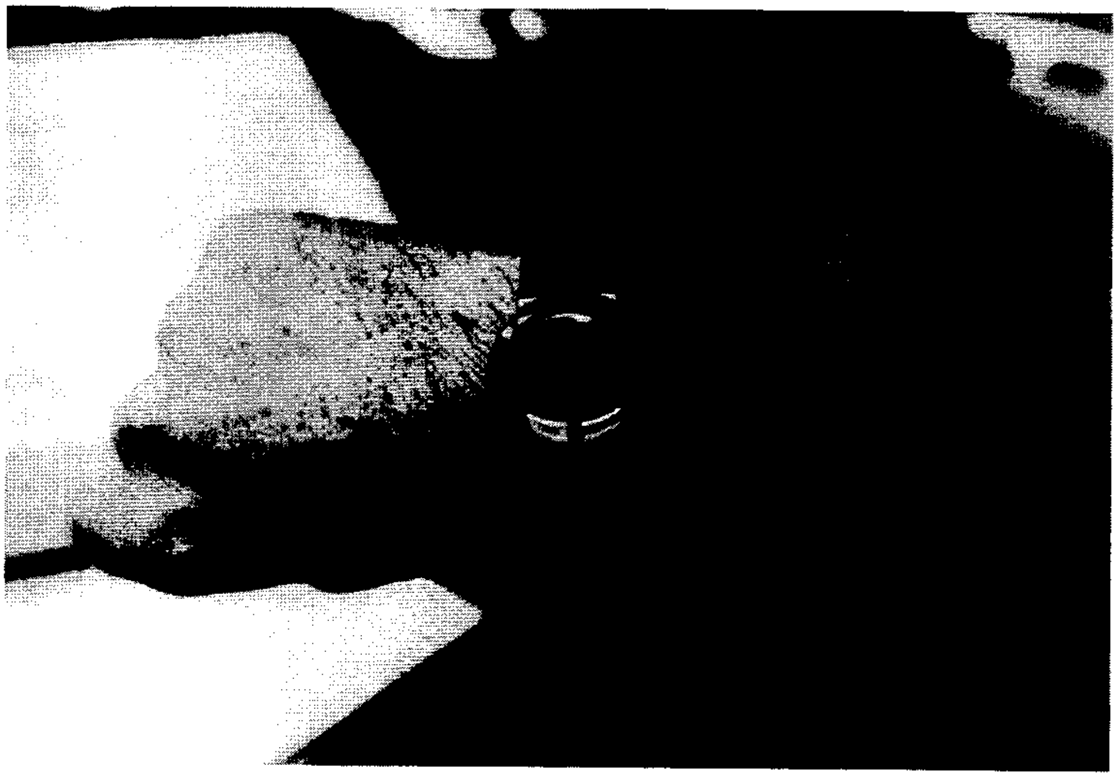

Figure 1-2. Seiko MessageWatch.

Delco In-Vehicle Navigation Device

This device incorporated a route-guidance component, GIS, GPS receiver and the speakers of a radio/compact disc player to present real-time traffic information to users. The whole package was placed into one of four vehicle types: 1995 or newer Buick Regals, Oldsmobile Cutlass Supremes and Saturns, and GMC Rally Vans.

The Delco device included the capability to select destinations from a "Yellow Pages" directory of local landmarks, hotels, restaurants, businesses and street corners selected by the user. The GPS provided the current location of the vehicle and a directional display associated with the route guidance system indicated the direction (relative to the vehicle) and distance to the selected destination. The stereo speakers were used to announce received messages.

Real-time traffic-incident information was transmitted over the Seiko HSDS. The HSDS receiver was built into the Delco in-vehicle navigation device filtered out any messages that were outside a pre-defined distance (e.g., 20 miles) from the current location of the vehicle. The navigation device also decoded upon demand the SWIFT traffic messages from text into a "voice" that provided incident details to the driver. Although messages were retransmitted every minute, only new or modified messages were announced to the driver.

Figure 1-3. Delco In-vehicle Navigation Device.

SWIFT Portable Computer

The SWIFT project primarily used IBM Thinkpad and Toshiba Satellite portable computers. Some Dauphin sub-notebook computers were distributed before they were discontinued due to negative user feedback. The Thinkpads were 486 machines, used Windows 3.1, had a built-in, "butterfly" keyboard and presented information on an active matrix, SVGA color display. The Satellites were Pentium 100 machines, used Windows 95 and also presented information on SVGA color displays.

A separate HSDS receiver unit was attached to the SWIFT portable computer's serial port. This unit had approximately the same footprint as the portable computer and was often attached to the portable computer via Velcro tape. Primary SWIFT information presented on the portable computer included real-time traffic incident, speed/congestion and bus-location information.

All of the traveler information for SWIFT portable computers was displayed using Etak Geographical Information System (GIS) software to show the location of each piece of data. The software allowed the user to select the type(s) of information (i.e., traffic incident, speed/congestion or transit-vehicle location) to be displayed on a map of Seattle. A "Yellow

Pages" directory was also installed and linked to the GIS software to show the location of a selected business or point of interest. SWIFT portable computers also offered transit schedule information from static database tables inside the computer.

Figure 1-4. SWIFT Portable Computer and RRM.

1.2.5. Data Interpretation

The data interpretation portion of the SWIFT system involved hypothesized processes that affected how users were able to interact with the system. Among those user perceptions that were addressed were the following :

- Data Reception— whether SWIFT information was received
- Data Timeliness— whether SWIFT information was received in a timely fashion
- Data Reliability— whether SWIFT information was regularly received
- Data Display— whether SWIFT information was displayed appropriately
- Data Fidelity— whether SWIFT information was accurate
- Data Validity— whether SWIFT information affected travel behavior.

1.3. SWIFT Field Operational Test Evaluation

Once the SWIFT system was completed, an FOT was conducted with approximately 690 users who were recruited from the community in order to assess the system. With the majority of the SWIFT system completed by June 30, 1996, the SWIFT FOT evaluation was conducted from

July 1, 1996 through September 20, 1997. The goals of the SWIFT FOT evaluation, listed in order of priority, were to evaluate:

1. *Consumer Acceptance, Willingness to Pay and Potential Impact on the Transportation System* – determine user perceptions of the usefulness of the SWIFT receiving devices, how much consumers would be willing to pay for such devices and services and assess how SWIFT-induced changes in users' driving behavior might impact the Seattle transportation network if the SWIFT system was fully deployed.
2. *Effectiveness of the HSDS Transmission Network* – determine how well the SWIFT HSDS communications system functions.
3. *Performance of the System Architecture* – determine how well the various SWIFT components work singularly and together.
4. *Institutional Issues That Affected the Operational Test* – identify how institutional factors associated with the SWIFT public-private partnership affected the FOT, with emphasis on implications for deployment.
5. *Deployment Costs* – estimate how much money it would take to deploy and maintain a SWIFT-like system.

Five evaluation studies were conducted as part of the SWIFT FOT evaluation. These studies paralleled the five SWIFT FOT evaluation goals and were implemented at various times during the 15-month test. Table 1-3 provides a summary of SWIFT evaluation information.

As part of the conduct of the SWIFT FOT evaluation, the Evaluator was responsible for user recruitment. This involved the recruitment of approximately 1,200 individuals before selection of the 690 FOT participants was made. The final breakout of SWIFT participants is shown in Table 1-4.

Selection criteria for each category of SWIFT user varied, primarily depending upon the assumed operational requirements for each device type. As a result, three types of Seiko MessageWatch users (i.e., existing [i.e., those who owned their own watches], new [i.e., those who were given a Seiko MessageWatch for the first time] and SST [i.e., those who participated in the SST program] and two types of Delco in-vehicle navigation device users (i.e., new [i.e., SOV commuters] and Metro Transit Van Pool [i.e., HOV commuters] were recruited. The majority of the eighty (80) SWIFT portable computer users were bus riders with mode-choice options.

The SWIFT FOT Evaluator was also responsible for the following activities:

- Device configuration/software installation
- Device distribution/installation scheduling
- Training/instruction on device usage
- Travel profile entry/maintenance
- SWIFT Help Desk
- User problem analysis/feedback to team members
- Device collection/de-installation

SWIFT newsletter (writing, publication and mailing; WSDOT responsible for editing and breadboarding).

Table 1-3. SWIFT Evaluation Information.

Study/ Activity	Study Leader	Test Plan Completion Date	Primary Data Collection Periods	Primary Data Collection Methods	Final Report Completion
Consumer Acceptance	Jeff Trombly	August 19, 1997	Spring, Summer and Fall, 1997	Question-naires, Telephone Surveys, Focus Groups	March 31, 1998
Communications	Jim Murphy	August 19, 1997	Fall, 1997	Field Tests	June 29, 1998
Architecture	Hesham Rakha	August 19, 1997	Spring, 1997	Data logging and Field Tests	March 31, 1998
Deployment Cost	Mark Jensen	August 19, 1997	Summer, 1997	Data Collection	March 31, 1998
Institutional Issues	Bruce Wetherby, Principal Investigator	August 19, 1997	Spring and Fall, 1997	Questionnaires and Semi-structured Interviews	March 31, 1998

Table 1-4. SWIFT Participant Breakout.

Device/Condition	Existing	New	Metro Transit Van Pool	SST	Total
Seiko MessageWatch	50	400	--	70	520
Delco In-vehicle Navigation Device	--	65	25	--	90
Portable Computer	--	80	--	--	80
Total	50	545	25	70	690

2. STUDY RESULTS

This section presents brief overviews of the five studies conducted under the SWIFT Evaluation project. These brief descriptions address study objectives, methods, and results.

2.1. SWIFT Consumer Acceptance Study

Purpose of Study. The *SWIFT Consumer Acceptance Study* was one of five component studies to the overall system evaluation. This report details the findings for the *SWIFT Consumer Acceptance Study* based on the evaluation objectives that were identified in the SWIFT Evaluation Plan (1995). The primary objectives of the *SWIFT Consumer Acceptance Study* were to assess the following:

- Importance of traveler information in travel planning
- Usefulness of SWIFT traveler information in travel planning
- Minimum set of user services and device features required to provide viable product and services
- User perceptions of SWIFT device usefulness
- Willingness-to-pay for different services.
- User perceptions of changes in travel convenience and efficiency
- User perceptions of changes in traffic congestion, air quality, energy consumption, and safety.

Additional *SWIFT Consumer Acceptance Study* objectives, conducted in support of the *SWIFT Architecture Study*, were to assess the following:

- SWIFT system reliability from a user perspective
- SWIFT system availability from a user perspective.

Methods. A variety of data-collection efforts were completed, including questionnaires, focus groups and telephone interviews. The questionnaires contained items that addressed objectives set out in the evaluation plan. The focus groups were conducted with small groups of users to obtain qualitative impressions from a smaller subset of users who were encouraged to speak openly and share their perceptions with other users.

The *SWIFT Consumer Acceptance Study* focused on measurement and analysis of user perceptions toward SWIFT system usefulness and performance. No attempt was made to quantify the system level impacts of SWIFT services on congestion, air quality, energy consumption or safety in the Seattle region. Rather, the assessment of system-level transportation impacts was limited to examining subjective data (e.g., traveler's perceptions) collected from users and determining whether these perceptions were consistent with a benefit.

2.1.1. Perceptions of Importance of Traveler Information

Results indicated that SWIFT users tended to place a high degree of importance on incident and congestion-related information in travel planning. Incident location and duration information was rated quite high in importance along with general traffic congestion information. For the group as a whole, information concerning bus schedule and route information and bus-location information was rated very low in importance, although these ratings were much higher in those users that actually used the bus. This was consistent with the automobile dependence reported by the group, and suggests that information concerning non-automobile options would not be used by the automobile-dependent group. Since users of the SWIFT portable computer were recruited from among transit users, this group generally rated transit information higher than other device users groups. However, the importance of this information was not as high as congestion and incident-related information.

Receipt of various general-information messages was not rated very high in importance by questionnaire respondents, with the exception of weather, sports and news items. Most SWIFT respondents indicated that the receipt of financial and other environmental information was not important. Of course, from a transportation-impact point of view, the receipt of these general-information messages was inconsequential. However, if device users were attracted by these messages it may make such services commercially viable to augment any potential benefit perceived by users through the receipt of travel-related information.

2.1.2. Perceptions of SWIFT Traveler Information Usefulness

Users tended to view the messages they received from the SWIFT systems as accurate, reliable, timely, easy to understand and useful. Among device types, respondents representing users of the Seiko MessageWatch expressed concern with the timeliness of incident-related messages. In addition, these respondents tended to rate ease of understanding lower than other user groups. Users of the Delco in-vehicle-navigation devices and SWIFT portable computers experienced problems in receiving personal-paging messages and these problems were reflected in respondent ratings.

The map-based display provided by the SWIFT portable computer resulted in generally higher ratings for this device over other devices in understanding incident location and the nature of congestion. Seiko MessageWatch users reported difficulty in understanding the extent of expected delay as well as the nature of congestion, while Delco in-vehicle-navigation device respondents reported difficulty in understanding the period of time for which a message applied.

Generally speaking, SWIFT participants endorsed a wide-range of improvements to messages provided by the SWIFT system. Most seemed to consider the operational test as a suggestion of what might be possible, rather than a demonstration of a final product. Among Seiko MessageWatch users, respondents expressed a desire for improved timeliness of messages as a top priority. Delco in-vehicle-navigation device respondents endorsed the need to develop route-specific messages and SWIFT portable computer respondents expressed a desire to cover more roads as a high-priority improvement.

2.1.3. Perceptions of Desired Services and Features

An examination of user perceptions regarding the physical and operational performance of their SWIFT devices reveals the following:

Delco in-vehicle navigation device— respondents reported a high level of satisfaction with the physical characteristics of the device. The most frequently encountered problems included difficulty in operating the message-filtering feature and difficulty in reading the monitor in sunlight. Respondents expressed a high level of dissatisfaction with the personal-paging feature and were somewhat neutral toward the voice sound "reading" messages. Respondents, however, did not perceive the "voice" announcement of messages a safety concern. Respondents endorsed a number of improvements to the unit features and operation, including the addition of a map-based display, provision of route-specific information and alternative-route information.

Portable Computer— results indicated that users were extremely dissatisfied with the Dauphin device both in terms of physical and operational characteristics. The IBM and Toshiba Portable Computers were rated more positively, but in general respondents were dissatisfied with the size and weight of the devices and the design of the communications connection (i.e., separate SWIFT portable computers and RRMs connected by a serial cable). Respondents using the IBM and Toshiba rated the information display feature of these devices quite high (in particular, the map information provided), and generally endorsed the need for a smaller, lighter and more portable device with an easier communications connection.

Seiko MessageWatch— Respondents rated the physical and operational characteristics of the device very high. However, improvements to the message display, including background lighting and message encoding, were recommended. Respondents endorsed a need for a full alphanumeric display, more storage capability, and different types of bands. Finally, respondents found travel profiles easy to use but quite limiting in some cases. Respondents suggested that on-line update capability would provide the flexibility to maximize the usefulness of profile data.

2.1.4. Perceptions of SWIFT Usefulness

Participants were clearly making use of the SWIFT information for travel planning. The results indicated that most users were consulting their devices to make travel-related decisions at least weekly. The results indicated that many device users relied upon commercial broadcasts as a first choice in trip planning with the SWIFT device used as a primary source for a significant number of participants. Users of the Seiko MessageWatch and Delco in-vehicle-navigation device found their devices to be convenient, comfortable, safe and easy to use. Users of the SWIFT portable computer generally rated their devices lower in these areas.

2.1.5. Perceptions of Willingness-to-Pay

SWIFT participants were eager to maximize opportunities to avoid congestion and improve travel convenience, safety and efficiency. Therefore, given some improvements in the service, they expressed a willingness to pay for the service. In focus groups, estimates of the value of SWIFT service tended to range between $5 and $10 per month. In questionnaires, willingness-to-pay was derived by asking participants to compare the value of other services with that of SWIFT. In this comparison, SWIFT was viewed as more valuable than on-line services (e.g., MSN, America On-line), satellite television, and 4-hours of parking in downtown Seattle. Traffic information on the radio was rated higher in value than SWIFT and similar to telephone voice mail and cellular phone service. Based on this comparison of value with other products and services, it was concluded that users might be willing to pay up to $20 per month for a SWIFT service

2.1.6. Perceptions of Changes in Travel Convenience and Efficiency

Users tended to perceive that SWIFT services allowed them to reduce stress and commute times, and allowed them to "keep moving." Reducing travel distance or changing means of travel were not viewed as major benefits. User of transit-related information stated that the SWIFT services provided them an opportunity to improve transfers, reduce stress and stay inside while waiting for the bus.

Users reported that radio traffic reports, actually encountering the incident, and SWIFT travel messages were key factors in influencing route choice decisions on a weekly basis. In the majority of cases, commuters implemented route-changing behavior to avoid congestion and did not report frequent mode changes in response to congestion.

Portable computer users were surveyed twice near the end of the SWIFT FOT regarding their use of real-time transit information. In these two surveys, one a telephone interview and the second a written questionnaire that was completed upon device return, 54% of the surveyed SWIFT portable computer users, on average, indicated that they used the real-time bus information. Of this group, 94% indicated that the display of this information was useful, while 81% indicated that the bus timepoint information was useful.

Regarding the specifics of their use of real-time SWIFT bus-location information, 33% of the respondents indicated that they used this information to monitor more than one bus route at a time. 2.2 was the average number of buses that were reported to be monitored at the same time by this group. Note, however, that for SWIFT, only one bus could be displayed if timepoint information was simultaneously displayed— thus, use of SWIFT timepoints necessarily restricted the use of real-time SWIFT bus-location information to monitor more than one bus at a time. Nonetheless, 18% of those SWIFT users who displayed real-time bus positions reported that this information was helpful in making transfers more convenient. These findings suggest that real-time bus position information was useful for making transfer decisions (e.g., when to get off their current bus in order to transfer to a bus that will take them more directly to their destination) among those who monitor more that one bus at a time.

Other findings regarding the use of real-time SWIFT bus-location information indicated:

- 50% used the information to monitor the arrival of buses
- 50% said it caused them to take alternative transportation modes (which direction, bus to vehicle or vehicle to bus, was not specified)
- 38% used the information to help them decide what bus to take
- 36% said the information made them feel less anxious about waiting for a bus

- 31% said it helped reduce bus-wait times
- 18% (corroborating earlier-reported results) reported that it helped them make bus-transfer decisions
- 12% reported that it increased their bus ridership

Regarding the use of the other information that was presented on the SWIFT portable computers, in addition to the real-time, bus-position data, SWIFT participants indicated that 78% used the congestion, or speed-flow, information; 54% used the traffic incident information; 49% used the street-address-search feature; 46% reported that the SWIFT map display helped them find alternative routes of travel; 40% used the "Yellow Pages" feature which provided telephone and address information for local businesses and organizations; and only 3% reported using the general information message and paging features of the system.

The high-level of dependence on SWIFT congestion, or speed-flow, information by SWIFT portable-computer users suggests that this information is very useful for making transit-related decisions, such as deciding whether to take the bus, which bus to take or when to take the bus. The low-level of reported usage of the SWIFT general-information messages and paging service was due to the fact that these services were generally not available for the majority of the SWIFT portable-computer users throughout the field operational test due to technical difficulties.

2.1.7. Perceptions of Changes in Traffic Congestion, Air Quality, Energy Consumption, and Safety

Participants perceived a number of benefits as a result of widespread use of the SWIFT services, including avoiding congestion, making better use of time, planning better routes, reducing stress, and saving travel time. Focus group participants were hopeful that widespread use of SWIFT services would reduce congestion and commute times.

2.1.8. Perceptions of System Reliability

Users generally found the devices to be reliable. Seiko MessageWatch users reported the highest reliability rates followed by Delco in-vehicle navigation device users, and SWIFT portable computer users. In focus-group discussions, SWIFT portable computer users expressed a concern with the signal connection and the receipt of general-information messages. These perceptions were due to technical problems associated with the receipt of general-information messages by these devices.

2.1.9. Perceptions of System Availability

Participants generally perceived that the SWIFT system was available. High terrain and being inside buildings appeared to have the greatest impact on receipt of messages for portable computer users. Users of the Delco in-vehicle-navigation device reported problems in receiving messages while in parking garages. Users of the Seiko MessageWatch reported few problems with the receipt of messages.

2.1.10. Conclusions.

The SWIFT FOT was a successful demonstration of HSDS technology for presenting ATIS data to travelers in a large, congested metropolitan area. Three types of traveler information were sent to three groups of SWIFT FOT participants with a reasonable degree of reliability.

SWIFT FOT participants generally viewed SWIFT as a beta—or proof of concept—test rather than a test of a finished product. Nonetheless, most indicated that they found the traveler information to be useful, incorporated it to make travel decisions and came to rely on it. Overall, the conclusions that can be drawn from the SWIFT FOT include the following:

- SWIFT was important for travel planning—the majority of users, regardless of device type, indicated that they found traffic incident and congestion information to be very important for making travel decisions.
- SWIFT was useful for travel planning—most participants, including those receiving the real-time bus-position information, indicated that they found the majority of the information presented by SWIFT to be useful for making travel decisions, such as what road/bus to take, what time to leave, etc.
- SWIFT had many desired features, but many suggestions for improvement were offered. Among those provided were to improve message timeliness, provide route-specific messages, improve accuracy, tell when an incident occurred and provide messages when the system goes down.
- SWIFT devices were perceived as useful, although improvements in portability were suggested for the portable computers, in particular.
- SWIFT participants indicated a willingness to pay of between \$5.00 and \$20.00 per month for a service that incorporated several improvements to timeliness, accuracy, reliability and convenience
- SWIFT users indicated that information provided by the system primarily helped them to "keep moving," "reduce my stress level" and "reduce my commute time." Others indicated that the information helped them change commute routes, change commute times and saved them time by assisting with the monitoring of bus arrivals.
- SWIFT was viewed as assisting, or improving the following: congestion, time utilization, route planning, stress levels and travel time.
- SWIFT was viewed as a reliable system—93% of Seiko MessageWatch users viewed the system as being available 75-100% of the time, while 79% of Delco-in-vehicle-navigation device and 44% of SWIFT portable-computer users made this attribution.
- SWIFT was viewed as being an available system, but one that was affected by buildings and terrain, particularly the SWIFT portable computers.

2.2. Communications Study

There were four (4) objectives of the *SWIFT Communications Study* testing in Seattle: (1) determine the basic capability of the HSDS subcarrier to deliver ITS information; (2) assess Received Signal Level (RSL), Bit Error Rate (BER) and Packet Completion Rate (PCR) at pre-selected field-test sites; (3) determine the existence of multipath radio signals due to reflection(s) off surrounding terrain and structures; and (4) assess in-building message-receipt probability. The reason items 2-3 were assessed was to determine possible causes of missing messages or delays in receiving them (i.e., low signal level, multi-path interference and in-building attenuation).

In order to select the most productive subset of test locations, the results of the a survey question asking where users experienced communications-coverage problems and the problem reports logged with the SWIFT Hotline were used as major inputs to this process. In addition, information previously gathered by the firm of Hatfield & Dawson, Consulting Engineers, during their earlier (1995) tests for FM channel interference by the Seiko messaging system, were also a factor in the decision process. Although H&D were primarily concerned with measuring the distortion induced into the FM entertainment channel by the Seiko HSDS messages, they also noted a number of locations that exhibited high levels of multi-path distortion in the HSDS signal.

2.2.1. Methods

The *SWIFT Communications Study* field tests were conducted during the week of July 28 to August 2, 1997 and data was collected at eight (8) field test locations using Seiko MessageWatch and RRM devices to receive pre-determined messages from the Seiko HSDS system. Test sites were selected where reception problems were anticipated; that is, the test locations were suspected problem sites. A number of methods were used to measure the coverage/performance of the SWIFT system at the test sites. In order to obtain both technical and operational measurements, the test suite included both the SEIKO MessageWatches and two laptop portable computers with RRM adapters. Test instrumentation included:

- An HP-8965E Spectrum Analyzer, which was used to provide accurate, calibrated measurements of received signal level (RSL) from the FM transmitters at each of the test sites. It was also used to measure the 'noise-floor' adjacent to the transmitter's channel. This measurement was used to calculate a signal/noise (SNR) measurement from a specific transmitter, which can be correlated to the bit error rate (BER), as well as the packet completion rate (PCR). The spectrum analyzer was also used to measure the variation in the signal level as a function of time. Large variations in received signal level, greater than 3-4 decibel (dB), are an indicator of multi-path signal propagation.

- The TREQ Monitor is a piece of portable Seiko test instrumentation, used by their field technicians to measure and evaluate the reception characteristics at a site. In use, it is locked to the frequency of one of the transmitters in the system, and consequently doesn't employ the channel selection algorithms incorporated in the Message Watch and RRM. For each transmitter, the unit records the RSL, BER, PCR and level of error correction that was necessary. This information is presented on a monitor, and can be saved as snapshot images for further analysis. The TREQ was the major source for technically detailed information on the reception performance for each channel and the calculation of BER/PCR rates.

- At each location global positioning system (GPS) information, received signal levels (RSL), delta RSL, bit-error-rates (BER), packet completion rates (PCR), base-band spectrum levels, and noise levels as well as test message data from 2 RRMs, 6 Seiko MessageWatches and a Seiko TREQ monitor system were collected. This information was recorded for each of the seven (7) HSDS broadcast stations supporting the SWIFT program in the Seattle area.

Results Detailed analysis of the user questionnaires and focus group reports indicated that the majority of SWIFT users, approximately 93%, reported no communications problems with the SWIFT HSDS. Thus, the Seiko HSDS worked quite effectively for the purposes of the SWIFT FOT evaluation.

Analysis of communications problem reports indicated that there were concentrations of areas where SWIFT message-reception problems existed. Four geographic locations (i.e., Downtown Seattle, University District, Redmond and SeaTac) contained concentrations of reported in-building message-receipt problems, while three areas (i.e., Everett, Federal Way and Tacoma) contained the greatest concentrations of outside message-receipt problems. In-building message-receipt problems were localized at the University of Washington in the University District and at Microsoft in Redmond.

Field testing was conducted at eight outdoor sites that were previously identified as possible locations where there may be message-receipt problems. One outdoor test site (i.e., Everett) was the same as one of the three primary locations were SWIFT participants reported problems receiving messages. Otherwise, indoor testing was also conducted at one site (i.e., Shoreline). Summary results for on-site testing indicated that for Site #1 (Bellevue), the BER and PCR were extremely good except for the most distant stations, KAFE and KBTC. Site #2 (West Seattle) faired much poorer, being able to receive messages from only one station, KCMS, which was directly across the water from the test site. Site #3 (SeaTac) exhibited reasonable BER and PCR performance from four out of seven HSDS signals, while Site #4 (Everett) was assessed to have an extremely harsh multi-path environment which could be mitigated somewhat by using a directional antenna to reduce reflected off-axis signals. Site #6 (Shoreline) exhibited problems with all but one station, KCMS where it was believed that the closeness to the transmitter resulting in a high RSL caused the devices to immediately lock onto this station. This could also explain the good performance experienced with KCMS at site #7 (Downtown Seattle), which was somewhat closer to this station and without obstructions than any of the other stations. Data collected at site #5 (South Seattle) through #8 (Puyallup) showed typical results, based on the area topography and confirm the user reports of problems. Thus, sites #4 (Everett) and #6 (Shoreline) were probably the worst performers of the lot. It should be noted that reception from only one station is required to receive messages. Despite test sites being problem sites, the Seiko MessageWatch received messages at all but one site.

The RSL measurements made as part of these tests tracked reasonably well with the predicted contours produced by Seiko. While the predicted levels were sometimes higher that those measured, the correlation was strong enough to support using the RSL contours for HSDS system coverage planning and transmitter site selection. Plots of BER and PCR as a function of RSL, produced from the test results, indicated that the error rate and minimum signal level quoted in Seiko's specifications were valid. There was, however, a strong suggestion that while sufficient RSL is necessary to successfully transmit messages at a particular location, it is not by itself a sufficient indicator of message-delivery success.

At least two sites were found to have a significant impact of the BER/PCR due to multi-path interference. In an area topographically prone to the creation of multi-path interference, such as Seattle, the use of RSL predictions alone were determined to be an inadequate measure of ultimate system performance. In other words, while a predicted RSL contour may indicate that a receiver should be able to lock onto several available HSDS signals, multi-path may render many unusable, despite more than an adequate RSL.

In building tests showed a significant overall drop off in RSL for locations A and D, this measured reduction in RSL of greater than 50 dB results in a corresponding decrease in PCR from 100% to approximately 65%, as well as a serious increase in BER from 10-6 to 10-2. What is even more important about the outcome of this test series is that the HSDS station (KCMS) used for this test is approximately 1.8 miles Northwest of the TSMC facility and has an extremely strong signal.

2.2.2. Conclusions

The SWIFT FOT was a success from a communications point of view. Analysis of user-reported problems with receiving messages indicated that the HSDS performed within predicted estimates provided by Seiko. That is, approximately 93% of all users reported that they experienced no problems receiving messages. In addition, field measurements of RSL, BER and PCR confirmed that the system performed within specifications, although the receipt of messages in some test locations appeared to be influenced by multi-path factors. In particular, the existence of multi-path appeared to degrade slightly the receipt of messages and measured BER and PCR levels at two sites. Finally, in-building receipt of messages was impacted by the distance a receiving device was located inside a building. Nonetheless, in-building degradation of message-receipt is a normal performance characteristic of an HSDS and one in which the environmental factors (e.g., building structures, antenna design) contributing to this effect are not completely known.

In summary, the *SWIFT Communications Study* documented the successful performance of an HSDS that was fielded in conjunction with a deployed ATIS in the Seattle, WA area. This conclusion is supported by the data that was collected during the conduct of this evaluation.

2.3. System Architecture

The *SWIFT Architecture Study* is one of five component studies to the overall system evaluation. Four evaluation objectives are identified in the *SWIFT Architecture Study* test plan. The first two of these objectives relate to the system performance when the system is operating according to its functional specifications, and is essentially free of any component failures. In contrast, the third and fourth objectives focus on what happens when part of the system becomes unavailable due to system component failures. For each of these conditions, the performance of the architecture were examined from both the user (objectives 1 and 3) and system (objectives 2 and 4) perspective.

In evaluating these four objectives, the *SWIFT Architecture Study* not only attempted to establish the consistency of user perceptions with the actual system performance, but also attempted to identify the operational characteristics of the system that were not recognized by the SWIFT field operational test participants. Furthermore, this study attempted to identify the source of any architectural limitations that were observed by the FOT participants. Finally, it focused on evaluating the SWIFT architecture for conditions that contributed to the system not operating as intended.

This section summarizes the findings of the *SWIFT Architecture Study* for each of the three reception devices that were tested during the field operational test before evaluating the issue of system expandability and transferability.

2.3.1. Seiko MessageWatch Device Findings

The Seiko MessageWatch device users rated the receipt of traffic incident and congestion messages high, however, the ease of understanding and the timeliness of incident information was rated the lowest of all characteristics across all devices. The usefulness of information, the reliability, and accuracy of information were rated the highest for all devices. Incident type information was generally rated lower than either incident direction or incident location information. In terms of device usability, the ability to decipher some of the messages was rated the lowest, however, in general the users perceived the device to be usable.

The field tests that were conducted as part of the architecture evaluation demonstrated that apart from some rare incidents (0.1 percent), delay within the system prior to transmission was less than 600 seconds (5 minutes). On average, verifying and inputting incident information required 90 seconds. Messages required, on average, 3 minutes between incident notification and final display on the Seiko MessageWatch device. Limitations in the architectural design of the Seiko MessageWatch device resulted in larger delays relative to the other devices (on average 800 percent higher). These delays were found to increase when the message spacing was less than 5.5 minutes. The high delays associated with the Seiko MessageWatch device resulted in the lowest ranking in data timeliness by the device users (based on questionnaires). This limitation was attributed to the design of the system architecture.

In terms of data accuracy, the duration of an incident, after visually verifying the existence of an incident, was estimated using human judgment and in most cases was set to level 1 (15-minute duration). Research has been conducted, and continues to be conducted, in the area of Incident Management in order to develop techniques that estimate incident durations more accurately based on historical incident data. The use of such techniques could potentially improve the accuracy of estimating the incident duration. Interestingly, the lack of a scientific basis in defining the incident information appeared to have a direct bearing on the low rating that users placed on this information. Alternatively, because the location and direction of the incidents did not require any forecasting techniques, the use of police reports and visual inspection was sufficient to provide accurate information. Consequently, the questionnaire participants ranked this information high. The low accuracy in accident duration estimation is related to the implementation phase of the system architecture.

The device usability test demonstrated that the Seiko MessageWatch device was easy to use and thus was rated high by the users. Although, the device usability test demonstrated that the users managed to decipher 91 percent of the messages, some rare messages were extremely difficult to decipher. Again, this finding is consistent with the user perceptions as identified in the questionnaires and focus groups. The limited graphical display of the Seiko MessageWatch device (related to design phase) resulted in some problems in terms of deciphering messages.

2.3.2. Delco In-vehicle Navigation Device Findings

The questionnaire results indicated that the Delco in-vehicle navigation device users were generally satisfied with the device color, size and styling and least satisfied with the message display size, illumination of buttons, and message display background lighting. Furthermore, the Delco device users were not satisfied with the timeliness of messages and the directional information for incidents. Finally, the Delco device users were found to be less likely to change their commute start time and mode of travel than other device users.

In terms of device usability, the results of the usability field test do indicate some problems in completing standard tasks (71 percent completed). The results of the questionnaires do indicate some concern regarding the usability of the device in terms of the illumination of the buttons and the message display lighting. These limitations are attributed to the design of the device.

The field tests demonstrated that verifying and inputting incident information required 90 seconds, on average, and required 100 seconds (approximately 2 minutes) between incident notification and final display on the Delco device. Clearly the delay associated with this device is lower than the delay associated with the Seiko MessageWatch device. The concern the questionnaire participants placed on the timeliness of the information could be attributed to the inconsistency of voice announcement for messages (field tests indicated that only 35 percent of the messages were confirmed). This problem is attributed to the implementation phase of the system architecture.

The low rating that the Delco in-vehicle navigation device users placed on the incident duration information is consistent with how the Seiko MessageWatch device users perceived the information. As discussed earlier, this architectural limitation is attributed to the implementation phase of the system. Noteworthy, is the fact that the Delco device users, unlike the Seiko MessageWatch device users, rated the accuracy of the incident direction as low. This low rating is attributed to a technical problem that resulted in the device reversing the direction of incidents (e.g. northbound indicated as southbound). This problem is a result of a problem in the system implementation as opposed to a problem in the system design.

The questionnaire results indicated that Delco device users were less likely to change their commute start time and mode of travel than other device users. This finding is consistent with the fact that the Delco device was the only in-vehicle device. As such, the users would not be able access the information until they entered their vehicle, unlike the other devices where they could access the information prior to entering their vehicle. Consequently, it is only natural, given that the person is in his/her vehicle, that they would be less likely to alter their time of departure and/or their mode of travel.

2.3.3. PC-Device Findings

The questionnaires and focus groups demonstrated that a high percentage of the PC-device participants used a combination of modes including bus, vanpool and carpool on their travel to work (57 percent). Consequently, in comparing the responses of the different device users one has to also bear in mind that the PC-device users had different travel characteristics than did the other device users.

The questionnaires and focus groups demonstrated that PC users placed a high amount of importance, relative to other users, on the receipt of traffic incident and congestion information and much less importance on general information, personal paging, and rideshare information. In general, the PC-users rated personal paging and general information messages low because the services were not consistently available to users as a result of some technical problems in message delivery. Incident duration information was also rated low along all message attributes. Other incident related information was generally rated quite high, as was traffic congestion and bus schedule/time point information. Bus position information was found to be easy to understand and useful by respondents. However, this information was rated low both in terms of reliability and accuracy. PC focus group device participants expressed a concern with the reliability of the signal connection.

The low rating in terms of the incident duration information is consistent with what was observed by the other device participants. This problem was attributed to the implementation of the system architecture.

In terms of the traffic speed data, the field tests and the user perceptions demonstrated that the data were fairly accurate. Specifically, field tests verified that 50 percent of the data were in a speed category that was consistent with the conditions in the field.

The field tests and user perceptions were consistent in ranking the reliability of the transit data as low. Specifically the field tests indicated that, on average, 30 percent of Metro Transit's buses were missing from the SWIFT data. The accuracy of the data was found to be within 500 meters, on average. This accuracy is much lower relative to what was claimed by the system developers. The system developers found the AVL system to be within 90 meters of its actual location for 95 percent of the time, and to be within 160 meters of its actual location for 99 percent of the time. The low ranking of accuracy is attributed to the use of the less sophisticated sign-post technology as opposed to GPS.

The field tests and questionnaire results indicated problems with the RRM. These problems were attributed to the design of the system.

2.3.4. System Expandability and Transferability

The components of the architecture that are related to data surveillance and collection all feed Seiko Communications Systems with a variety of traffic and/or transit data. This component of the architecture, which involves the nodes at Washington State Department of Transportation (WSDOT), the University of Washington, Metro Traffic Control, and Metro Transit, are virtually independent of the number of customers. Instead, the load on these components, as well as the links between them, are controlled by the size of the area that is under surveillance.

In order to expand the system on the freeway side, a larger percentage of the road network would need to be equipped with loop detectors. This represents a moderate cost, only partially because of the hardware involved. The bulk of the costs associated with expanding the number of loop detectors is in the installation cost, the traffic disruption costs during installation, and the linkage of the loops back to WSDOT's control center. In contrast, the increased cost of putting the expanded bus network under surveillance would primarily be tied to the purchase of autonomous navigation units for each new bus. The bus control center would likely be able to handle more equipped vehicles at only a moderate increase in cost.

The amount of data processing that would be required at each of the nodes leading up to the Seiko distribution center would similarly increase in a linear fashion, but the inclusion of additional and/or faster computers should be able to accommodate these requirements at a moderate cost. The need for increased data communication capacity, up to the Seiko center, could similarly be accommodated quite readily using modest increases in costs, as all of these costs are primarily related to land based communications. Land based communications are, in general, not only cheaper but also have much higher capacity reductions. The only exception to this relates to those communications that currently take place over the Internet. In this case, dedicated lines could be added.

The communications from the Seiko Communications Systems onwards are still tied to some extent to the size of the area that is under surveillance. However, in some of the system's services, capacity issues are tied more closely to the number of users. Specifically, some of the SWIFT services rely on strictly a one-way broadcast. In this case, the communications load is independent of the number of users. However, in some cases, the communications load is a direct function of the number of users, as user-specific messages are broadcast.

The SWIFT system as it existed in the field operational test transmitted three data streams, namely: traffic incident data, traffic speed data, and bus location data. Given that most major cities in the US have detectors installed on their freeway systems and incorporate some form of incident detection and management, it would be easy to utilize existing loop and incident data for a system like SWIFT. Furthermore, the use of AVL systems for transit bus location is becoming more common. Consequently, it appears that the data are available in most major cities in North America.

The use of the Internet as the backbone for the SWIFT architecture together with the self-defining-packet concept allows for an extremely flexible architecture. Furthermore, the use of FM sub-carriers as the communication medium negates the need for infrastructure installations. All these factors grouped together clearly indicate that the SWIFT architecture is extremely flexible in terms of system transferability.

2.4. SWIFT Deployment Cost Study

The primary purpose of the *SWIFT Deployment Cost Study* was to provide an independent Life Cycle Cost Estimate (LCCE) of an operational and fully deployed SWIFT system. Moreover, it is intended to provide both the SWIFT participants and the FHWA with a measure of the commercial viability of "SWIFT-like" systems nationwide. Table 2-1 shows the organizations that were included in the *SWIFT Deployment Cost Study* LCCE and commercial viability analysis.

Table 2-1. Deployed SWIFT Participants (Cost/Revenue Participants).

Industry	Government/Institutional
• Seiko Communications Systems, Inc. (SCS) • Metro Networks • Etak, Inc. • IBM (FOT Development Only) • Delco Electronics (FOT Development Only)	• King County Metro Transit • University of Washington (UW)

The methodology for the *SWIFT Deployment Cost Study* LCCE relied on standard proven cost estimation and data collection and analysis techniques to provide cost estimates for each SWIFT participant shown above across the following three life-cycle phases:

1) FOT development (costs of current SWIFT Test)
2) Commercial Development (additional development and procurement costs for fully deploying an operational SWIFT system (follows the completion of the SWIFT test)
3) Annual Commercial Operations (annual operations costs for a fully deployed SWIFT system)

A summary of the resulting life cycle cost estimate (LCCE) for the deployed SWIFT system is presented in Table 2-2. Here, the FOT Development phase (based on SWIFT test actuals) was estimated to cost $6.4 Million, the Commercial Development phase was estimated to cost $1.5 Million, and the Annual Commercial Operations costs were estimated to be $0.8 Million.

Table 2-2. SWIFT LCCE Summary.

Participant	FOT Development				Commercial Development				Annual Commercial Operations				Life Cycle Cost (5 years of Ops.)			
	Hours	Labor	ODC's	Total	Hours	Labor	ODC's	Total	Hours	Labor	ODC's	Total	Hours	Labor	ODC's	Total
SCS	19,137	$1,605K	$500K	$2,105K	1,005	$64K	$82K	$147K	804	$51K	$66K	$117K	24,162	$1,926K	$911K	$2,837K
Metro Networks	4,348	$264K	$320K	$584K	8,249	$493K	$11K	$504K	6,188	$370K	$2K	$371K	43,536	$2,604K	$340K	$2,944K
Etak	7,760	$639K	$248K	$887K	3,840	$254K	$0K	$254K	1,920	$134K	$0K	$134K	21,200	$1,565K	$248K	$1,813K
UW	32,136	$857K	$220K	$1,077K	10,998	$442K	$81K	$522K	1,922	$105K	$30K	$135K	52,741	$1,822K	$450K	$2,272K
Metro Transit	1,751	$73K	$2K	$75K	2,060	$86K	$0K	$86K	1,545	$65K	$0K	$65K	11,536	$483K	$2K	$485K
IBM	5,123	$342K	$194K	$536K	0	$0K	$0K	$0K	0	$0K	$0K	$0K	5,123	$342K	$194K	$536K
Delco	14,101	$750K	$344K	$1,093K	0	$0K	$0K	$0K	0	$0K	$0K	$0K	14,101	$750K	$344K	$1,093K
TOTAL	84,356	$4,529K	$1,828K	$6,357K	26,151	$1,339K	$174K	$1,513K	12,379	$725K	$97K	$822K	172,401	$9,493K	$2,488K	$11,981K

As shown in Figure 2-1, when viewed across the life cycle time period (1995-2003), the cost estimate followed the expected traditional life cycle curve of high initial development costs tapering down to lower annual operations costs as the years progressed – this was true for both labor and other direct charges, (ODC's).

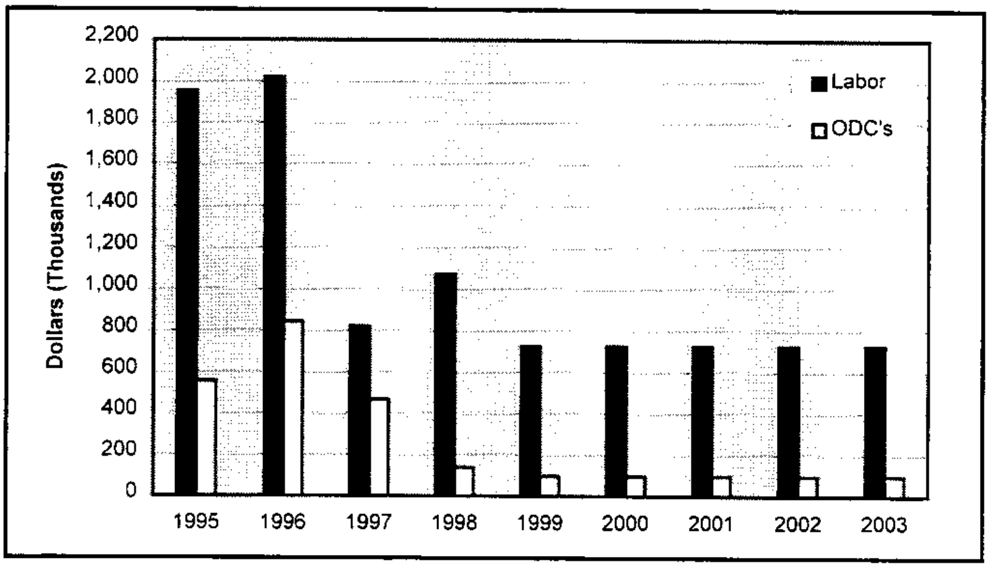

Figure 2-1. SWIFT LCCE Overview by Life Cycle Phase Total Cost.

As can been in Figure 2-2, as the life cycle progressed from the FOT Development phase to Commercial Deployment and then to Commercial Operations, the SWIFT team member's role and their share in the effort changed significantly, with SCS providing for the largest share of costs (for hardware and software development tasks) in the FOT Development phase, and Metro networks providing for the largest share of costs (for SWIFT TWS operations) by the Commercial Operations phase.

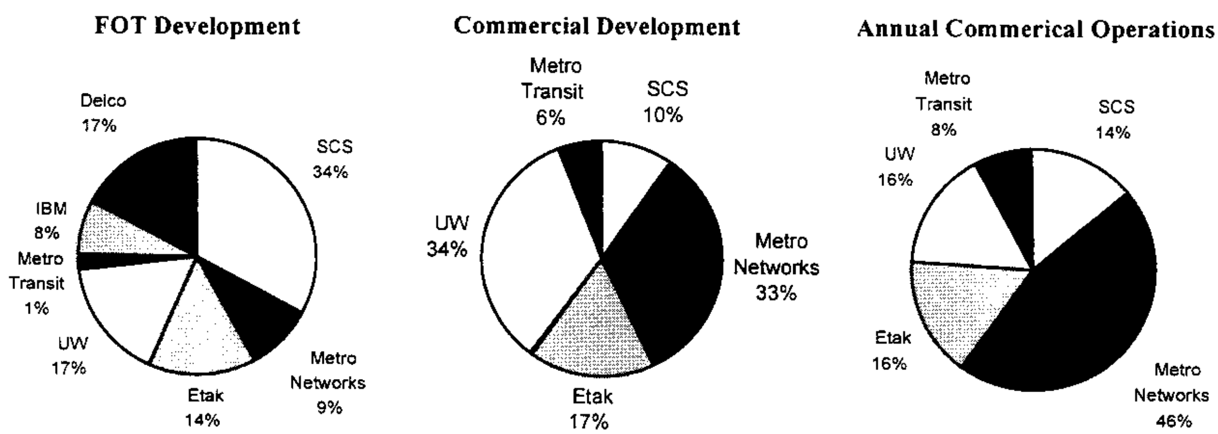

Figure 2-2. LCCE Overview by SWIFT Participant Share.

A summary of the methodology for the *SWIFT Deployment Cost Study* commercial viability analysis (CVA) is presented in Figure 2-3. This methodology was largely focused on developing consumer market penetration estimates for SWIFT user subscription. The methodology incorporated "willingness to pay" results from SWIFT user surveys conducted in the *SWIFT Consumer Acceptance Study.* The methodology results in a comparison of an estimate for annual SWIFT revenues with the Annual Operations cost estimate from the LCCE above.

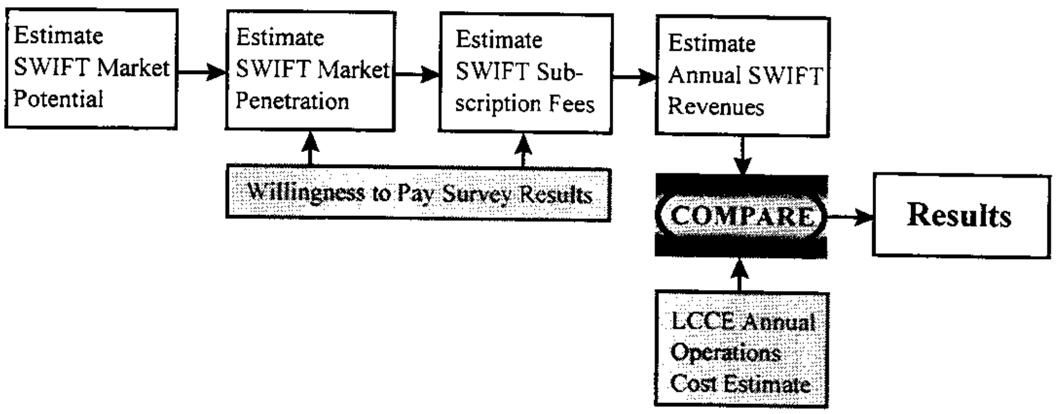

Figure 2-3. SWIFT Deployment Cost Study CVA Methodology.

As shown below in Figure 2-4, the commercial viability analysis (CVA) found that a deployed SWIFT can be expected be a viable commercial enterprise. Even under the most conservative market penetration scenario, the CVA analysis still showed that annual revenues exceeded annual operations costs by a factor of more than 3 to 1. This provides the result that in terms of operations, that a fully deployed SWIFT system as defined in this study would have a high likelihood of being commercially viable.

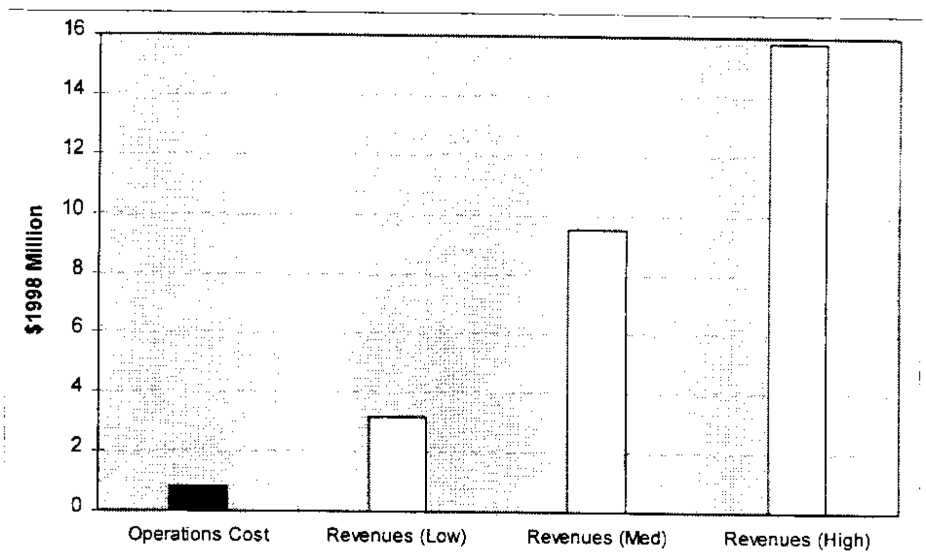

Figure 2-4. SWIFT CVA Results Summary.

Based on the results of the CVA, it would seem that if the deployed SWIFT were addressed as an investment opportunity, that it would have been seen as a reasonable investment. Moreover, based on the most conservative market penetration scenario (annual revenues of $3.1M), and assuming a bank corporate loan rate of 6%, if the entire SWIFT development cost of $7.9 had been financed by a loan from an investment bank, then the "payback period" on the loan (i.e., the "break-even" point on the investment) would be about 4½ years. This lies within the typical "5 year return on investment" that many large companies use to analyze potential investment projects. Note that after the 4½ year point, the deployed SWIFT Team members under this scenario would divide approximately $2.3M annually in profits!

Conclusions of the *SWIFT Deployment Cost Study* were largely focused on application of the results to other potential metropolitan areas. Specifically, in developing SWIFT as a commercial enterprise in other metropolitan areas where SCS operates an HSDS and Metro Networks/Etak are involved, dramatic savings should be realized in the development costs of a SWIFT-like system:

- SCS and Metro Networks/Etak would apply results (e.g., the expertise, software, and the hardware designs) of the SWIFT deployment (i.e. a substantial reduction in the "learning curve")
- A much shorter test period would likely be required (i.e., "validated" SWIFT technologies would be used)
- The lack of government oversight could facilitate reductions in labor costs -- according to Metro Networks SWIFT Project Manager Joan Ravier: "Some projects we're involved with would be a lot cheaper to run if we were doing them for ourselves, because following government procedure requires us to do all kinds of things we wouldn't do normally."[1]

In terms of "lessons learned," the potential development of SWIFT-like ATIS systems as commercial ventures in other metropolitan areas where different commercial enterprises would implement a similar system, the following should be considered:

- The deployment of an FM-subcarrier ATIS in other cities may require the expenditure of up-front "infrastructure" costs (i.e., costs associated with developing the required HSDS hardware and software and integrating it with available FM radio stations)
- Significant FM-subcarrier ATIS deployment costs are likely to be encountered during the development phase, where software development, integration and test costs are incurred

---

[1] Nancy Johnson and Christina Steffy, "What will it Take to Create a Profitable Business in the Market for In-Vehicle ITS Systems and Services," <u>ITS World</u>, September/October 1997, p. 39.

- Operations costs for FM-subcarrier ATIS projects should be fairly stable, and will center on the human element of managing and inputing traffic information into the ATIS system (eg., Metro Networks TWS operators)
- Successful commercial deployment of FM-subcarrier ATIS projects should be based upon the development of sound market-penetration scenarios
- Future ITS public-private joint ventures should stipulate in their teaming agreements that the private-sector partners will provide full details of their development costs to the evaluation team, with appropriate non-disclosure agreements set up as required.

Future ITS public-private joint ventures should stipulate in their teaming agreement that all costs will be invoiced according to an activity-based Work Breakdown Structure (WBS) of at least three (3) levels of detail for each Team Member in order to allow costs to be tracked by activity throughout the project.

2.5. SWIFT Institutional Issues Study

The primary purpose of the *SWIFT Institutional Issues Study* evaluation was to collect information regarding the institutional issues (e.g., policies, jurisdictional issues, internal and external factors) that affected design, development, testing, deployment and conduct of the SWIFT Field Operational Test (FOT); determine how these issues were overcome and what lessons could be learned. A secondary purpose of the evaluation was to document the history of the SWIFT project.

The methodology for the *SWIFT Institutional Issues Study* consisted of two sets of questionnaires and two sets of semi-structured interviews that were conducted with fourteen (14) SWIFT team-member representatives at two different points during the conduct of the SWIFT FOT: about midway through the conduct of the test and after the test was completed. All SWIFT team-member responses were independently collected and SWIFT institutional issues were primarily identified by determining which topics were addressed by two or more individuals. Historical information was collected from various sources throughout the project.

SWIFT represents one of the first ATIS FOTs conducted in this country. Earlier tests were conducted in Orlando, FL (TravTek) and Minneapolis/St. Paul (Genesis) among others, yet the SWIFT FOT appears to have extended considerably the available database of information regarding ATIS effectiveness and acceptance. The addition of real-time bus information, in particular, has set the SWIFT FOT apart from others already conducted.

One of the significant aspects of the SWIFT teaming agreement was the long-term interest in ITS and commitment of the organizations involved. For instance, the majority of the SWIFT team members articulated a long-term interest in ITS deployments. In addition, three organizations—Seiko, Etak and Metro Traffic Control—committed themselves to fielding a "SWIFT-like" system after the project was completed. This degree of interest and commitment resulted in all of the SWIFT team members working together in a very effective, cooperative fashion throughout the FOT.

A critical organizational structure that was instituted to implement SWIFT was the weekly teleconference. This simple, yet cost-effective method of managing and discussing the technical issues involved with the project was attributed by many of the SWIFT team members to a primary instrument of the project's success. In particular, the SWIFT teleconferences enabled the representatives of each organization to keep abreast of the developmental status of the project, to brainstorm solutions to encountered problems and to develop scheduling sense to see the project through to the end. Others simply enjoyed the "camaraderie" that was exhibited by the teleconferences, and felt that these discussions cemented their commitment to each other.

Evaluation issues were important to the SWIFT team members throughout the project. On many occasions, team-member representatives reiterated or stated their commitment to assisting with the independent evaluation, as the documentation left by this effort would be the primary legacy of the project.

Institutional issues that primarily affected the SWIFT project were:

- Responsibilities— because some team members did not meet expectations others had of them, other SWIFT team members ended up performing activities that were outside, or in addition to, their responsibilities when they started the project.
- Role clarity— related to responsibilities, differential expectations regarding the role that each organization should play in the SWIFT teaming agreement caused some development, testing and deployment delays.
- Public/Private Partnership— confusion as to the differential role of public and private agencies in a public/private partnership caused delays in contract negotiations.
- Patent/Copyrights— related to public/private partnership issue, concerns about how patent and copyrights should be assigned to the SWIFT team members caused contract-signing delays and/or re-negotiation of SWIFT contracts.
- Standards/Protocols— SWIFT team member representatives differed in their attributions as to whether ITS standards and protocols might save development time
- Procurement/Acquisition— Some felt that ill-defined procurement processes contributed to SWIFT problems such as the use of Dauphin sub-notebook computers and "phased" deployment of end-user devices.
- Market Uncertainty— Not knowing whether consumers will ultimately accept ITS products and services contributed to some development uncertainty and associated deployment problems with the SWIFT project
- Contracting/Auditing— Difficulty understanding and submitting to government contracting requirements caused some headaches among SWIFT private-sector team members
- User Perception/Acceptance— concern was expressed about how well the SWIFT system would be accepted by end users, or operational test participants, because user inputs and prototyping were minimal during the design phase.

Organizational/jurisdictional (i.e., the first three items above), financial (i.e., the second three items above), regulatory/legal issues (i.e., the seventh and eighth items above) and public acceptance (i.e., the last item above) categories of issues were rated as the most important by SWIFT team-member representatives as measured by the number individuals who wished to discuss issues in these categories. In particular, each of the institutional issues in the organizational/ jurisdictional category were each discussed by three (3) or more people, while the same number of issues were each addressed by two (2) people in the financial category. In addition, the two regulatory/legal category issues were discussed by two (2) or more people and the issue discussed in the final issue category (i.e., public acceptance) was addressed by three (3) SWIFT team-member representatives.

Primary organizational/jurisdictional concerns centered around the significance of ensuring that each and every member of the team understands its responsibilities and roles throughout the development process. Earlier on, for instance, apparent differences in how some organizations viewed their involvement in the SWIFT project caused some to view certain development activities (e.g., bubble diagrams) as being a waste of time. Others didn't understand and/or misinterpreted their role in the project which also caused them to waste time. Integrating the concerns of the issues addressed in this category can lead to the attribution that some organizations viewed the SWIFT FOT as being a "research and development" project rather than a "demonstration," or actual implementation project. As a result, some organizations exhibited a greater sense of urgency in completing their assigned tasks, or in building the SWIFT system, than did other organizations. This occurrence resulted in some hard feelings among the team members, but it was generally conceded that others "picked up the slack" for those who didn't clearly understand their responsibilities and roles.

Financial issues related to the conduct of the SWIFT FOT addressed procurement/acquisition, contracting/auditing and market uncertainty. Procurement issues causing SWIFT to be defined and built very quickly causing certain operational disadvantages (e.g., use of Dauphin sub-notebook computer) to be built into the system. In addition, contracting/auditing issues contributed to development delays in other areas of the project that otherwise resulted in the perception of an uneven workflow for the project. For example, these issues were generally thought to have been the primary contributor to the "phased" deployment of end-user devices that was experienced by the project. Finally, issues and questions regarding the ultimate marketability of ATIS services such as those provided by SWIFT probably caused some of the SWIFT participants question and/or otherwise delay some of the development efforts for the project.

SWIFT regulatory and legal issues were significant in that the SWIFT project represented the first time some of the private team members had ever dealt with government contracts and/or entered into a "public/private teaming agreement." As a result, some private SWIFT team members were concerned about losing the proprietary rights to some of the software they contributed to the project, while some public SWIFT team members felt uncomfortable with granting their private-sector counterparts the capability to make money on the joint efforts of the group. The primary result of the lack of clarity regarding SWIFT regulatory and legal issues was a delay in getting many of the SWIFT team-members under contract. This caused the project to be subjected to unnecessary risk according to some team members, or caused a lot of anxiety among others with vested financial interests in the project.

A final important issue, in the public acceptance category, was the FOT participant, or end-user's, perception and acceptance of the SWIFT system. With all of the respondents who addressed this issue being from the private sector, the significance or implication of this issue is that customer acceptance of ITS projects is crucial to the overall success of this type of application. Thus, it is crucial to obtain end-user inputs throughout the system design, development, testing and fielding process.

As with other ITS FOTs, a number of newly-identified issues were delineated by the SWIFT project. These issues primarily centered around the particulars of developing new systems, such as human factors contributions during user-interface design, integration testing, protocol migration and server connectivity. Nonetheless, other newly-identified issues addressed other implementation aspects of the SWIFT project, such as the general lack of familiarity with transit data, that team members were spread out geographically, leadership issues, education and training of co-workers and how the independent evaluation was supposed to be conducted. Overall, a good summary is that it is important to address the "logistical" aspects of applying information technology to solving transportation problems.

Primary SWIFT lessons learned were:

- Responsibilities of the team members need to be clear from the onset
- Roles of the team members need to be delineated and understood by all
- Each side of the public/private partnership needs to understand the principles and ideals that govern the other
- Patent and copyright rules of the Federal government need to be modified to include models for public/private partnerships that address the distribution of patent and copyrights among the team members
- ITS standards and protocols should be modified so that both public and private entities agree as to their contents
- Procurement and acquisition processes need to be better defined so as to facilitate, not hinder, ITS deployments
- Issues regarding ITS market uncertainty need to be delineated so that development processes will be facilitated
- Government contracting and auditing requirements need to be clarified for private-sector ITS public/private partnership team members
- Market research and user-system prototyping should be included in ITS projects to ensure that the system is well received

Other findings indicated that the goals of the SWIFT project were relatively clear; the perceived benefits and risks of participating in the FOT varied widely among the team members; WSDOT, Seiko and Etak were most often mentioned as the champions of the project; the majority of the team members agreed that consumer acceptance was crucial to commercial deployment of the system; and that a subscription-based model was best suited for future deployment of the SWIFT system. The historical significance of providing real-time bus information was also cited as a major contribution of the project.

3. CONCLUSIONS

Overall, the SWIFT operational test was a success. All of the goals that were identified by the partners were addressed. Furthermore, in most cases the system was found to perform at or above expectation.

The test demonstrated the efficacy of using a High Speed Data System (HSDS), or FM Sub-carrier, to disseminate incident, bus and speed/congestion information via three different end-user devices: pager watch, portable computer and in-vehicle navigation device. Six hundred ninety (690) Seattle-area commuters, many with route- or mode-choice options, participated in the FOT and provided user-acceptance evaluations which showed that the system was perceived to be useful for avoiding traffic incidents, traffic congestion and for making transit-related decisions. Evaluations of the communications and architectural components of the system showed that the system was operational over 90% of the time and performed as expected. The evaluation identified various institutional issues that affected the project—which were minimal in their perceived impact—and determined that the financial bases for future deployment of such ATIS projects were good. Finally, the test results yielded recommendations for the deployment of future traveler information systems.