SWIFT

Seattle Wide-area Information For Travelers

Architecture Study

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EXECUTIVE SUMMARY

The SWIFT (Seattle Wide-area Information For Travelers) Field Operational Test was intended to evaluate the performance of a large-scale urban Advanced Traveler Information System (ATIS) deployment in the Seattle area. The unique features of the SWIFT ATIS were the provision of information for multiple transportation modes, the delivery of this information using three different devices, and the use of the FM sideband as the primary communication medium. A total of approximately 800 system users were recruited during the course of the study.

The *SWIFT Architecture Study* is one of five component studies to the overall system evaluation. This report details the results of the *SWIFT Architecture Study* based on the evaluation objectives that were initially identified in the *SWIFT Architecture Study* test plan (1996). Specifically, 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 will be 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 attempts to establish the consistency of user perceptions with the actual system performance, but also attempts to identify the operational characteristics of the system that were not recognized by the SWIFT field operational test participants. Furthermore, this study attempts to identify the source of any architectural limitations that were observed by the FOT participants. Finally, it focuses 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.

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.

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 the 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.

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 that 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.

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.

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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, 1998 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

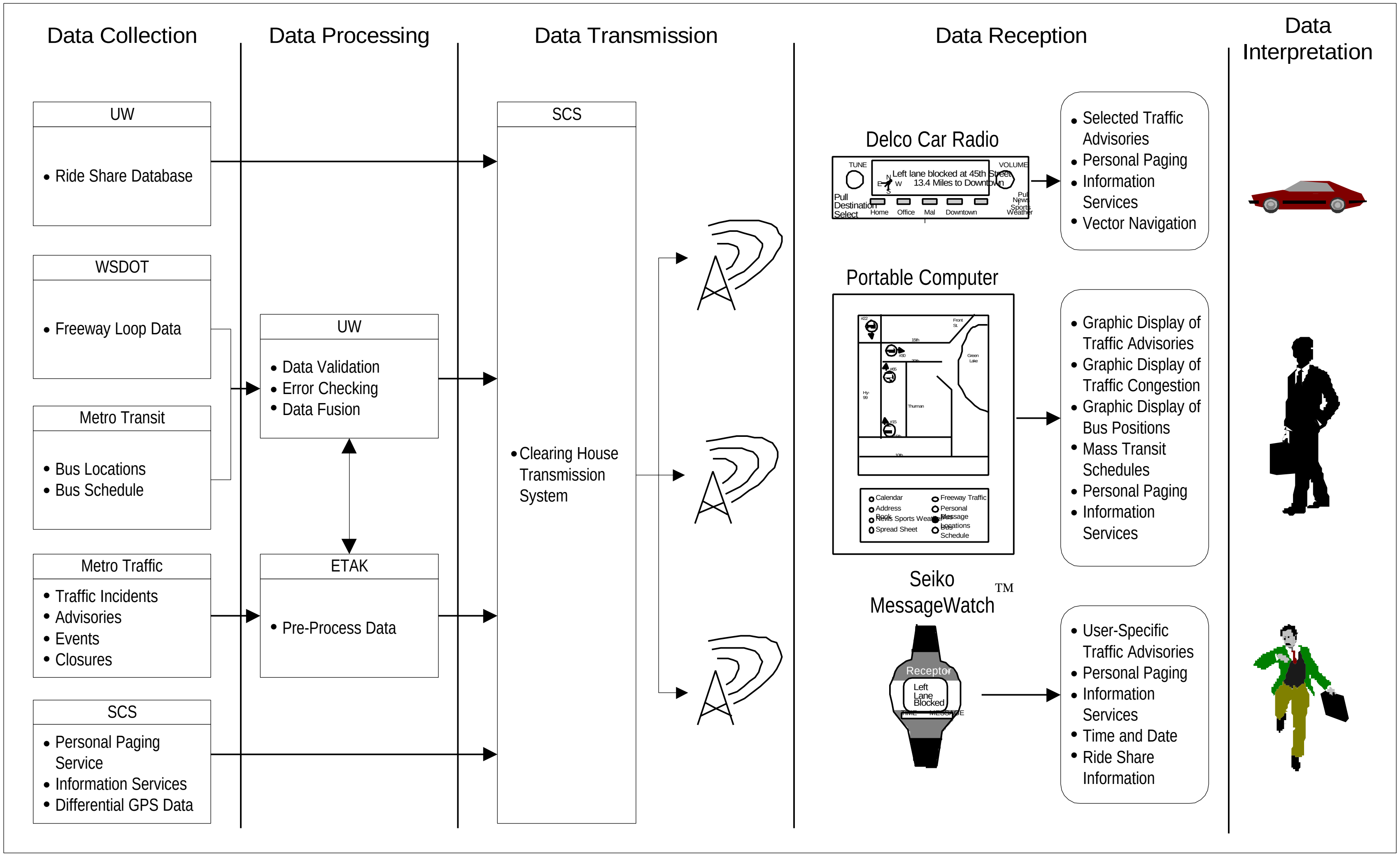


Figure 1-1. SWIFT System Description.

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 only once.

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— 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 unit filtered out any messages that were outside a pre-defined distance (e.g., 20 miles) 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.

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.

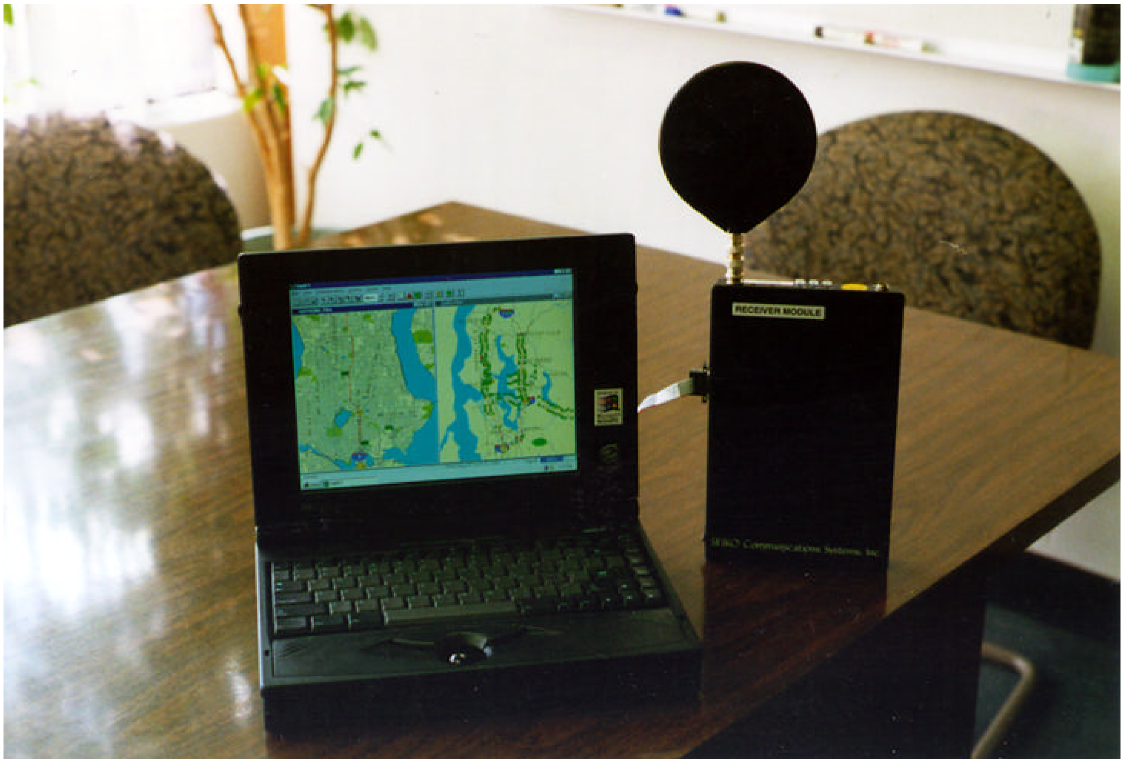


Figure 1-4. SWIFT Portable Computer and RRM.

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.

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

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)

1.4. Purpose of SWIFT Architecture Study

The purpose of the *SWIFT Architecture Study* is to determine how well the various SWIFT components work singularly and collectively. The *SWIFT Architecture Study* considers the SWIFT architecture in terms of both how the architecture was designed, how this design was implemented, and how the implemented design operated in the field. This distinction is intended to separate any deficiencies in the original design from problems introduced during the system implementation. Similarly, deficiencies in the way the system is operated are distinguished from those related to design and implementation.

The latter issues are especially critical for the *SWIFT Architecture Study*, as the effort will consider two further architecture deployment stages which relate to the extent to which the SWIFT architecture can be expanded within Seattle with respect to the number of users and the system scope, and the extent to which the system architecture can be implemented elsewhere in North America. The entire sequence of 5 different deployment stages are itemized in Table 1-5.

Table 1-5. SWIFT Architecture Deployment Stages.

System Architecture Deployment Stages	Core Issue
System Design	To what extent is a particular SWIFT system attribute a function of the original design
System Implementation	To what extent is a particular SWIFT system attribute a function of the manner in which the design was implemented
System Operation	To what extent is a particular SWIFT system attribute a function of the manner in which the implemented design operated
System Expansion	To what extent is the SWIFT architecture suitable for expansion in Seattle in terms of number of users and scope
System Transferability	To what extent is the SWIFT architecture suitable for implementation elsewhere

1.5. Objectives

The primary objectives of the overall SWIFT Field Operational Test have been stated as:

- To develop and deploy systems that will aggregate, fuse and deliver source ATIS data from existing public surveillance systems
- To also integrate additional ATIS data from private information providers who collect complementary data
- To provide the above fused traveler information in a timely manner to test subjects through three parallel delivery systems, and
- To demonstrate the delivery of traffic and transit information to these delivery systems by means of an FM subcarrier based communication system

The architecture evaluation attempts to qualify the overall architecture in terms of how well each of its objectives were achieved.

In view of the above considerations, four evaluation objectives are identified for the *SWIFT Architecture Study*. The first two of these objectives relate to the system performance when the system is operating as intended in its functional specifications and is essentially failure free, while the third and fourth objectives focus on what happens when all or part of the system becomes unavailable due to system component failures as indicated in Table 1-6. Within each of these pairs of objectives, the first objective usually relates to the user's perceptions of the system, while the second relates to the more technical system designer's perspectives of the system architecture design, implementation and operation.

Table 1-6. Conditions and Perspectives Associated With the SWIFT Architecture Test Plan Objectives.

	System User	**System Developer**
System Operating as Intended	Objective 1	Objective 2
System not Operating as Intended	Objective 3	Objective 4

Therefore, the *SWIFT Architecture Study* will pursue the following four objectives, as specified earlier in the original SWIFT Evaluation Plan:

- To assess qualitatively the user's perceptions of the ability of the SWIFT architecture to deliver effective ATIS in Seattle as perceived through the use of one or more of the three SWIFT devices during the operational test. This analysis is conducted by evaluating how users perceive the system to address the relevant ATIS user needs.
- To assess quantitatively the performance of the system as a whole in terms of its throughput capacity, update frequency, transmission rates/delays, relative to the original system design criteria. Furthermore, this objective investigates the potential for expanding the SWIFT system both in terms of the number of system users and the system scope in Seattle. In addition, this objective also evaluates the potential for deploying a similar system in other locations within the U.S.
- To assess the system reliability and availability from a user perspective. Specifically, an assessment will be made how often the system was available with full or partial functionality, and what the duration and impact of such unavailability was. In addition, field measurements conducted as part of the Coverage Test (Communications Study) will be augmented with the user perceptions in order to assess the reliability of HSDS reception throughout the SWIFT Operational Test area, including in-building, in-vehicle, and in-street traveler environments.
- To assess the system reliability and availability from a more technical component level, especially with the intent of identifying to what extent the system reliability and availability could have been improved with an alternate system architecture and/or alternate system components. In addition, the system architecture will be assessed relative to the extent redundancies were able to deal with single point failures, and how well the architecture permitted graceful degradation and rapid regeneration.

It should also be noted that the *SWIFT Architecture Study* touches on many system features that are also relevant to the other SWIFT evaluation studies. In each of these cases, the architecture analysis relied on data collection and analysis efforts that were conducted for other complementary studies, and focused the architecture specific resources on the collection and analysis of any missing data, as well as the synthesis and integration of these other data. Specifically, data collected to address objectives 1 and 3 of the *SWIFT Architecture Study* were collected as part of the *SWIFT Consumer Acceptance Study*, with the *SWIFT Architecture Study* focusing on providing the relevant questions to the *Consumer Acceptance Study*. In addition, data collected to address objectives 2 and 4 were mainly derived as part of the *SWIFT Architecture Study* except for the FM sub-carrier coverage analysis which was conducted as part of the *SWIFT Communications Study*.

The *SWIFT Architecture Study* was conducted utilizing a number of data sources. These data sources included:

- System documentation
- User questionnaire
- Focus group summaries
- Field measurements
- Automated and manual system failure/maintenance reports
- Desk-top analyses

2. SWIFT SYSTEM ARCHITECTURE DESCRIPTION

The objective of this section is to describe the SWIFT architecture in terms of its component nodes and links as a first step to evaluate the SWIFT architecture. The intent of this description is to identify the main architectural building blocks of the SWIFT system and to describe how these building blocks interact. The building blocks and the connection links will be described in detail in order to set the foundation for the architecture evaluation. This description is based on literature and discussions with the SWIFT partners.

Initially, the unique features of the SWIFT system are described in Section 2.1 followed by a description of the architectural building blocks in Section 2.2. In Section 2.3 the connection links are described. Finally, Section 2.4 describes the SWIFT reception devices in further detail.

2.1. Introduction

This section provides an overview of the SWIFT architecture and some of the descriptive features of this system.

2.1.1. Overview of SWIFT System Architecture

The SWIFT ATIS deployment in Seattle, Washington has several unique features that distinguish it from other systems. The most significant of these features are:

- The provision of both automobile and transit data
- The use of a data fusion/broker
- The combined use of the Internet, satellite links, and a High Speed Data System (HSDS) FM sub-carrier to transfer the data from source to user
- The use of several user devices to convey the data to the end user
- The integration of ATIS information and alpha-numeric paging

The following description provides a brief overview of the overall architecture of the SWIFT system utilized in the Field Operational Test prior to discussing the details of each component node and link.

Data Collection and Fusion

The SWIFT system collects ATIS data with respect to three main entities. First, it collects numeric highway traffic congestion data from loop detectors installed on the major freeways in the Seattle area. Secondly, it provides numeric data on the status of individual buses progressing through the network on active passenger service. Finally, SWIFT assembles less precise anecdotal data on the location and severity of any significant recurring and non-recurring congestion.

The fusion of the numeric automobile and transit data to a Geographic Information System (GIS) reference scheme is performed by the University of Washington, which also conducts significant end-to-end data tracking.

Data Dissemination Reception

The numeric traffic data is forwarded to the Traffic Work Station (TWS) at Metro Traffic. The loop data is displayed by the TWS for the benefit of the Metro Traffic operator usage to alert aircraft and other observers about developing traffic problems. The TWS is also used by the Metro Traffic operators to enter, edit, and encode other anecdotal information about traffic and road conditions as well as other traveler concerns such as scheduled road maintenance, sporting events, and concerts. These anecdotal data are then sent via the Internet to Seiko Communications in Portland.

In addition, the ATIS transit data is forwarded from the University of Washington to SEIKO Communications in Portland via the Internet. In turn, SEIKO converts these data to a format suitable for transmission via satellite to its FM stations, that transmit the data on their sideband to a series of pager-like receivers. The smallest of these receivers is a large-sized wrist watch. The next largest user device is a PC-compatible PDA or laptop computer. Finally, the above data are also available on a specially configured in-vehicle radio receiver. In addition, the size of the above alternatives are also unique in terms of their display and functionality.

SWIFT Data Flow Links and Nodes

The SWIFT architecture can be viewed in terms of a network of links and nodes, as illustrated in Figure 2-1. The nodes represent a set of data processing activities confined by organizational rather than geographic boundaries. The links provide data connections between the different architectural nodes.

The SWIFT architecture has been divided into six architectural nodes as illustrated in Figure 2-1. These nodes are: (a) Metro Transit Control, (b) Washington State Department of Transportation (WSDOT), (c) University of Washington, (d) Metro Traffic, (e) Seiko Communications system, and (g) the receiver devices. These architectural nodes are connected by links that include: (a) Internet links and (b) High Speed Data System (HSDS) FM sub-carrier links.

2.2. SWIFT System Architecture Nodes

In total, the SWIFT architecture was composed of six nodes, as illustrated in Figure 2-2. Five of these six nodes are described in detail in this section while the sixth node (the SWIFT reception devices) is described separately in Section 2.4.

2.2.1. Washington State Department of Transportation (WSDOT)

The Washington State Department of Transportation (WSDOT) has a total of 2,200 loop detectors installed along the major freeways in Seattle. The majority of the loop detector stations include single loop detectors with a small number of dual loop detectors. The dual loop detectors provide volume, occupancy and speed measurements every 20 seconds, while the single loop detectors provide volume and occupancy measurements every 20 seconds. The volume measurements are defined as the number of detector activations in the polling interval, while the occupancy measurements are defined as the percentage of time that the detector is activated in the polling interval. Occupancy measurements range from 0 to 1, where a 0 indicates that the detector was not occupied in the polling interval and an occupancy of 1 indicates that the detector was occupied for the entire duration of the polling interval.

The accuracy of the detector measurements is a function of the detection technology utilized. The detection technology installed along the Seattle major freeways (inductance loop detectors) is currently the norm in North America. However, the majority of the inductance loop detectors in Seattle are single loop detectors. Consequently, the accuracy of the speed estimates should be evaluated.

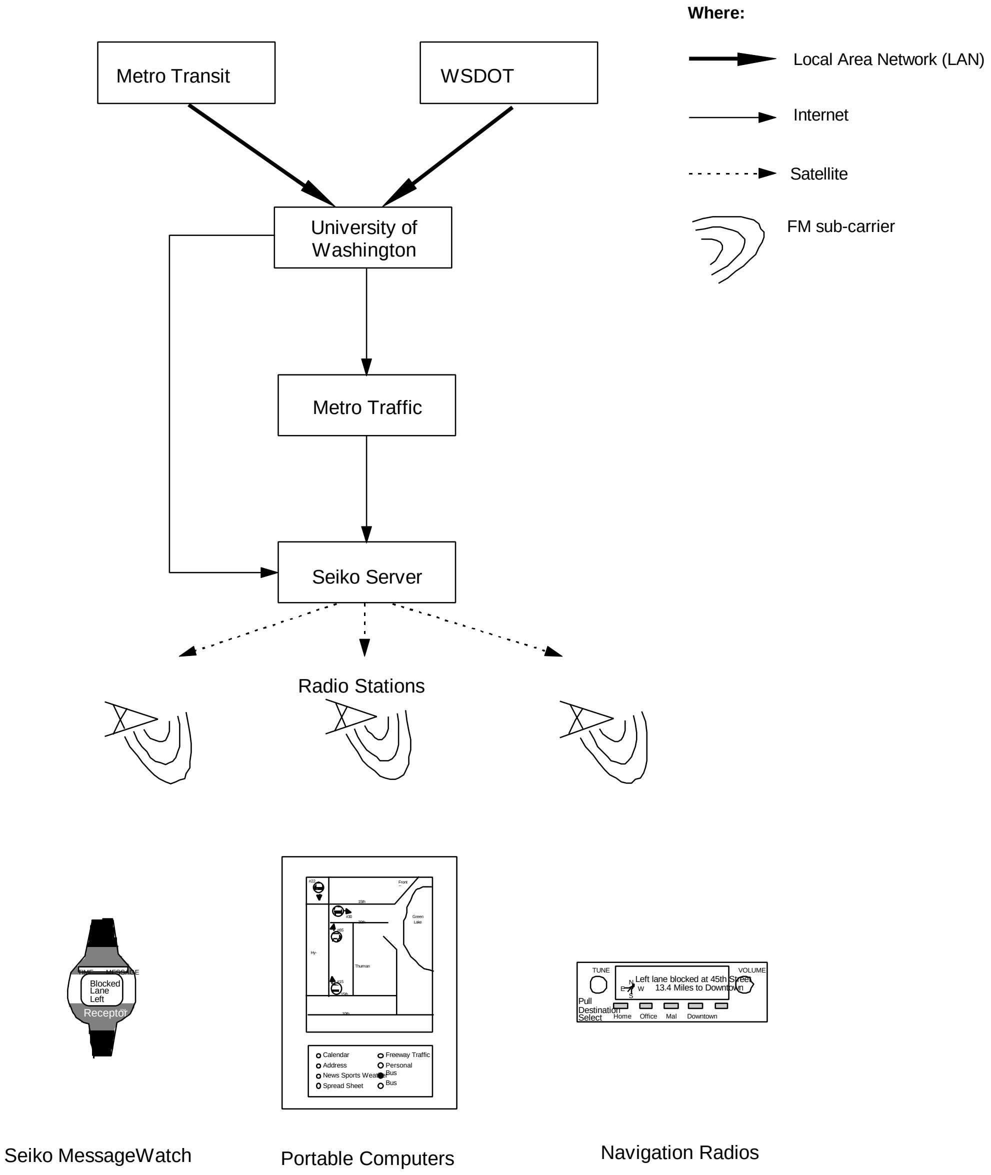


Figure 2-1. SWIFT Field Operational Test Architecture.

2.2.2. Metro Transit

Metro Transit implemented an Automatic Vehicle Location and Computer-Aided Dispatch (AVL/CAD) system in 1993 in order to improve fleet management and operator security. The vehicle location and schedule adherence for the 1,150 buses is based on a less sophisticated signpost technology as opposed to Geographic Positioning Systems (GPS) because GPS were not widely available when the contract for the project was released in 1989.

The AVL system is composed of a central computer, 255 signpost transmitters that are located throughout the 5000 square kilometer service area, an odometer sensor on each bus, a Mobile Electronic Tracking System (METS) located on each bus, and a two-way radio system on each bus. The system's main computers are loaded with the current bus schedules and routings, including the identity of each signpost transmitter on the route, and distance between signposts, as illustrated in Figure 2-2. The bus driver identifies his or her assignment number when leaving the base. When the bus passes each battery-powered signpost, a small receiver on the bus captures the signpost signal and stores it in the memory of an on-board processor. This information, together with the current odometer reading, is sent back to the central computer each time the bus is polled via the data radio system. Polling occurs nominally every 1 to 2 minutes during the peak when up to 900 buses are in service, and more frequently during off-peak periods. A polling rate of 5 to 15 seconds is available for single vehicle tracking and emergency alarm processing. Once the polling data is received by the central computer, it calculates whether the bus is on schedule based on time stamps for each scheduled time point along the route and it estimates the bus location on the network based on the location of the last signpost encountered and the odometer reading since the last signpost.

The AVL system was tested by the system developers and found 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 on-route schedule was found to be within 1 minute of the actual schedule 95 percent of the time throughout the system. These findings are not consistent with the results of the SWIFT evaluation as will be described in Section 3.

The AVL system suffers from a major drawback, namely; its inability to deal with temporal changes in bus schedules and spatial changes in bus routes unless these changes have been input to the central computer system. The use of a Differential Geographic Positioning System (DGPS) would definitely improve the accuracy of the vehicle location system. Consequently, while evaluating the SWIFT architecture the evaluators should recognize that the accuracy of the bus tracking data in the SWIFT system is limited by the accuracy of the current technology and not necessarily by the architecture of the system.

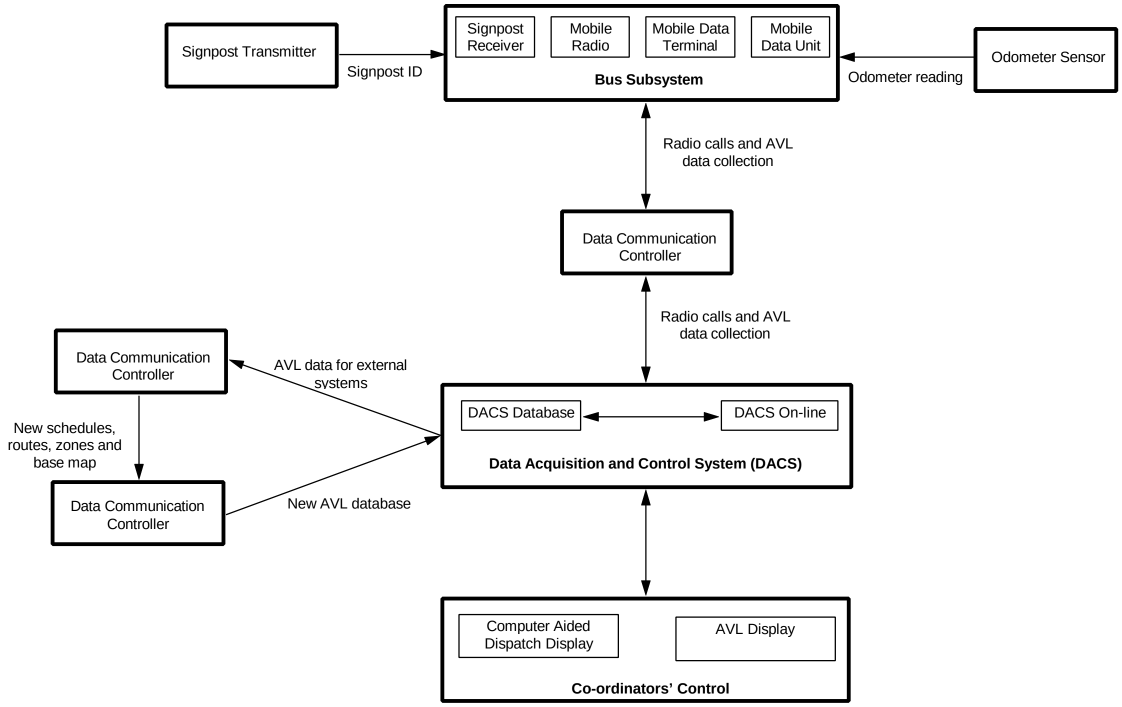


Figure 2-2. Automatic Vehicle Location (AVL) System Architecture.

2.2.3. University of Washington (UW)

The University of Washington is responsible for fusing data from two sources, namely:

- Loop detector data from WSDOT indicated by volume, occupancy and speed in the case of dual loop detectors and volume and occupancy in the case of single loop detectors.
- AVL data from Metro Transit indicated as routes (a series of geographical locations placed sequentially in a file), and status (a code indicating such parameters as type of route, type of vehicle, schedule adherence, etc.).

The UW node receives data from two sources, namely; loop data and transit AVL data. These data are used to generate two types of output, namely; link speeds on the major freeway sections in Seattle and transit vehicle positions. The flow and fusion of data at the UW node is summarized in Figure 2-3.

The link speeds are estimated based on direct measurement in the case of dual loop detectors and estimated using a Kalman filter for the case of single loop detectors. The Kalman filter, which is a maximum likelihood technique that computes the speed using observed volumes and occupancies, will be described in further detail in Section 5. The single loop speed estimates and dual loop speed measurements are used to generate an estimate of speed along the major freeway segments in Seattle.

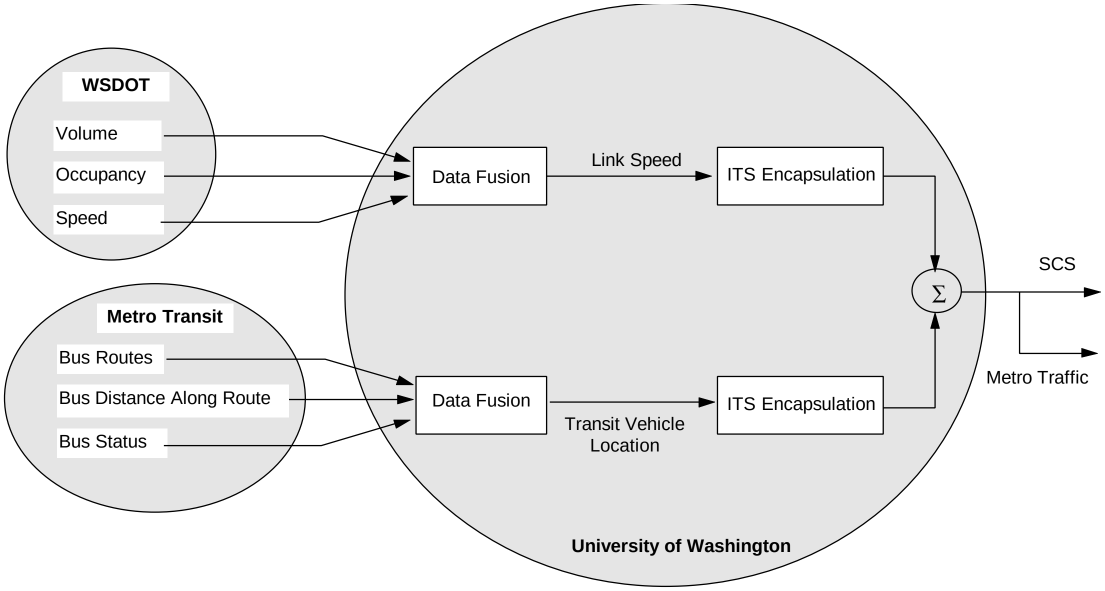


Figure 2-3. Overview of Data Flow at the UW Node.

The Transit vehicle locations are estimated based on combining apriori knowledge of the routes and schedules of the buses together with odometer information indicative of the distance traveled by each vehicle. These locations along the route are converted into latitude and longitude coordinates which constitutes the transit vehicle position data stream.

All data are encapsulated in a standard format before transmission to Seiko's HSDS. SWIFT data encapsulation uses the ITIS standard to define the structure of communication between data providers and data consumers. The details of this data format is described in the next section.

The development architecture is composed of four types of components, depending on how they affect the flow of data (Dailey *et al.*, 1996). The component types are: (a) a Source Component, which makes a data stream available, (b) a Redistributor Component, which receives a data stream from one component and redistributes it to one or more other components, (c) an Operator Component, which receives data streams from one or more components and creates a new data stream for distribution to one or more components, and (d) a Sink Component, which receives data streams from one or more components. Redistributors and Operators function both as client and server, while Sources are servers and Sinks are clients.

The Source component communicates directly with any input data streams to obtain information about format, contents, and meaning of the data stream. The Source component then produces self-defining data streams with an initial dictionary and following data. As the content of information being received changes in format, content, and structure, this component builds a new data dictionary and passes it on to downstream components.

The UW node uses existing network Inter-Process Communication (IPC) facilities as a base for implementing the components that make up the UW node. The Transmission Control Protocol/Internet Protocol (TCP/IP) is used to provide the transport layer services implicit in the use of IPC services. The use of TCP/IP as the transport layer allows the application to be distributed geographically while guaranteeing connectivity, in addition it allows data to be shared by other architectural nodes.

In summary, the UW node is constructed in a modular form by connecting Sources, Redistributors, Operators, and Sinks in a hierarchical structure. Consequently, this architectural node appears to be highly flexible in terms of expanding the number of operations, upgrading the operations, and/or modifying the node structure.

2.2.4. Metro Traffic Control

This section describes the architecture of the Traffic Work Station (TWS) that is located at Metro Traffic Control. A more detailed description of the TWS architecture and flow of data can be found in Sweeney and Chow (1996).

Metro Traffic receives traffic information from a number of sources, including: police reports, state and local DOTs, special event operators, cellular phone calls and loop detector data from the University of Washington, as illustrated in Figure 2-4. Metro Traffic operators phone state patrol three times every hour during peak traffic conditions and two times every hour during off-peak traffic conditions. Most of the data is received orally over telephone and radio, and is manually keyed into text to be communicated to, and read by, traffic reporters, radio and television broadcasts. The SWIFT TWS allows the Metro Traffic Control operator to conveniently convert the information into a geo-referenced form which is then communicated via the Internet to the SEIKO broadcast server for FM sub-carrier transmission.

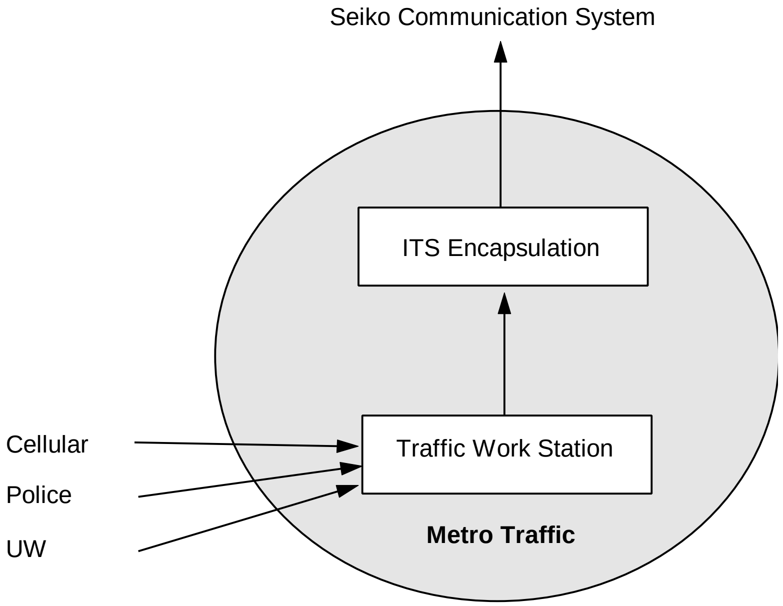


Figure 2-4. Data Flow at Metro Traffic.

The SWIFT TWS can communicate entered incidents or events in one of two ways, namely: (a) as a reference location, or (b) as a latitude/longitude location. The reference location selects the location from a Location Reference Table which consists of 65,536 locations. Although, the use of the Location Reference Table limits the number of locations for which events are associated with, it reduces the number of bits required to locate the event from 32 bits, in the case of the latitude/longitude reference, to 16 bits.

The TWS event descriptions are based on the ITIS standard which provides 2,048 standard messages for describing traffic and road conditions, and other common traveler information. The TWS allows the operator the flexibility of selecting the most relevant code using menus. The final choice produces an 11-bit message code from the ITIS message list. The 11-bit message code combined with the 16-bit Location Reference Code or the 32-bit latitude/longitude code is sent via the Internet to the Seiko Communication System.

Because the watches cannot interpret Location Reference Codes nor can they interpret Message Codes, short text messages must be independently developed for the pager watches. In addition, due to limited memory and battery capacity, the watches can handle only a fraction of the messages sent to the computers and navigation units. Hence, the TWS message table contains watch messages only for the most important incidents. Furthermore, the Location Reference Table includes abbreviated road and location descriptions that are suitable for pager watch display. In addition, the pager watch users provide the TWS with a list of most frequently used freeway road sections (user profile). The user profiles are updated on a weekly basis in order to reduce the amount of messages sent to the pager watches. The TWS automatically produces pager watch messages, but the operator can select from a message-list which messages are actually sent. In addition, the TWS operator can create custom messages for transmission to the watches (and to the other devices). The advantage of the message-list approach is that it provides a compressed format by which detailed descriptions of incidents and events can be transmitted with relatively little channel capacity compared to sending the descriptions themselves.

The TWS also receives loop data from the University of Washington. The loop data is sent in the High Speed Data System Bearer Application Protocol (HSDS-BAP) format from UW so that the data received by the TWS is already properly formatted for transmission and broadcast. The intent was to allow the TWS operator to edit loop data. Although this initial plan was abandoned, the traffic loop data still proceed through the Metro Traffic Control node. The Loop data and event/incident messages in HSDS-BAP format are then sent via the Internet to the Seiko Communication System for final broadcast.

2.2.5. Seiko Communications Systems

This section describes the architecture and data flow at the Seiko Communications Systems. In addition this section describes how the data is formatted for transmission via the FM sub-carrier. A more detailed description of the Seiko Communications Systems can be found in the literature supplied by Seiko Communications Systems, Inc. (1995).

The Seiko Communications Systems (SCS) is composed of the SWIFT Message Delivery System (MDS) and the FM stations that broadcast the information. Conceptually, the SWIFT Field Operational Test MDS consists of several input streams each entering via a Message Entry (ME) unit, as illustrated in Figure 2-5. The relevant data then passes through a Message Processor (MP) which routes the data to a multiplicity of Transmission Equipment (TREQ) units where each TREQ unit prepares the data for transmission. The data are then transmitted via satellite to seven FM stations in the Seattle area, which in turn broadcast the data via an FM sub-carrier to be received by the three test devices. The focus of this section will be on describing the MDS component.

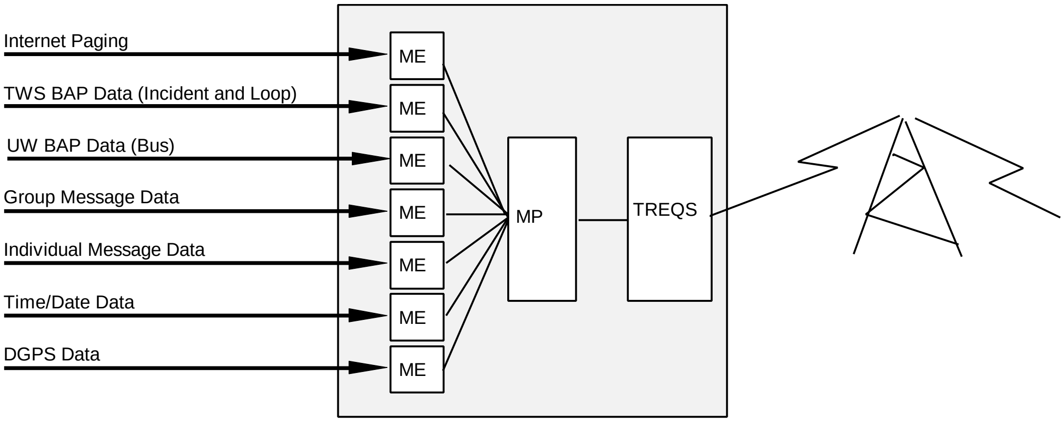


Figure 2-5. Data at the Seiko Communications System Node (Source: Seiko, 1996).

The SWIFT MDS receives data from a variety of sources as follows:

- Telephone input and voice response for individual paging messages
- Telephone input utilizing modems for entering alpha-numeric messages
- Geographic Positioning System (GPS) receivers used to update time/date
- Operators at specialized computer terminals input 16-character text messages to MessageWatches consisting of general information such as news, sports and weather
- Freeway loop data and incident data in HSDS-BAP format received from Metro Traffic Control via the Internet
- Traffic incident data destined for the MessageWatches received from Metro Traffic Control via the Internet in Wireless Message Format (WMF)
- Bus location data in HSDS-BAP format received from the University of Washington via the Internet
- Electronic mail confirming a ride share match received from the University of Washington via the Internet
- Differential GPS received from differential location corrections data stream in RTCM-104 format
- Internet input to Seiko’s site allows text paging messages to be sent.

There are three potential message types defined for the SWIFT MDS, as follows:

- HSDS-BAP Data Gram Service
- Wireless Message Format (WMF) Paging Data
- Simple Mail Transport Protocol (SMTP)

HSDS-BAP and WMF ITS Data

The HSDS-BAP ITS data consists of an integral number of 14 byte transport packets, as illustrated in Figure 2-6. The WMF ITS data consists of 1 or more variable messages, as illustrated in Figure 2-7. Each message consists of a 1 byte field to define the message type, a 1 byte field to specify the length of the message and the message whose length is defined by the length field minus 2 bytes.

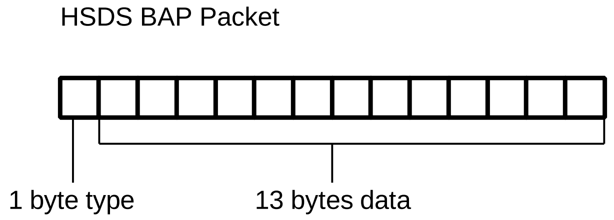


Figure 2-6. HSDS-BAP Packet Structure (Source: Seiko, 1996).

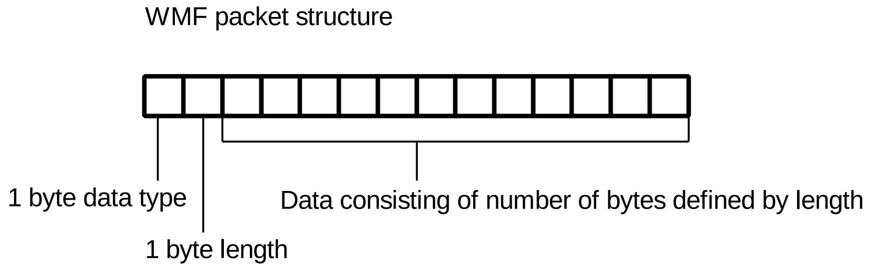


Figure 2-7. WMF Packet Structure (Source: Seiko, 1996).

The SWIFT HSDS-BAP uses the 1C6 data type from the University of Washington for bus data and the 1A0 and 2B2 data types from Metro Traffic for link data. The SWIFT MDS does not verify or inspect the HSDS-BAP data that it transports, and all HSDS-BAP data use the same air channel number.

Information from Metro Traffic and the University of Washington in HSDS-BAP form utilize HSDS-95LCG Packet Format (as described in the HSDS-95 Protocol Document). Each HSDS-BAP packet can stand alone and be interpreted by the devices without regard to future packets.

WMF Paging Data

The WMF provides the ability to enter traffic incident reports that are targeted for individual receivers. The information is provided as individual messages to each traveler rather than as a group message with a group ring. This method was chosen to keep available the group ring and allow for personalized service.

The packets are validated to verify that the destination of the receiver is valid and to generate receiver registration numbers, message numbers and translate the ASCII message into the appropriate Personal Paging Messages. The Personal Paging Messages are as follows: 16 characters in length, moderately reliable, high priority, maximum battery savings, and maximum local coverage.

The information is then transmitted over the HSDS FM three times with each transmission consuming a 1.875 minute time slot. Thus, the MessageWatch can require up to approximately 5.5 minutes to receive ITS personalized messages (3×1.875). This is intended to extend the battery life of the wrist watches.

Simple Mail Transport Protocol (SMTP)

The MDS provides Simple Mail Transport Protocol (SMTP) as the primary method for SWIFT ride share match and acceptance. The source for ride match is the University of Washington. When users at UW terminals receive a ride match they will be able to notify the person with whom the match has been allocated via electronic mail. The first 16 characters of the subject will be sent to the MessageWatch or other HSDS receivers using Personal Paging Message service. The MDS upon receiving mail validates the user ID (the international phone number associated with the receiver).

2.3. SWIFT System Architecture Links

The SWIFT system utilizes a variety of information sources and delivers information on several platforms. The fidelity of the information delivered can be limited by either the capabilities of the architectural nodes, as in the case of the wrist watch, or by the capabilities of the architectural links, as in the case of the hand-held computer which is limited by the bandwidth of the wireless communication links. Consequently, both the architectural nodes and links of the SWIFT system should be considered when evaluating its architecture.

The previous section described the architectural nodes associated with the SWIFT system. In this section the links that connect these architectural nodes are described. The links associated with the SWIFT system are: the Internet and FM subcarrier links.

2.3.1. Background

The Electronic Digital Interchange for Advanced Communications Transport (EDIFACT) standard was chosen for the transfer of traffic/traveler information in the SWIFT system. The EDIFACT standard provides an efficient means of guaranteeing accurate communication over the HSDS. It provides a database of messages that is shared by both ends of the communication and a common messaging format to encapsulate messages from the shared database for transmission over HSDS. To transfer information in an EDIFACT format, the information source first consults the dictionary of possible messages and selects the one most appropriate for the situation. This message is represented by a relatively short code that is transmitted across the communication media. The user device receives the code and converts it back into the extended message by consulting the peer database maintained on the user device. This method compresses the information transmitted, however, it does require that the database be maintained at both ends of the communication link.

The International Traveler Information Standard (ITIS) is a proposed standard for EDIFACT messaging in the traveler/traffic information arena. For the SWIFT project, the HSDS-BAP specifies a means of applying the proposed ITIS standard to Seiko's wireless technology. The partners, lead by Seiko, developed an open non-proprietary HSDS-BAP that specifies the list of messages and the message format for use in traffic/traveler information systems over an HSDS. This definition for the structure of information allows the information providers to encode information efficiently while the message definitions allow the messages to be device specific. This style of messaging allows for efficient use of Seiko's HSDS and provides a defined structure for the information providers to build packets of data of appropriate size and format to interface with the HSDS.

2.3.2. Internet Links

The communications backbone in the SWIFT system is built on the Internet suite. The Internet allows for similar communication with other components in the SWIFT architecture. The protocols and interfaces are such that a new application can communicate directly with an existing component for its own purposes without impacting the performance of the other existing applications. Thus, within this framework, new components can be added and new Intelligent Transportation Systems (ITS) applications can be designed by selecting various components of the architecture.

The use of the Internet as the SWIFT backbone, on the one hand, allows partners to be located anywhere on the Internet or to select private data lines for interconnection. However, the use of the Internet, on the other hand, provides a communication backbone that the system does not have complete control over. Consequently, the performance of the communication backbone might be impacted by factors that are beyond the control of the SWIFT system, like for example the Internet usage.

The data transfer between the data sources and the HSDS is done in an atomic manner using a specified HSDS-BAP packet for each type of message and encapsulating it in the Transport Control Protocol (TCP) from the Internet suite.

This section describes in some detail the Internet communication links between the University of Washington, on the one hand, and the Seiko Communications System, and Metro Traffic, on the other hand, and the Seiko Communications System.

Internet Communication Overview

The reliable stream delivery, as defined by the Transmission Control Protocol (TCP), is utilized for the Internet connections. A framing structure is used to package multiple application packets (either HSDS-BAP or WMF) into larger units to be transported over the Internet to the Seiko Communications System as illustrated in Figure 2-8.

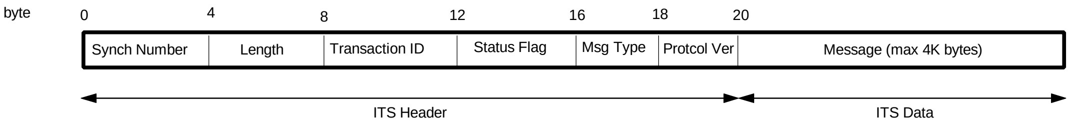


Figure 2-8. ITS Message Frame (Source: Seiko, 1996).

The synchronization number field is used to detect loss of synchronization. When any ITS message is sent, the first four bytes contain the synchronization number. If the synchronization number is not detected, synchronization has been lost and the receiver proceeds in its error handling process.

The length field contains the entire length of the ITS message, including both the header and the data. The Transaction ID field contains a number beginning at 1 upon connection and incremented for each ITS message request sent from the client. The Status Flag field is not utilized in SWIFT. The Message Type field defines the structure of the ITS Data field. There are three possible messages, namely; HSDS-BAP messages, WMF messages, and TD messages. These message types were described earlier as part of the description of the SCS architectural node, and are not discussed any further in this section.

Link Between University of Washington and Seiko Communications Systems

In the TCP/IP connection between the University of Washington and the SWIFT MDS, UW acts as the transport-layer server and the SWIFT MDS acts as the transport-layer client. ITS data flow from UW to the SCS SWIFT MDS.

Connection is initiated by the client (SCS) which creates a socket. The client then connects the socket to the UW server using the IP address “bap.ivhs.washington.edu” and port 8299. Once a good connection is established, the client issues a read request to pull in ITS messages from the TCP/IP stream.

The client assumes a disconnection whenever a read returns a 0 value indicating End of File (EOF). It then handles the EOF as an error. Once an error is discovered, the client issues a TCP shutdown system call, if needed, to close its end of the connection and then begins a reconnect request.

The reconnect sequence relies on two parameters. The first parameter specifies the maximum amount of time between connection attempts while the second parameter specifies maximum number of retries to attempt. When attempting to reconnect, the client starts with a “sleep” time of 1 second. If the reconnect attempt fails, the “sleep” time value is doubled. This doubling of the reconnect time continues after each fail until the maximum duration for reconnection is reached. The “sleep” value will remain at that point until a connection is established or the maximum number of retry attempts has been reached.

Link Between Metro Traffic and Seiko Communications Systems

In the TCP/IP connection between the Traffic Work Station (located in Metro Traffic) and the SWIFT MDS, the SWIFT MDS acts as the transport-layer server and the TWS acts as the transport-layer client. Data flows from the TWS to the SCS SWIFT MDS. The server provides a single logical port for each type of HSDS-BAP data that it expects to receive from the TWS client, so that all types of HSDS-BAP data are received on that logical port.

The server process creates a socket for the logical port, binds to the socket, and issues a listen system call to prepare the socket for connection. The server then issues an accept system call to wait for a connection request. Once a connection request is received from the TWS the server establishes the connection using the socket created by the accept function to handle the communication with the client. The server then issues a read on the socket to begin taking in ITS message frames that contain either HSDS-BAP (loop data) or WMF (incident information) data.

The server assumes a disconnection whenever a read encounters an End of File (EOF) which is handled as an error. Once an error is discovered, the server issues a TCP shutdown system call, if needed, to close its end of the connection. It closes the socket and begins a reconnect sequence which is identical to the connect sequence.

2.3.3. HSDS FM Sub-carrier Links

Sweden in 1978 was the first country to use sub-carriers for paging using Radio Data Systems (RDS) (Elliot and Dailey, 1995). The RDS Frequency Modulation (FM) sub-carrier system takes advantage of the radio towers that are already in place to broadcast FM programming and multiplexes a 57 kHz data sub-carrier along with the FM signal. A clear advantage to this system is that the amount of infrastructure required to implement FM-based paging is greatly reduced; a disadvantage results from FM’s inability to penetrate as deeply into buildings as traditional paging signals.

The SWIFT Field Operational Test transmits traffic and pager information via an FM sub-carrier High Speed Data System (HSDS) that was developed by Seiko Communications Systems, a member of the Seiko Group of companies. The HSDS was developed as a means of creating a network for delivering personal communication information services. HSDS has been commercially deployed in Portland, Seattle, Los Angeles, San Diego, Las Vegas, and New York City in the US and in the Netherlands overseas.

The HSDS protocol is a time-division multiplex service similar to the digital cellular telephone networks common in the US, Japan, and most of Europe. However, instead of requiring the construction of numerous individual transmitters (cell sites) to service the region, HSDS takes advantage of the un-utilized spectrum available in the non-audio region of commercial FM transmitters in the 75-108 kHz frequency band around the world.

By taking advantage of the existing worldwide FM broadcast infrastructure, HSDS technology dramatically decreases the cost basis of delivering personal communication services to the consumer. Any FM broadcast transmitter can be enabled to carry the HSDS sub-carrier. HSDS can be transmitted in conjunction with other sub-carrier services such as Radio Data Systems (RDS).

HSDS Description

This section provides a brief description of the HSDS protocol and compares it to another sub-carrier service, namely; the Radio Data Systems (RDS). For more information on the HSDS the reader may refer to Gaskill and Gray (1993).

The HSDS protocol is a one-way communications protocol that permits the use of very small receivers. Receivers, with duty cycles varying from continuously on to duty cycles less than 0.01 percent on, provide flexibility to select message delay, data throughput and battery life. HSDS can operate as a stand-alone single station (channel) system, or as multiple systems operating independently in a geographical area with each system including multiple stations. Multiple stations are accommodated by frequency-agile receivers and time offset message transmission on each station.

The HSDS is time division multiplexed by dividing time into a system of master frames, subframes and time slots. Each slot contains a packet of information. In multiple station systems, each station's transmission is synchronized. Each receiver is assigned a subset of slots as times for monitoring transmissions. Each slot is numbered and each data packet contains the slot number in order to permit rapid location of assigned time slots.

The HSDS data rate is 19 kbps in a bandwidth of 19 kHz, which is symmetric and centered at 66.5 kHz (i.e. between 57 kHz and 76 kHz). The HSDS sub-carrier is added onto the FM station's baseband signal before being FM modulated onto the Radio Frequency (RF) carrier.

HSDS Reliability

Robust wireless systems require methods to address multipath and shadowing issues which play a significant role in determining system performance. Multipath can be viewed as a time-varying non-linearity that can distort or reduce the received signal to a point that reliable reception is no longer possible. Shadows behind hills and mountains or due to man-made structures can reduce signal strengths below sensitivity levels.

Some systems attempt to address the multi-path and shadowing problems utilizing extensive error correction schemes. While these schemes may be useful for a moving receiver, they become ineffective when the receiver is stopped in an extremely low signal strength area or the receiver is moving very slowly through multi-path nulls. A car stopped at a traffic signal or a person inside a building are two examples of the breakdown of even the most robust error correction methods. The HSDS addresses multi-path and shadowing problems utilizing a diversity of techniques including: frequency, space and time diversity and message numbering.

Frequency diversity can be achieved through the capability to tune any frequency in the range from 87.5 to 108 kHz. By transmitting on multiple frequencies a receiver in a multi-path null at one frequency is not likely to be in a multi-path null on another frequency. However, transmitting on multiple frequencies clearly consumes more bandwidth than single transmissions.

Space diversity (transmitters at different locations), on the one hand, provides paths from two or more directions reducing the size of shadowed areas, and reducing the possibility of missed messages. Time diversity, on the other hand, can be provided in two ways, namely; multiple transmission from the same station or delayed transmission between stations. Multiple transmissions of information several minutes apart is utilized for wrist mobile applications where a receiver may be passing through a radio frequency shielded area temporarily, such as a tunnel or deep basement. The second method for time diversity includes a time offset for data transmission between stations. This time offset between stations provides an opportunity for low data rate receivers to change the tuned frequency and make subsequent attempts to receive a packet. When much greater throughput is required, receivers only operate on the best station selected from the stations available.

In addition to diversity techniques, each transmission includes a transmitted message number that eliminates duplicate messages and permits detection of missed messages. By receivers rejecting duplicated messages, multiple transmissions would not appear as duplicate messages on the receivers. A receiver can keep track of the received message numbers, and if there is a skip in the message sequence, it can detect that a message was missed. The input system can log each message by message number and permit retrieval of missed messages by phone. Messages are stored for 48 hours at the SCS in order to allow retrieval of missed messages.

For the SWIFT FOT, traffic data in addition to paging data are transmitted from seven radio stations in the Seattle area. These seven stations provide coverage from Olympia and Eatonville in the south to Bellingham in the north as illustrated in Figure 2-9.

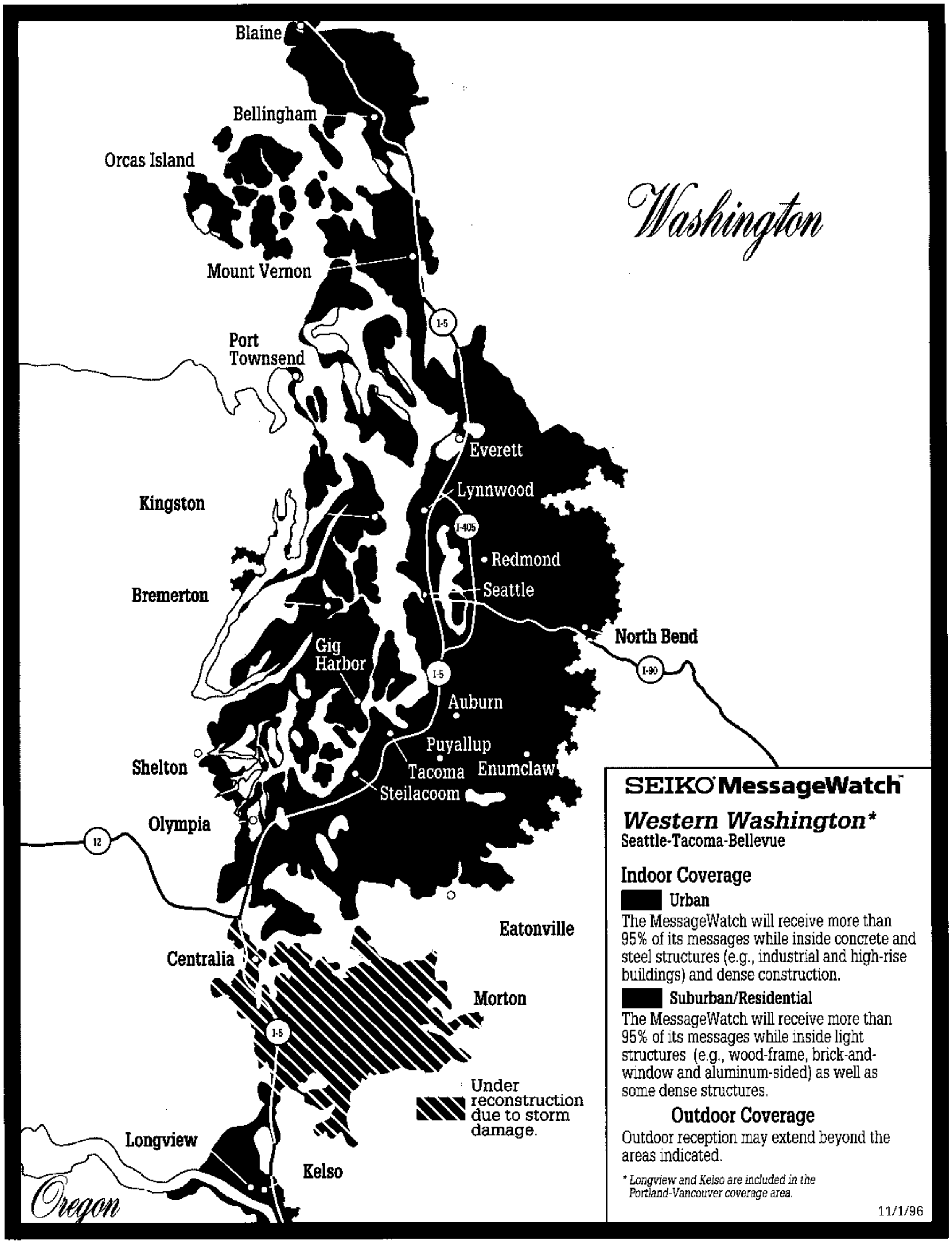
Field Testing of HSDS

Two field tests in Portland, Oregon were conducted in order to evaluate the performance of the HSDS. The first set of tests, in 1987, was utilized for initial range and performance evaluation including error correction techniques. The second set of tests, in 1989, was utilized to determine coverage of the commercial system. The first set of tests indicated that the effectiveness of error correction was clearly significant and helpful at relatively high RF power levels. These tests also indicated that more extensive error correction schemes would not improve the results significantly but would negatively impact the capacity of the system. Consequently, it was decided that multiple transmissions would be utilized in order to address error correction issues. The second set of tests indicated that there was significant increase in coverage associated with multiple transmissions.

The Field Operational Test SWIFT is also another avenue to evaluate the efficiency of the HSDS. Both the Architecture and Communications Studies will attempt to quantify the efficiency of HSDS. The *SWIFT Architecture Study* will evaluate the HSDS as a link in the entire SWIFT architecture while the Communications Study will evaluate the coverage of the HSDS.

HSDS Versus RDS

The Radio Data System (RDS) for FM broadcasting was developed within the European Broadcasting Union (EBU). This system was specified by the EBU in 1984 and has been introduced in the large majority of European countries since 1987. Later the system was slightly enhanced through several modifications, and in 1990 was adopted as a European standard of CENELEC (EN 50067).



SEIKO MessageWatch™

Western Washington*

Seattle-Tacoma-Bellevue

Indoor Coverage

■ **Urban**

The MessageWatch will receive more than 95% of its messages while inside concrete and steel structures (e.g., industrial and high-rise buildings) and dense construction.

■ **Suburban/Residential**

The MessageWatch will receive more than 95% of its messages while inside light structures (e.g., wood-frame, brick-and-window and aluminum-sided) as well as some dense structures.

Outdoor Coverage

Outdoor reception may extend beyond the areas indicated.

** Longview and Kelso are included in the Portland-Vancouver coverage area.*

11/1/96

Figure 2-9. Washington State Coverage Map.

In the USA, a sub-group on radio broadcast data systems of the National Radio Systems Committee (NRSC), sponsored by the Electronics Industry Association (EIA) and the National Association of Broadcasters (NAB) made an attempt to keep the US standard compatible with the EBU standard. However, it became evident that the completely different broadcasting structure of the US required a number of modifications to be made to the RDS. The US standard needed to cover AM broadcasting in addition to FM broadcasting. In August 1992, the NRSC adopted the Radio Broadcast Data System (RBDS) as the standard.

RDS and RBDS have the same data broadcast signal modulation characteristics. Both occupy the 54.6 to 59.4 kHz band and provide a data rate of 1187.5 bits per second (bps). Consequently, it is evident that HSDS throughput capacity is approximately 15 folds higher than the RDS and RBDS throughput capacities (19,000 versus 1,187.5 bps). The reason the EBU selected RDS as opposed to HSDS as the standard for broadcasting data was because they had not done field tests evaluating the robustness and reliability of HSDS and thus selected, in their opinion, a more reliable lower capacity system. Again, the SWIFT Field Operational Test will provide a unique opportunity to evaluate the effectiveness of HSDS as a data transmission system.

Lab tests were conducted at Seiko Communications Systems (Gaskill and Gray, 1993) to evaluate the effects of the HSDS signal on RDS reception. The results indicated that the impact of the HSDS signal on RDS sensitivity was less than the impact of L-R audio (0.75 dB versus 1 dB) and thus it was concluded that HSDS would not impact RDS sensitivity.

Summary

The HSDS communication links are much more complex than the other architectural links that were described in this section. The complexity arises from the fact that some of these communications (but not all) are dependent on the number of concurrent users of the system. In addition, the volume of other paging activities, that may be completely unrelated to the transportation functions of SWIFT may have a considerable impact on the performance of the SWIFT system. Capacity is also more limited in the final wireless communications, compared to the other communication links, and a change to the nature of these communications would significantly change the architecture of the system. This fact, together with the special issues surrounding signal interference, signal coverage, and queuing delay, warrant a special in depth analysis of this final communication link.

The purpose of the *SWIFT Communications Study* was to focus specifically on the final communication link from the FM transmitter to the end user devices. The *SWIFT Architecture Study* will not duplicate this effort, but instead it will incorporate the results of the Communications Study for the evaluation of the efficiency and reliability of the HSDS link as part of the overall SWIFT FOT architecture.

2.4. SWIFT Field Operational Test Reception Devices

Three types of HSDS-capable receiver devices, each developed and manufactured by private entities, provided SWIFT users with traffic advisories and congestion information. Some of these devices provided the SWIFT users with bus information, personal-paging capabilities and informational messages, depending upon the device. These devices included:

- Delco In-Vehicle Navigation Devices
- PC computers including Dauphins, Thinkpads, and Toshiba machines
- Seiko MessageWatch™

Each of these device types is described in the following sections.

2.4.1. Delco In-Vehicle Navigation Device

The multi-featured Delco device incorporated an in-vehicle navigation unit that presented real-time traffic information. The navigation unit came with a radio/compact disc player and replaced an existing car radio in one of three, 1995 or newer, vehicle types: Buick Regal, Oldsmobile Cutlass Supreme, and Saturn. One hundred (100) Delco in-vehicle navigation units and radio/compact disc players were used in the SWIFT FOT.

Destinations can be selected from a “Yellow Pages” directory of local landmarks, hotels, restaurants, businesses and street corners selected by the user. A Global Positioning System (GPS) provides the current location of the vehicle. The GPS is augmented by a Differential GPS (DGPS) signal from the Seiko HSDS sub-carrier system to improve accuracy to less than 10 meters. A display indicates the direction (relative to the vehicle) and distance to the selected destination.

Real-time traffic incident information is transmitted over the Seiko HSDS system using an International Traveler Information System (ITIS) format. The Seiko-HSDS receiver is built into the Delco in-vehicle navigation unit. The navigation unit filters out any messages beyond the specified radius. The navigation unit also decodes the ITIS messages into text, which is converted to voice and announced to the driver. Although messages are retransmitted every minute, only new or modified messages are announced.

The Delco in-vehicle navigation device also supports personal paging and other existing Seiko information services (weather, financial and sports information).

2.4.2. IBM Portable Computers

The SWIFT project also used Dauphins, IBM Thinkpads, and Toshiba Satellite portable computers as user receiver devices. As mentioned earlier, the Dauphins were abandoned during the FOT because of the black and white display of the devices which deemed it impossible to view the traffic information. All the applications ran under Windows 3.1 in the case of Thinkpads and under Windows 95 in the case of the Toshiba Satellite. The Thinkpads had a built-in, “butterfly” keyboard and had an active matrix, SVGA color display. The Toshiba laptops were Pentium Pros with 16 Mbytes of Random Access Memory (RAM). One hundred portable computers, with a mix of the two PC’s, were used in the Field Operational Test in order to test the SWIFT system for different PC hardware and software environments.

A separate Seiko-HSDS Radio Receiver Module (RRM) unit was attached to each PC in order to receive the traveler information and to send the information to the portable computer's serial port. The data was sent in the HSDS ITIS format. Traveler information for the computer included traffic incident, congestion and bus-location information. The portable computers also supported personal paging, other existing Seiko information services (e.g., weather, financial reports and sports scores) and ASCII text messages to support more detailed presentations of Seiko information services.

All of the traveler information for portable computers were displayed using Etak map-based software to show the location of each piece of data. The software allowed the user to select the type of information (i.e., traffic incident, congestion or transit vehicle location) to be displayed. Each type of information was updated once a minute. A "Yellow Pages" directory was also installed and linked to the map-based software to show the location of a selected business. The computer also offered transit schedule information from static database tables inside the computer.

2.4.3. Seiko MessageWatch

Seiko MessageWatches are already commercial and are currently used to deliver paging messages and "information services." Current information services include weather forecasts, financial market summaries, local sports scores and winning lotto numbers. The watches also automatically update their time at least 36 times a day. The full-featured MessageWatch measures 3.5 centimeters across, and is 1 centimeter thick and weighs 1.2 ounces. The MessageWatch is designed to check for information 0.1 seconds every 1.87 minutes in order to allow a standard lithium battery to last for approximately a year to a year and a half.

Traffic messages are featured as an added information service for the Field Operational Test. Test participants using the Seiko MessageWatch supply information about usual routes and the times of the day they travel. Traffic messages indicating the location and severity of traffic problems that the user might encounter are sent based on the resulting travel profile. Because Seiko MessageWatch pagers only store eight messages, only traffic problems that would result in substantial delays are sent. Traffic problems are sent as personal paging messages to specified users, allowing messages to be tailored to individuals. Five hundred and twenty (520) Seiko MessageWatch users were participants in the SWIFT Field Operational Test, 470 new watch users and 50 existing users.

The SWIFT traffic message display for the Seiko MessageWatch provides SWIFT participants with the severity and location of major traffic incidents on the freeway system in the greater Seattle area. To limit the number of messages, only those incidents that are beyond normal congestion levels and that substantially affect traffic are sent to the MessageWatch. Participants indicate when they want to be notified and which highways they want to know about by selecting the highway segments on their route, by indicating the times of day they travel, and by specifying the days of the week that they want to be notified. Traffic messages “beep” if the beeper function is selected on the watch as indicated by the “B<” icon.

The Seiko MessageWatch has a limited 16-character alphanumeric display. Each of the character positions is comprised of seven segments, making it difficult to display letters with anomalies like “G” and “Q” or diagonals like “M” or “X.” The characters that can be displayed are: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, a space, -, [,], A, b, d, E, F, H, J, L, n, P, r, t, U, y, -, =, and the degree symbol. Some undisplayable alpha characters are replaced with displayable characters. For example “C” is replaced by “[”, “G” with “6”, “g” with “9”, “I” with “1”, “O” with “0”, “Q” with “9”, “S” with

“5”, and “Z” with “2”. The undisplayable alpha characters K, M, V, W, and X have no reasonable replacements, so they are replaced with an underscore (“_”).

Traffic Messages consist of a top line and a bottom line of up to 8 characters each. The left portion of the top line of the display always begins with the letter “H” followed by a 1 to 3 character number, signifying the interstate/highway on which the incident is located.

The right-hand portion of the top line is a three character alphanumeric display that begins with either the letters “CL” (indicating that the highway is closed), or the letter “L” (severity level) followed by the severity level indicator (1, 2, or 3). A level 1 incident indicates a traffic accident that has caused a traffic backup but one or more lanes are open so that traffic can get through. A level 2 incident indicates an accident which blocks most or all of the freeway section, causing very extensive traffic backup with only a small amount of traffic getting through. A level 3 incident indicates an extremely serious traffic accident that has caused the freeway to be closed for an indefinite period of time.

The last character on the upper right-hand portion of the top line is a letter indicating the direction of the highway in which the incident is located. For example, an “E” is used for eastbound traffic, a “5” for southbound traffic, an “n” for northbound traffic, and an “_” for westbound traffic. A letter “b” indicates that both directions are impacted by the incident.

The bottom line of the display is an 8 character abbreviation of the cross street nearest to the incident. Some of the names are very easy to read, but because of the limited nature of the display and the difficulty in compressing long names into 8 characters, some street names can be somewhat difficult to interpret. For example, the message that is illustrated in Figure 2-10 indicates that I-90 is closed in the westbound direction at the East Mercer interchange.

Figure 2-10. Sample MessageWatch Message.

From the description of the Seiko MessageWatch that was presented in this section, it appears that the display limitations of the Seiko MessageWatch are clearly technological limitations as opposed to architectural limitations.

2.5. SWIFT “Problems”

Although the SWIFT FOT was successful in deploying and demonstrating the features and impacts of an ATIS fielded in a metropolitan environment, some “difficulties” or “glitches” were experienced by the end-users of the service. Thus, a list of the most salient of these technical problems is presented in order to provide the reader with a more complete understanding of the situational context within which SWIFT was evaluated and, in particular, to understand the meaning of the results that are presented in this report. Among the “problems” experienced by SWIFT participants were the following:

Seiko MessageWatches

- *Traffic Workstation (TWS) Updates Would Require System to be Turned Off*—Importing of SWIFT traveler profiles could only be accomplished if SWIFT system was shut down and traffic-incident operations stopped. (Not fixed during SWIFT)
- *Server Connectivity Problems*—SWIFT operations would be interrupted by inability of TWS to connect to Seiko server. (Not fixed during SWIFT)
- *Message Delay*—Each SWIFT message was sent three (3) times, once every 1:52. If more than one message was sent at one time, message transmission to user was delayed proportionally. This is an inherent feature of the Seiko MessageWatch. (Not fixed during SWIFT)

Delco In-vehicle-Navigation Devices

- *Unit “locks up”*—booting problem upon startup caused units to freeze up, or not work. (Fixed with software update)
- *Readout of Affected Roadways Obscured*—SWIFT messages presented in display monitor were presented in long-text form, thus making it impossible for driver to see complete incident roadway intersection. (Fixed with software update)
- *Wrong Direction Indicated*—“Voice” readings of SWIFT messages provided opposite roadway direction. (Fixed with software update)
- *No General-Information Messages and Personal-Paging Services*—general-information messages were not received and personal-paging function did not work. (Not fixed during SWIFT)
- *Water Leakage*—water leaked into vehicle from area where GPS-antenna wire was threaded from roof around door jam into vehicle dashboard. (Fixed upon request)

Portable Computers

- *Incorrect Display of Speed/Congestion Information*—Data conversion problems caused incorrect mapping of speed data for locations and/or incorrect interpretation of speed data for a given location (Fixed with software upgrade)
- *No General-Information Messages and Personal-Paging Services*—general-information messages were not received and personal-paging function did not work (Not fixed during SWIFT)
- *Real-Time Bus Position Information Missing*—approximately 30% of all buses were not displayed (Not fixed during SWIFT)
- *RRM Connectivity Problems*—RRM would connect on an intermittent basis, possibly due to an insufficient battery charge since this problem became less frequent as the

SWIFT FOT elapsed and SWIFT RRMs were used more regularly. (Not fixed during SWIFT)

2.6. Summary of SWIFT Architecture Overview

The objective of this section was to describe the SWIFT system architecture as a first step in the architecture evaluation. The SWIFT system architecture was decomposed into its constituent architectural nodes and links in order to facilitate the architecture evaluation. The architectural nodes represent a set of data processing activities confined by organizational rather than geographical boundaries. The links provide data connections between the different architectural nodes. Based on the architectural description, the following sections evaluate the architectural objectives that were defined in the previous section.

3. TEST METHODOLOGY AND RESULTS

The methodologies that were utilized to collect data and the results of the *SWIFT Architecture Study* are presented in the following sections according to each evaluation objective.

- System operating as intended from user's perspective
- System operating as intended from system's perspective
- System not operating as intended from user's perspective
- System not operating as intended from system's perspective

The objectives of this section are four-fold. First, it establishes the consistency of user perceptions with the actual system performance. Second, it attempts to identify the operational characteristics of the system that were not recognized by the SWIFT field operational test participants. Third, this section attempts to identify the source of any architectural limitations that were observed by users during the field operational test. Finally, this section focuses on evaluating the SWIFT architecture for conditions that contributed to the system not operating as intended.

3.1. Objective 1: Assess System Performance from User's Perspective

The user perspective on system performance was evaluated through questionnaires and focus groups through questions that were constructed as part of the *SWIFT Architecture Study*. These questionnaires were conducted as part of the *SWIFT Consumer Acceptance Study*. In addition, the *SWIFT Architecture Study* conducted a limited field test that evaluated the usefulness of the three SWIFT reception devices. An overview of each of these procedures and the results of these procedures are provided in the following sub-sections.

3.1.1. Test Methodology

User Questionnaires and Focus Groups

The questionnaire portion of the *SWIFT Architecture Study* focused primarily on capturing the experiences and perceptions of system users during the course of their use of a particular SWIFT device. Some of the questions within the questionnaires were tailored towards a specific SWIFT device and user type (e.g. automobile, ride share, or transit), while most others were common across devices and user types. These questionnaires were administered to SWIFT users on four occasions:

1. Before beginning SWIFT use (user profile questionnaire)
2. At the end of one month of use
3. At the end of six months of use
4. At the end of twelve months of use

The *SWIFT Architecture Study* provided the *SWIFT Consumer Acceptance Study* with questions to be included in the evaluation questionnaires. The *SWIFT Consumer Acceptance Study* then compiled the questions, coordinated, administered and conducted the questionnaires. The questionnaire results were provided to the *SWIFT Architecture Study* in order to conduct its analysis.

The next method to be utilized in evaluating the SWIFT architecture was through the organization of focus groups. While the conduct of these focus groups was mainly targeted towards the needs of the *SWIFT Consumer Acceptance Study*, some of the discussions were directed to also serve the needs of the *SWIFT Architecture Study*. Each focus group included approximately eight users. Separate focus groups were conducted for each SWIFT device. Focus group activities were conducted at various times during the operational phase of the test, with the first activity beginning during the second month of the field operational test.

Device Usefulness Field Test

The SWIFT device usefulness field test, which involved two tasks, was conducted on eight participants for each of the three SWIFT reception devices. The first activity was a questionnaire intended to evaluate the impact that the SWIFT information had on the participant's travel behavior. The second task was a questionnaire on positive and negative operational features of the SWIFT devices.

3.1.2. Results

The objective of this section is to summarize the user perceptions of the SWIFT system for conditions when the system operated as intended.

Questionnaire and Focus Group Results

This section summarizes the results of the *SWIFT Consumer Acceptance Study* for conditions when the SWIFT system was operating at full functionality.

Initially, the travel characteristics of the SWIFT test participants are described. These travel characteristics are extremely important while evaluating the system because it determines how travelers will respond to traffic information. For example, travelers will only be able to alter their selected route of travel, in response to traffic information, if they have multiple routes along their trip. Otherwise, the provision of traffic information will be of little benefit to the travelers in terms of their route selection.

How the participants perceived the importance and usefulness of the SWIFT traveler information is presented. In addition, the SWIFT user perceptions of the device usefulness are also summarized. Finally, the impact the SWIFT information had on the users' travel behaviors are also described.

Travel Characteristics of Test Participants. The questionnaires indicated that the SWIFT device users utilized a variety of modes for transportation to and from work. Nearly 53% of Seiko MessageWatch respondents classified themselves as exclusively drive alone auto mode commuters while approximately 44% of the Delco Device respondents and 19% of PC device respondents classified themselves into this category. Nearly 57% of PC device respondents reported using a combination of modes including bus, vanpool and carpool to travel to work. Nearly one-third of Delco respondents classified themselves as primarily carpool or vanpool commuters. Approximately two-thirds of respondents reported traveling 30 or more minutes to work. Questionnaire respondents reported having a lower amount of flexibility in choosing times to leave home for work than in leaving work for home. Over half of the participants reported that they had three or more routes to choose from when commuting to and from work.

Importance and Usefulness of Information. The majority of the Delco in-vehicle navigation device and Seiko MessageWatch respondents reported consulting traffic information at least once a week. Approximately 70% of the respondents representing users of the PC device reported consulting traffic information once a week. Over 60% of respondents reported using transit location and schedule information at least once a week while fewer than half of the respondents reported using address finding or “Yellow Pages” features at least once a week.

As part of the first and second surveys, device users were asked to indicate when they consulted their device features and information. Most respondents reported consulting information immediately before leaving on a trip. Over 20 percent reported that they consulted information while en-route. The results suggested that information provided immediately before travel had the most relevance to travelers.

The results indicated that Seiko MessageWatch users placed a great deal of importance on the receipt of traffic incident and congestion related information. The users were neutral toward general information.

In general, the Seiko MessageWatch users rated personal paging and general information messages very high across all these dimensions, as illustrated in Figure 3-1. Incident related messages were generally not rated as high along these dimensions by respondents. The ease of understanding and the timeliness of incident information was rated the lowest of all characteristics among Seiko MessageWatch users while the usefulness, reliability, and accuracy were rated highest. Incident type information was generally rated lower than either incident direction or incident location information. Seiko MessageWatch focus group participants expressed a concern with the timeliness of messages and expressed a desire for the addition of congestion related information, speed information, and a route planning service.

The results for the Delco users, as illustrated in Figure 3-2, were very similar to those observed for the Seiko MessageWatch users except that the Delco users appeared to place slightly more importance on the receipt of traffic incident and congestion related information.

The results indicate that Delco users rated personal paging lower than other information sources. This is a reflection of the technical problems that were experienced by the users. Respondents generally found the information to be easy to understand but less useful. The timeliness of incident information was rated lowest among all incident related items. Delco device focus group participants expressed a concern with the accuracy of directional information and also expressed a need to provide congestion related information. This concern regarding the accuracy of the directional information emanates from some technical problems that were encountered during the FOT which will be discussed in further detail while evaluating objective 4.

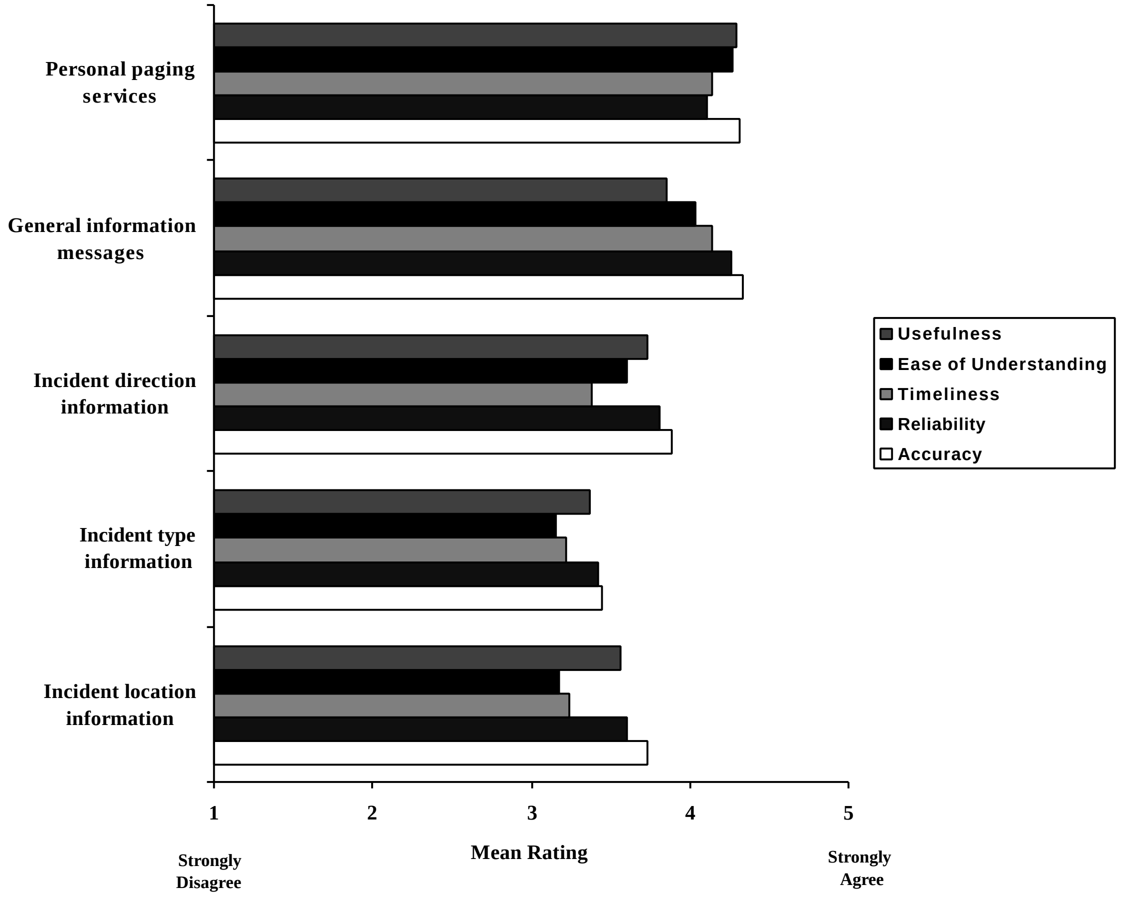


Figure 3-1. Seiko MessageWatch User Perception of Message Accuracy, Reliability, Timeliness, Ease to Understand and Usefulness.

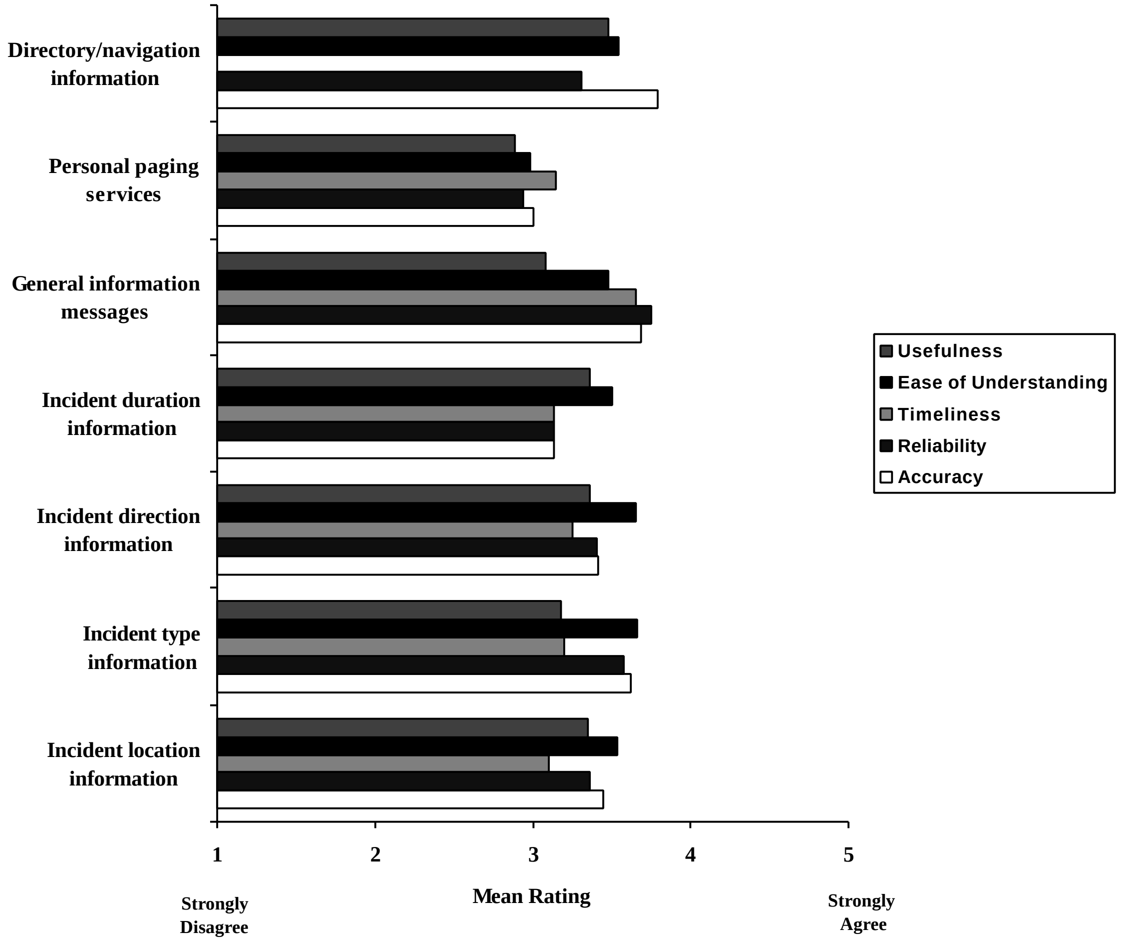


Figure 3-2. Delco User Perception of Message Accuracy, Reliability, Timeliness, Ease to Understand and Usefulness.

SWIFT 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, as illustrated in Figure 3-3.

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 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 and an expansion of the transit related data to other transit operators in the region.

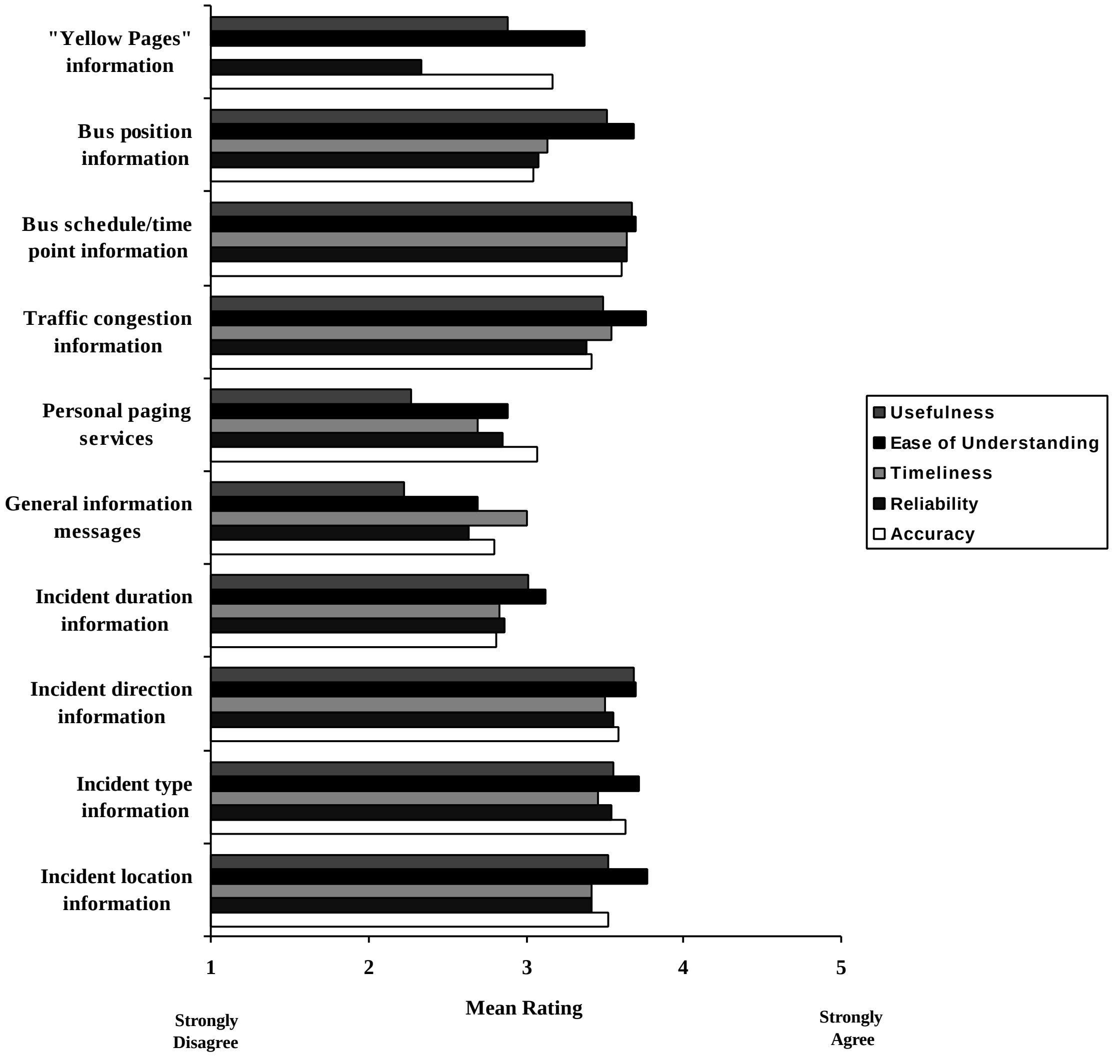


Figure 3-3. PC User Perception of Message Accuracy, Reliability, Timeliness, Ease to Understand and Usefulness.

Device Usefulness. Users of the SWIFT devices were asked, as part of the third survey, to assess several characteristics of their devices including ease of use, safety, comfort, and convenience. The results are presented in Figure 3-4. Respondents representing users of the PC device generally provided lower ratings for device convenience, comfort, and ease of use than other device users.

Overall, users of the Seiko MessageWatch rated all features higher than any other device user groups. Users of the Delco in-vehicle navigation device rated safety of use quite high, however, this rating was lower than for other device user groups.

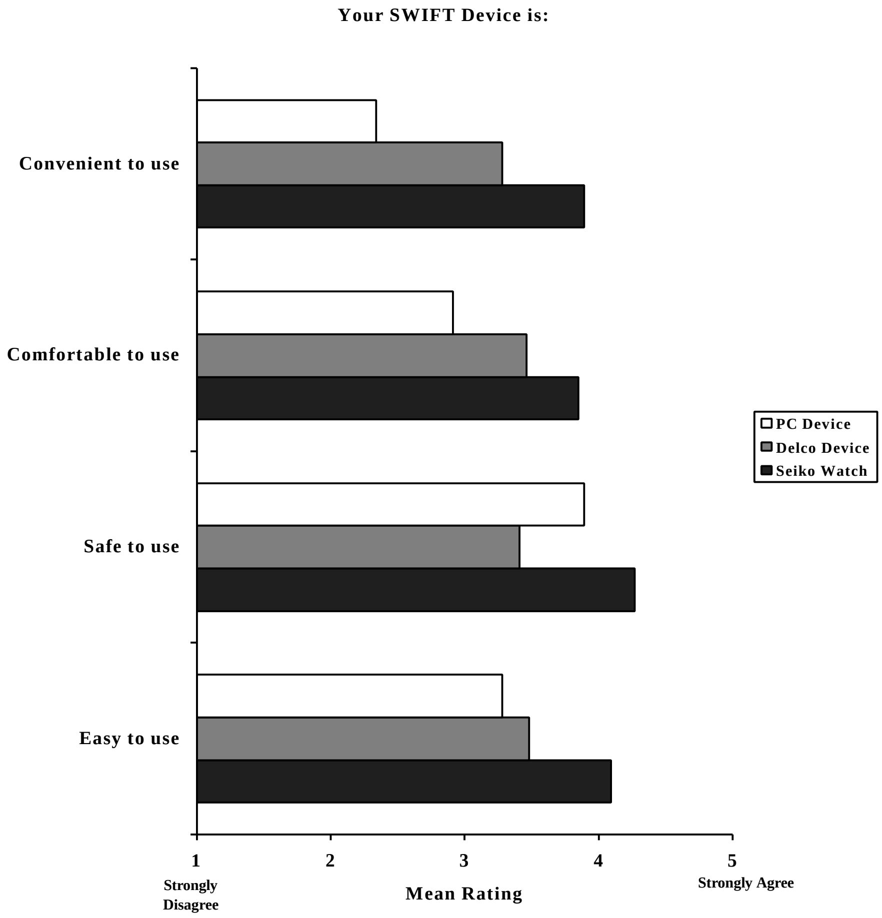


Figure 3-4. User Perception of SWIFT Device Usefulness.

Device users were asked to rate the overall usefulness of their devices on three occasions (as part of each user survey). Seiko MessageWatch users were generally very satisfied with the usefulness of their devices. Over 75 percent of the respondents to the third survey were either "extremely satisfied" or "satisfied" with the usefulness of the device. Users of the Delco in-vehicle navigation units were somewhat less satisfied than users of the Seiko MessageWatch.

Specifically, approximately 40 percent of the respondents in the third survey were either “extremely satisfied” or “satisfied”. However, nearly 30 percent were either “dissatisfied” or “extremely dissatisfied”. Users of the PC Devices were less satisfied with the usefulness of their device than users of other devices. Nearly 50 percent of the respondents to the last survey were either “dissatisfied” or “extremely dissatisfied”.

In general, Seiko MessageWatch users were satisfied with the physical characteristics of the device including the number and location of buttons as well as the message display size. Users were less satisfied with the styling and message display background lighting. In general, users were satisfied with the operating characteristics of the Seiko MessageWatch devices including the automatic storage of messages. Users reported the lowest level of satisfaction with the continuous display of the most recently received message until a new message was received or the “Time” or “Message” button was pressed.

Results for Delco Device users indicated that this group was most satisfied with the device color, size, and styling and least satisfied with the message display size and illumination of buttons and message display background lighting. The results of the questionnaires also indicated a low degree of satisfaction with personal paging, message filtering, and voice “announcement” of messages. The participants were not satisfied with the voice announcement of the messages because it interrupted the radio broadcast before and during the announcement of the message. Overall, users were somewhat neutral in the level of satisfaction for other features. The Etak Guide rated as highest in satisfaction.

In general, users of the Dauphin devices reported a lower level of satisfaction than either the IBM or Toshiba user groups for all the physical characteristics. Dauphin users appeared to be most satisfied with the screen size, and mouse/pen operation and least satisfied with the speed, weight and size of the device. The users of the Dauphins were least satisfied with the black and white display which made it extremely difficult to view the traffic information.

IBM users appeared to be most satisfied with the screen size, color and styling of the device and least satisfied with the weight and size of the device. Toshiba users followed a similar pattern. Users of the Toshiba device were most satisfied with the device color, styling, and size of the device and least satisfied with the weight of the device. In addition Toshiba users appeared to be less satisfied with the mouse/button operation than IBM Thinkpad users.

Impact of SWIFT Information on Trip Actions. In the third user survey, respondents were asked to identify the frequency with which they implemented an action affecting their commute travel as a result of receiving SWIFT travel messages. The results presented in Figure 3-5 indicate that a significant majority of respondents changed their commute route one or more times per week (70 percent) as a result of travel messages received from the SWIFT system. Another large percentage changed their commute departure time at least once a week as result of receiving SWIFT travel messages (40 percent). Approximately 20 percent combined trips or changed their travel done as part of work and less than 10 percent changed their commute mode or canceled their trip.

These results were fairly consistent across device user groups with some exceptions. Delco device users were less likely to change their commute start time and mode of travel than other users while PC device users were more likely to change their commute start time and mode than other device users. Noteworthy is the fact that only 19 percent of the PC users classified themselves as drive alone commuters while 53 percent for the Seiko MessageWatch users and 44 percent for the Delco device users classified themselves as drive alone commuters. Consequently, the discrepancies across devices could be attributed to the differences in mode of travel across device users as opposed to the differences in SWIFT devices and/or differences in SWIFT information. Among all user groups changing commute routes was the most frequent response to information provided by the SWIFT system.

In the third survey the users were also asked to identify the frequency with which they changed their commuting route as a result of various factors including the receipt of travel messages on their SWIFT Device. The results indicate that the route choice of a significant majority of respondents was affected by the receipt of radio traffic reports followed by actually encountering the incident and then by the SWIFT travel messages.

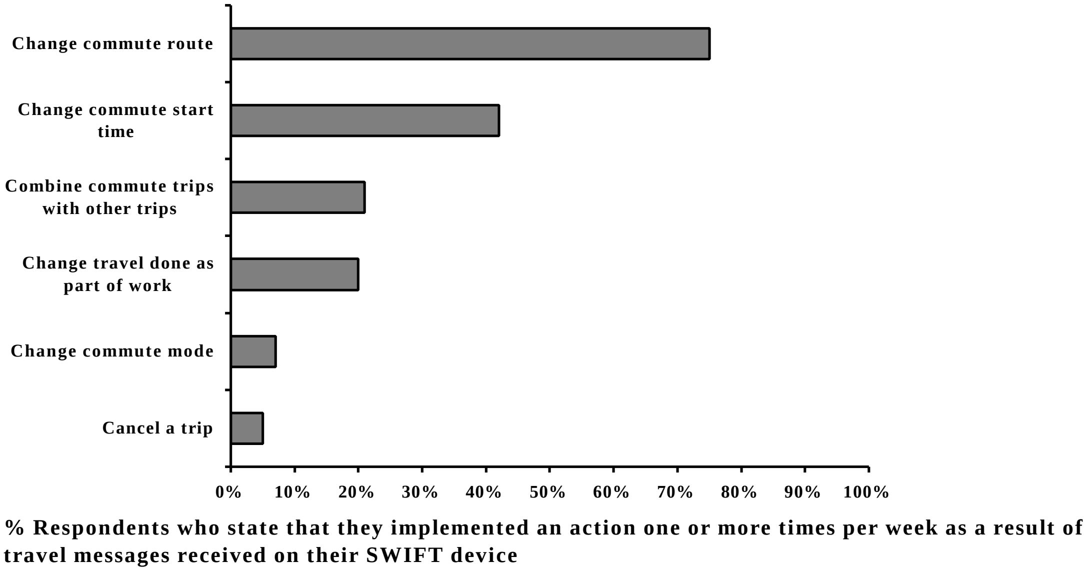


Figure 3-5. Actions Implemented by Respondents One or More Times per Week As a Result of Travel Messages Received on Their SWIFT Device.

Product Usefulness and Likeness Field Test Results

In order to further evaluate how the test participants found the information to be useful, a number of questions were asked of eight participants for each of the SWIFT reception device types (Seiko MessageWatch, Delco unit, and PC device). The eight participants per device were recruited as part of the device usability test which will be described in the objective 2 evaluation.

The questions that were asked of the users included the following:

- Do you refer to your SWIFT device frequently, often, sometimes, rarely, or never?

- Before you leave for travel, does SWIFT traveler information influence the time you leave frequently, often, sometimes, rarely, or never?
- Before you leave for travel, does SWIFT traveler information influence your route choice frequently, often, sometimes, rarely, or never?
- Before you leave for travel, does SWIFT traveler information influence your means or mode of transportation frequently, often, sometimes, rarely, or never?

Figure 3-6 illustrates that there appeared to be no obvious trend with regards to referring to the Seiko MessageWatch and PC devices, however, the navigation devices were highly utilized by the participants. Specifically, 62 percent of the navigation unit participants frequently referred to their device, 27 percent referred to their device often, and 11 percent referred to their device sometimes.

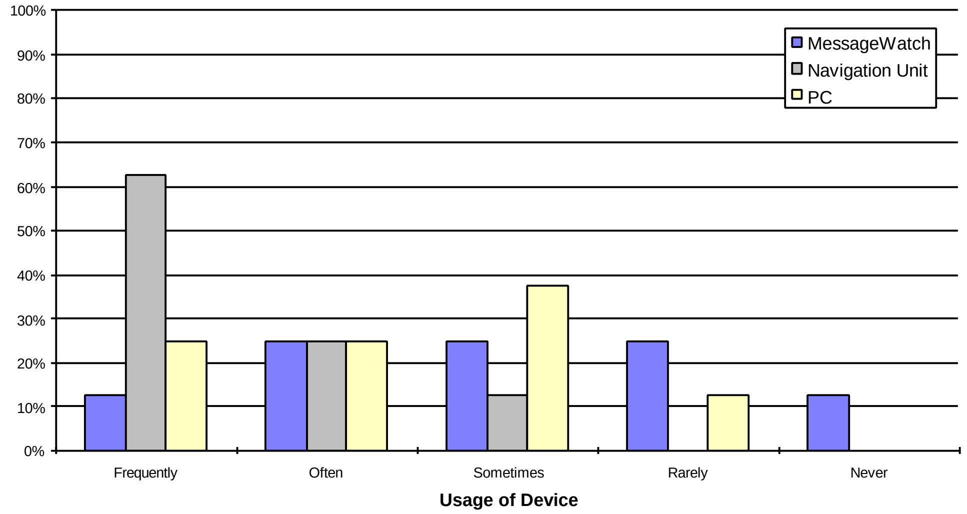


Figure 3-6. SWIFT Device Usage Frequency.

The SWIFT information appeared not to have a conclusive impact on the departure time of MessageWatch, navigation unit, and PC users, as illustrated in Figure 3-7. In other words, the majority of participants did not consider the SWIFT information in selecting their time of departure (the majority of participants were in the “rarely” and “never” categories). The questionnaire responses, however, indicated that a considerable number (40 percent) of the SWIFT participants changed their departure time at least one or more times per week in response to the SWIFT information. Given the small sample size of the usefulness test (8 participants per device) the questionnaire findings would be more representative of the user’s perceptions.

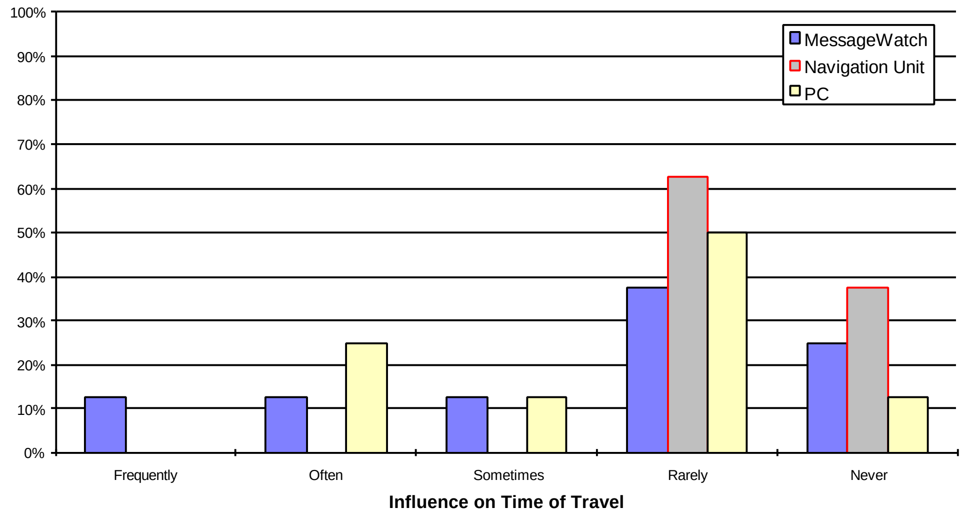


Figure 3-7. Influence of SWIFT Devices on Trip Departure Time.

Figure 3-8 illustrates that the SWIFT information did not result in conclusive changes in route selections, although multiple routes were available to most participants (on average, 4 routes were available to Seiko MessageWatch participants, 2.56 routes for navigation participants, and 4.67 routes for PC participants). Again, this finding does not agree with the responses to the questionnaires (70 percent changed their route one or more times per week). Given the small sample size of the usefulness test (8 participants per device) the questionnaire findings would be more representative of the user's perceptions.

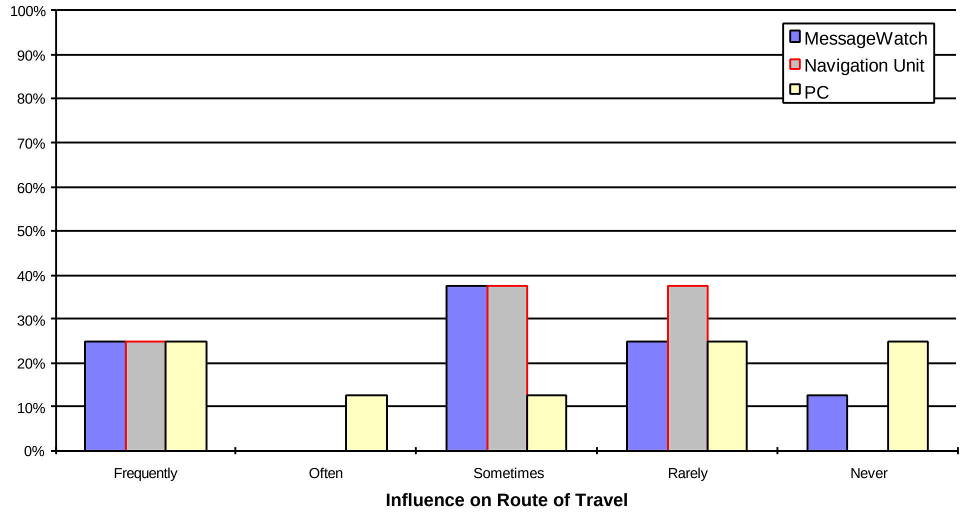


Figure 3-8. Influence of SWIFT Devices on Travel Route.

Figure 3-9 clearly illustrates that the SWIFT information did not result in a change in the mode of travel for any of the SWIFT device participants. This finding is consistent with the user responses to the questionnaires.

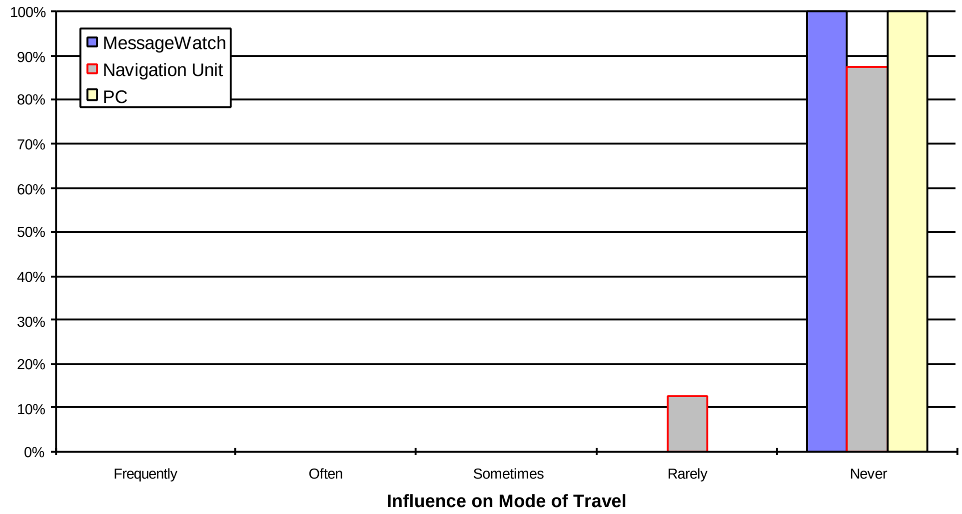


Figure 3-9. Influence of SWIFT Devices on Mode of Travel.

The participants were also asked to identify three positive and negative operational features of the SWIFT device that they used. Interestingly, of the seven Seiko MessageWatch participants, only one identified the traffic information as one of the positive operational features, as demonstrated in Table 3-1. Three identified the weather and financial information and four identified the accuracy of time as positive features. In terms of negative operational features, three participants complained about the watch aesthetics, three complained about the watch lighting, and two complained about the beeping of the traffic messages, as demonstrated in Table 3-2. One participant complained that the traffic information was not accurate or relevant to the mode of travel.

Table 3-1. Positive Operational Features of Seiko MessageWatch.

Positive Feature	Number of Participants
Accuracy of time	4
Weather and financial information	3
Dual time feature	2
Display and light feature	2
How system operates in general	2
Pager feature	2
Sports information	1
Water resistant	1
Save message option	1
Portable	1
Traffic information	1

Table 3-2. Negative Operational Features of the Seiko MessageWatch.

Positive Feature	Number of Participants
Watch aesthetics	3
Back light poor	3
Message stays on watch too long	3
Symbols not clear and small	2
No sound differentiation between incoming pager and traffic messages	2
Buttons on side are difficult to operate	1
Traffic information is not accurate or relevant to mode of travel	1
Slow response time	1

The navigation unit participants, unlike the Seiko MessageWatch participants, found the traffic information to be more useful, as demonstrated in Table 3-3. Specifically, six of the eight participants listed the traffic information as one of its positive operational features. Furthermore, the navigation and destination information and the address location feature were listed as positive operational features of the navigation unit. The major complaint of the participants was that they felt that the extent and accuracy of the Etak guide was limited, as summarized in Table 3-4.

Table 3-3. Positive Operational Features of Delco Navigation Unit.

Positive Feature	Number of Participants
Traffic information	6
Navigation and destination information (ETA, address and phone number)	4
Address location feature	2
Storing and recalling destinations	2
Voice text safety feature	2
News feature	1
Initial greeting	1
Sports scores	1
Pager feature	1
Navigation directional arrow	1
Location of device in vehicle	1
Etak guide information	1

Table 3-4. Negative Operational Features of Delco Navigation Unit.

Positive Feature	Number of Participants
Extent and accuracy of Etak guide	4
News feature	2
Message interruption	2
Problems with sort feature	2
Messages not stored long enough	1
Traffic messages do provide temporal relevance	1
Screen time out too short	1
Need to scroll screen to view text messages	1

The PC participants listed the bus schedule information and visual display of information as the highest positive features of the system, as summarized in Table 3-5. The traffic incident information, traffic loop information, and address location were also listed as positive features of the PC device. In terms of negative features, the unreliability of the Radio Receiver Module (RRM) and the number of key strokes to complete tasks were ranked number one, as summarized in Table 3-6.

In general, the findings for various SWIFT devices are consistent with the user perceptions of the SWIFT system as concluded from the questionnaires.

Table 3-5. Positive Operational Features of PC.

Positive Feature	Number of Participants
Bus schedule information	5
Visual display or mapping features	5
Traffic incident information	2
Address and location information	2
Congestion flow information	2
Bus tracking system	2
Timeliness of information	2
Ease to use	1
Usefulness of information	1

Table 3-6. Negative Operational Features of PC.

Positive Feature	Number of Participants
RRM not reliable	4
RRM and device too large	4
Too many key strokes required	3
Coverage area limited	2
Bus tracking inaccuracies	1
Too many pieces to connect system together	1
Too short battery life for Thinkpads	1
Inability to terminate Yellow Page search	1

3.2. Objective 2: Assess System Performance from System's Perspective

Objective 1 evaluated the user perceptions of the SWIFT system when it operated at full functionality. Alternatively, objective 2 evaluates the performance of the SWIFT system when it operated at full functionality from the system developer's perspective. This evaluation is intended (for conditions when the system operated at full functionality) to establish consistency between user perceptions and system performance, to identify the operational characteristics of the system that were not recognized by the SWIFT field operational test participants, and to attempt to identify the source of any architectural limitations.

The user perceptions indicated some concern regarding the timeliness of some information, the accuracy of some of the information (incident duration and transit AVL data), and the usability of some of the SWIFT devices (PC device). Consequently, the evaluation of objective 2 focused on a number of field tests that would not only validate these perceptions but also identify any architectural limitations that could be the source to these problems. These field tests included two delay field tests, a data fidelity field test, and a device usability field test. The methodology that was utilized in order to collect and conduct these field tests together with the findings of the field tests is described in this section.

Because the SWIFT system transmitted multiple data streams to multiple devices, and because not all devices received the various data streams, two delay field tests were conducted. The first field test (Data Stream Delay and Throughput Field Test) evaluated the delay associated with two of the three data streams that were received by the PC reception device. The second field test (Incident Data Stream Delay Field Test) evaluated the delay associated with a single data stream (incident data stream) to the three reception devices (MessageWatch, PC, and navigation unit).

In order to evaluate the accuracy of SWIFT data, a data fidelity field test was conducted. The data fidelity field test evaluated the accuracy of the transit AVL data (rated low by SWIFT users), the broadcast speed category estimates (rated high by SWIFT users), and the single loop speed estimation technique. Finally, a device usability field test was conducted in order to evaluate the usability of the three SWIFT reception devices because users of the PC device ranked it low in terms of its ease to use.

3.2.1. Test Methodology

Data Stream Delay and Throughput Field Test

As discussed earlier, the SWIFT architecture was viewed, for the purpose of the system architecture evaluation, in terms of a network of links and nodes. In order to compute data stream propagation delays, six measurement points were identified along the system architecture, as illustrated in Figure 3-10. The data content that traversed each of these measurement points was stored together with a time stamp for an entire week of system operation. Table 3-7 demonstrates sample data that were recorded at each of the six measurement points.

The SWIFT system involved three data streams that followed different paths within the system architecture. The loop detector speed data originated at the WSDOT node (upstream of point A) and propagated to the UW node, the Metro Traffic node, the Seiko Server node. Finally, it was received by the PC device (A-C-E-F path). The traffic incident data originated at the Metro Traffic node, traversing the Seiko node and then ending up at the PC device (E-F path). Finally, the transit data stream originated at the Metro Transit node, traversing the UW node the Seiko server before finally ending up at the PC reception device (B-D-F path).

As described in the architecture overview, the University of Washington was responsible for fusing the transit and speed data to a Geographic Information System (GIS) reference. In addition they were responsible for packaging the data in the BAP format for transmission. Consequently, the data format changed at the UW node. In order to estimate delays it was essential, therefore, that the data contents be matched at the different measurement points that were identified along the system architecture. The matching of data upstream and downstream the UW node was achieved by providing a unique transaction ID for each data record at measurement points A and B (prior to data fusion), and at points C and D (after data fusion), as demonstrated in Table 3-7. Using these unique ID's, data propagation delays between points A and C (for traffic speed data), and between points B and D (for transit data) were computed. Data records at the measurement point E included transaction ID's. However, they were not consistent with those recorded at points A and C. Data records at measurement point F did not include a record ID. Consequently, tools were developed that could match the hexadecimal representation of the data contents as they traversed points C, E and F (for speed data), points E and F (for incident data), and points D and F (for transit data).

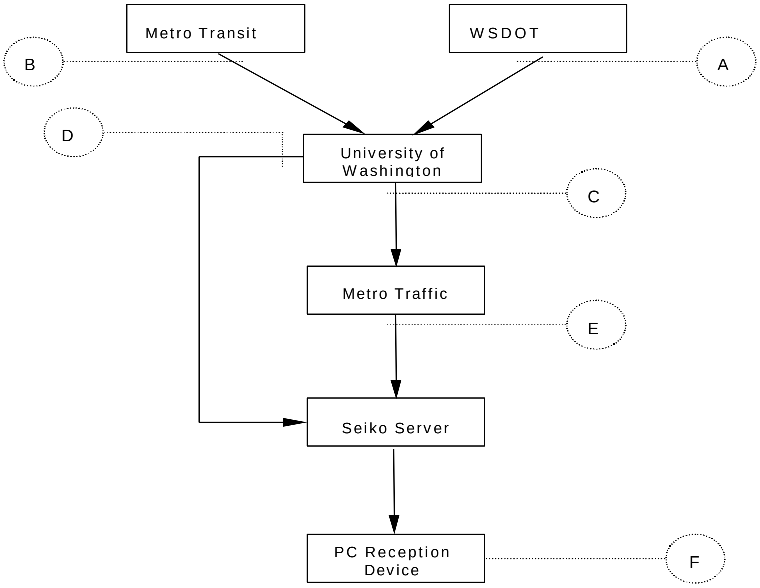


Figure3-10. Measurement Points Along SWIFT System Architecture.

Table 3-7. Example Illustration of Data Recorded.

Measurement Point	Record Fields	Representative Data Records
A	Date, Time, Transaction ID	05/12/97 08:27:11 16464 05/12/97 08:27:33 16465 05/12/97 08:27:51 16466 05/12/97 08:28:12 16467 05/12/97 08:28:31 16468 05/12/97 08:28:53 16469
B	Date, Time, Transaction ID	05/12/97 08:28:22 558514 05/12/97 08:28:23 558515 05/12/97 08:28:23 558516 05/12/97 08:28:23 558517 05/12/97 08:28:23 558518 05/12/97 08:28:23 558519
C	Date, Time, Transaction ID, Hexadecimal representation of packet content	05/12/97 08:23:53 16454 0F 00 00 00 00 00 0D BE 1E 69 EC FA 6F C0 05/12/97 08:23:53 16454 0F 01 E3 8D FE FC 71 F0 DB 61 BE FB ED F6 05/12/97 08:23:53 16454 0F 02 DF 6F 3E 83 FF F7 FE 7F F3 F3 FF FF 05/12/97 08:23:53 16454 0F 03 1B 6E 05 03 61 BD 1A FC 3C FB 51 F6 05/12/97 08:23:53 16454 0F 04 E3 DF B0 1E 0C 3E 1C 0B 6F FF F0 0 0 05/12/97 08:23:53 16454 0F 05 00 00 06 C0 79 F7 B6 E1 F0 E0 0E 00
D	Date, Time, Transaction ID, Hexadecimal representation of packet content	05/12/97 08:23:42 4424301 0A 30 85 F7 A7 62 0E E1 C8 01 79 38 82 B9 05/12/97 08:23:42 4424301 0A 5D 00 98 0 7 46 1A 40 C0 B7 08 18 22 8A 05/12/97 08:23:42 4424301 0A 41 C1 00 87 58 11 E0 00 00 00 00 00 00 05/12/97 08:23:42 4424302 0A 21 02 28 A1 B6 37 60 AD 06 08 85 22 01 05/12/97 08:23:42 4424302 0A 0B 0F 08 82 A2 53 F1 2C 21 78 49 22 71 05/12/97 08:23:42 4424303 0A 3B 40 58 8A 20 26 82 10 1D 79 8D A2 A7
E	Date, Time, Transaction ID, Hexadecimal representation of packet content	05/12/97 08:23:53 4672 0F 00 00 00 00 00 0D BE 1E 69 EC FA 6F C0 05/12/97 08:23:53 4672 0F 01 E3 8D FE FC 71 F0 DB 61 BE FB E D F6 05/12/97 08:23:53 4672 0F 02 DF 6F 3E 83 FF F7 FE 7F F3 F3 FF FF 05/12/97 08:23:53 4672 0F 03 1B 6E 05 03 61 BD 1A FC 3C FB 51 F6 05/12/97 08:23:53 4672 0F 04 E3 DF B0 1E 0C 3E 1C 0B 6F FF F0 00 05/12/97 08:23:53 4672 0F 05 00 00 06 C0 79 F7 B6 E1 F0 E0 0E 00
F	Time stamp embedded every second and Hexadecimal representation of packet content	T:863452733 E:02 13 00 C1 0A 30 C0 00 8C 16 35 70 18 00 52 A3 B1 03 02 **12 00 C0 73 74 78 4E 73 5F 74 5F 41 63 44 7A 5E 03 A:C1 0A 33 40 38 8A E6 31 C0 00 00 00 00 00 00 A:C1 0A 03 40 47 8B 06 3B 33 08 68 89 9E E1 8E A:C1 0A 1A 80 48 99 02 0C 53 A4 00 08 62 84 59 A:C1 0A 30 C0 00 8C 16 35 71 A4 00 89 A1 C1 E6 T:863452734 A:C1 0A 3A 41 38 88 9C 28 70 00 00 00 00 00 00 A:05 39 37 30 35 31 32 30 38 35 38 35 34 4D 4F

Table 3-8 demonstrates the size (in Kilo Bytes) of the data files at the various measurement points. One can observe a large increase in the size of files between points A and C, in the case of the speed data, and between points B and D, in the case of the transit data. This expansion arose from the inclusion of the hexadecimal representation of the data packet at points C and D. Furthermore, one can observe a larger amount of data associated with the transit system versus the traffic speed system (comparison of the size of file D versus file C). Finally, the data file at point F does not equal to the sum of data files at points D and E. This inconsistency stems from two reasons: first, file F does not include the transaction ID, which was included in files D and E, and second, some data packets were not received by the PC.

As mentioned earlier, data were recorded for an entire week of system operation (May 12, 1997 to May 19, 1997). Because the intent of the analysis was to evaluate data propagation delays for an ATIS at full functionality, only those days that did not experience major sub-system failures were included.

Figure 3-11 illustrates the flow rate of packets that were observed at point E and F over the seven-day analysis period. It appears from Figure 3-11 that reception on the latter two days (120 to 168 hours) of the analysis was not as good as that on the former five days (0 to 120 hours). Next, Figure 3-12 illustrates how the delay between points C and E (traffic speed data) varied over the seven day analysis period. Again the results demonstrate consistent delays (less abnormal fluctuations in delay) for days 4 and 5 (72 to 120 hours on the X-axis). Based on similar plots of data flow and delay between other measurement points, two consecutive days were selected for further analysis (days 4 and 5 (May 15 and May 16)).

Table 3-8. Measurement File Sizes.

Measurement Point	File Size (Kbytes)
A	575
B	7,309
C	30,000
D	98,000
E	29,000
F	107,700

It must be noted at this point that the time stamps, that were imbedded in each of the data files, came from the same source except for file F. In the case of file F, the time stamp was the PC time stamp. To ensure consistency, the PC time was set equal to the common time reference prior to collecting the data. Some problems were found with the data collected at point D including the date and time stamp. Consequently, it was not possible to evaluate the delay associated with the bus data stream.

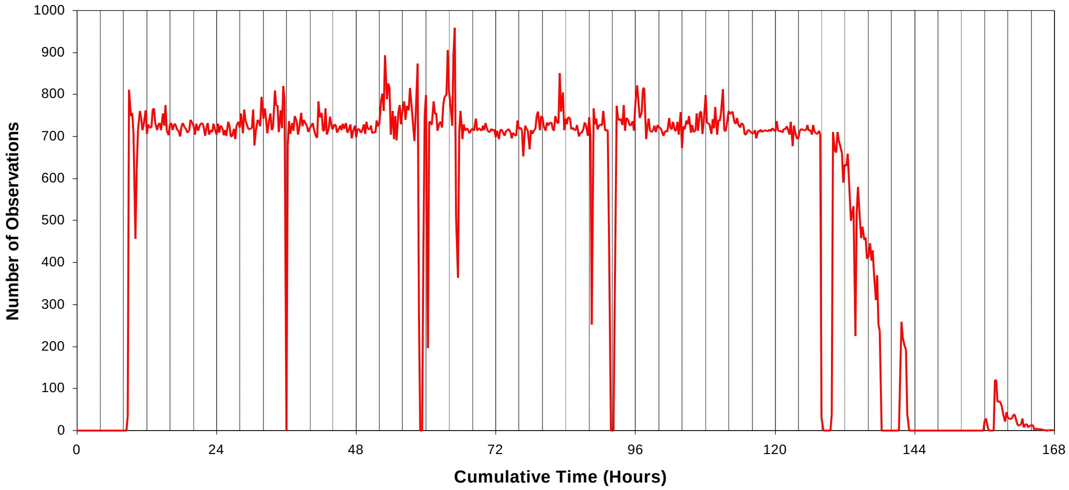


Figure 3-11. Packet Flow Rate Between Points E and F (Packets/15 minutes).

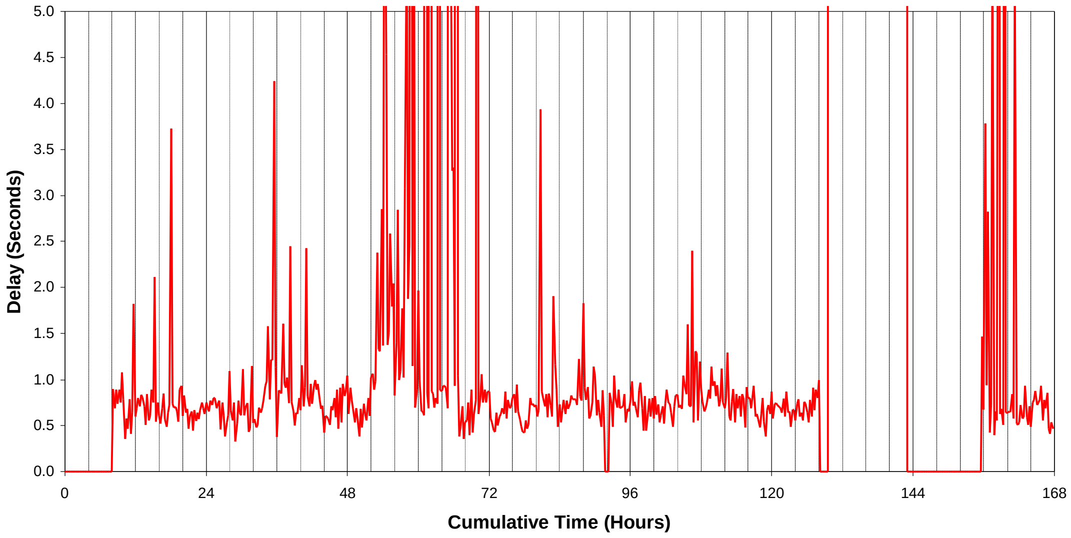


Figure 3-12. Packet Delay Between Points C and E.

Based on the data collection exercise, which was conducted as part of the architecture analysis, the following lessons can be learnt:

- Data matching in a multi-node system is not an easy task, because data are manipulated and transformed as they propagate through an ATIS
- In evaluating a system it is important to anticipate problems with the data collection exercise and the data itself, and
- The analysis of the data requires considerable computing power because of the large size of data

Incident Stream Delay Field Test

Incident data were collected over a two week period from March 17, 1997 through March 31, 1997 in order to quantify the time lag between the time at which incident data arrived at Metro Traffic Control and the time at which the data were displayed on the receiver devices. These data were gathered from 7:00 AM to 9:00 AM, 12:00 PM to 3:00 PM, and 5:00 PM to 7:00 PM on weekdays (Monday through Friday) and from 10:00 AM to 7:00 PM on weekends. It is important to note that during the analysis period the SWIFT system was in full operation and did not experience any major malfunctions.

Table 3-9 provides an example illustration of the data collected over the analysis period. From these data it was possible to compute the percentage of data received by two of the receiver devices (the PC and MessageWatch), the time to process the incident data at the Traffic Work Station (TWS), and the time required for the incident data to propagate through the SWIFT system until they were received by two of the receiver devices (PC and MessageWatch) located at Metro Traffic Control. A total of 270 data incidents were recorded during the two-week analysis period. Most time stamps were recorded from the same source, namely the Seiko MessageWatch that automatically updated its time at least 36 times a day.

In addition, the time stamp and messages that were received by a Delco navigation unit located in the SAIC office in Bellevue were recorded for portions of the analysis period. When the navigation unit verbally acknowledged receipt of a message the time of arrival was recorded. Interestingly, not all messages received by the device were verbally confirmed (only 35 percent were confirmed). In total only 32 messages were usable in the delay analysis (i.e. within same period and verbally confirmed).

As is the case with any field study, the data collection exercise suffers from a number of deficiencies, as follows:

- Device message appearance times were recorded instead of message arrival times. The former include the screen update time in addition to the message transmission time.
- Some of the PC time stamps were based on the PC internal clock as opposed to the Seiko MessageWatch time.
- The data were collected manually and thus may include human errors that are more prone to occur when the messages are closely spaced.
- Navigation unit data were collected at another location (SAIC office versus Metro Traffic office) and by different personnel.

Table 3-9. Example Illustration of Data Collection Form.

Initial Time Received	Primary Road	Secondary Road	Time Input into TWS	Time Received by PC	Time Received by Watch	Comments
7:13:27	I-512	Pacific Ave.	7:13:55	7:14:15	N/A	
7:21:30	I-5	North Gate	7:22:10	7:22:15	7:23:50	
7:35:18	I-512	Steel	7:35:49	7:35:54	N/A	

Data Fidelity Field Test

The user's had some concern regarding the accuracy and reliability of the transit AVL data, while the accuracy of the traffic congestion data was ranked high. This section describes the procedures for evaluating the accuracy of these two data streams.

As described earlier, three data streams were broadcast as part of the SWIFT FOT. Two of these data streams included numeric data (transit and traffic speed data) while the third data stream included anecdotal data (traffic incident information). The Data Fidelity Field Test evaluated the fidelity of the two numeric data streams that were broadcast as part of the SWIFT FOT. An evaluation of the fidelity of the anecdotal data stream (incident data) was not possible because precise information on actual incident occurrence times, clearance times and incident severity were not available.

The next section describes the transit data fidelity test in terms of the field data that were gathered and the specifics of how the fidelity test was conducted. In a similar fashion, the Speed Data Fidelity Field Test section describes the traffic speed data fidelity test procedures. Because the SWIFT system broadcast traffic speed information as seven speed categories any observed inaccuracies within the speed estimates could have been masked by the aggregation/ categorization process. Consequently, a study was conducted to further quantify the accuracy of the speed estimates derived from single loop detectors (majority of loop types in the Seattle area) relative to speed measurements from dual loop detectors and a radar gun. Finally, the Single Loop Speed Data Fidelity Field Test section describes the data collection procedures that were utilized to evaluate the single loop speed estimates.

Transit Data Fidelity Field Test. Three bus stops were selected for the evaluation of the accuracy of the SWIFT transit location data, as illustrated in Figure 3-13. The bus stops included: a downtown bus stop along the underground tunnel (University Station, Southbound and Eastbound), an urban bus stop (University of Washington in front of the student hub), and a freeway bus stop (Evergreen Point, Westbound along I-520). These bus stop locations were deliberately diversified in order to evaluate the fidelity of the transit data across different locations. In addition, data were gathered during different periods in order to quantify the temporal accuracy of the SWIFT transit data. Specifically, field data were gathered during the AM peak (7:00 to 9:00 AM), during the off-peak (2:00 to 4:00 PM), and during the PM peak (4:00 to 6:00 PM). The data that were gathered included the vehicle route number, the vehicle ID and the time at which the transit vehicle was observed at the location. The time stamp was the Seiko MessageWatch time stamp which was consistent with the time stamps imbedded in the SWIFT data. It should also be noted that only King County buses were recorded because these were the only buses that were equipped with the AVL system.

The SWIFT data that were compiled by the University of Washington included the date, the time at which the data were observed, the transit vehicle route number, the transit vehicle ID, and the estimated latitude and longitude. A sample of the SWIFT transit data is presented in Table 3-10.

In order to evaluate the fidelity of the traffic speed data that were broadcast as part of the SWIFT field operational test, nine drives were completed in each direction along a 16 kilometer (10 miles) section of the I-5 freeway. The section that was driven extended from Boeing field at the south end of the section to 135th street at the north end of the section, as illustrated in Figure 3-13. The objective was to drive along the I-5 section during uncongested and congested conditions in order to evaluate the accuracy of the traffic speed estimates under varying traffic conditions. Each 0.5 mile initiating from the first milepost along the section, the time at which the vehicle passed the location (Seiko MessageWatch time stamp) and the speed of the vehicle at that location were recorded.

The speed estimates that were transmitted as part of the SWIFT field operational test were then compared to the speeds that were encountered during the nine test drives in each direction (northbound and southbound).

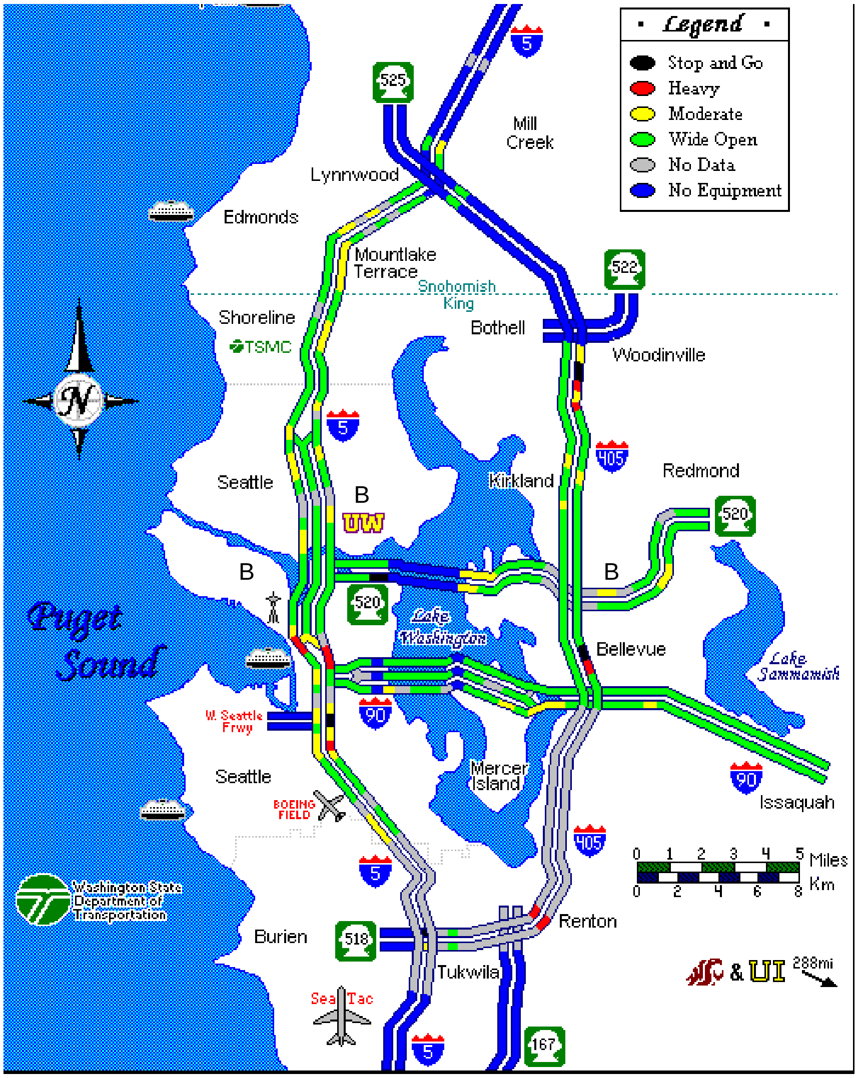


Figure 3-13. Location of Bus Stops in the Seattle Area (Bus Stop Identified by Letter "B").

Table 3-10. Raw Transit Data Format.

Day	Time	Route #	Veh. ID	Lat.	Long.
14	24922	251	3368	47.67118	-122.13211
14	24924	258	5176	47.62908	-122.32681
14	24925	252	5047	47.60108	-122.32641
14	24933	267	5046	47.63238	-122.18061
14	24933	260	3224	47.63918	-122.24781
14	24942	262	3356	47.64508	-122.28741
14	24942	272	2153	47.63998	-122.25351
14	24942	254	3377	47.61588	-122.33311
14	24944	275	2154	47.64268	-122.19501
14	24945	311	3399	47.64158	-122.21411
14	24945	274	1792	47.57368	-122.11691
14	24945	956	3298	47.58658	-122.22851
14	24945	267	5234	47.67858	-122.12721
14	24945	273	1787	47.63188	-122.13641
14	24945	272	1644	47.57648	-122.13671
14	24945	253	5178	47.61768	-122.14591

Speed Data Fidelity Field Test. The SWIFT system broadcast the speed data as speed categories in order to minimize the bandwidth requirements for data transmission. A three-bit data representation allowed the speed categories to range from 0 to 7, as demonstrated in Table 3-11. This section describes the data collection exercise that was involved in order to evaluate the accuracy of the speed categories that were broadcast as part of the SWIFT field operational test.

Table 3-11. SWIFT Speed Data Categorization.

Category	Speed Range (mph)
0	No data
1	Stopped/closed
2	>0 to 9
3	>9 to 18
4	>18 to 30
5	>30 to 42
6	>42 to 54
7	>54

The SWIFT data packets were stored, as part of the SWIFT field operational test, in a hexadecimal representation in order to minimize the size of data transmitted. Table 3-12 provides an example illustration of the hexadecimal representation of the packets. Because there were different packet types, one for each data stream, a unique packet type identifier was included in order to uniquely define the type of data stream packet. Furthermore, a group number uniquely identified the set of loop detectors associated with the packet. It must be noted at this point, that the SWIFT data that were compared against the field data were received by the Radio Receiver Module (RRM) of one of the SWIFT laptop devices.

Table 3-12. SWIFT Traffic Speed Raw Data BAP Format.

Day	Time	Packet Type	Group #	Hexadecimal Representation of Packet
15	44982	0F	00	00 00 00 00 0D BE 1F 7E FE 9B 5F C0
15	44982	0F	01	E3 F7 FC FC 61 FF FF E1 F8 FC 6C 3E
15	44982	0F	02	1B 8F FF FF 7E 3F E3 F1 C7 FC 7E 3F
15	44983	0F	03	03 8C 06 03 EE 3F FF FD FF FF FF FF
15	45002	0F	00	00 00 00 00 0D BE 1F 7D 3E 9B 5F C0
15	45002	0F	01	03 F7 FC FC 61 F7 FF F1 F8 FF ED FE
15	45002	0F	02	1B 8F FF FF 7F BF E3 F1 C7 FC 7E 3E
15	45002	0F	03	E3 8C 06 03 EE 3F FF FD FF FF 7F FF
15	45021	0F	00	00 00 00 00 0D BE 1F 7D 3E 82 5F C0
15	45022	0F	01	E3 F7 C4 FC 6F F7 FF F1 F8 FC 6D FE
15	45022	0F	02	FF 8F FF FC 7F BF FB 71 FF FC 7F F7
15	45022	0F	03	03 8E 06 03 E0 3F 1F FD F7 FF 7E 3F

The process of extracting the speed data from the hexadecimal packet representation required some data manipulation. First, each of the 12 hexadecimal representations was converted into 8 binary bits, as demonstrated in Table 3-13, resulting in a stream of 96 binary bits (12 units x 8 bits). The 96 binary bits represented a total of 32 ASCII numbers (96 bits/3 bits per category) from left to right, as demonstrated in Table 3-14. Table 3-13 demonstrates the ASCII representation of the packets that are presented in Table 3-14.

Table 3-13. Conversion of SWIFT Traffic Speed Data Packets from Hexadecimal to ASCII Representation.

	SWIFT Traffic Speed BAP Packet Representation
Hexadecimal	00 00 00 00 0D BE 1F 7E FE 9B 5F C0
Binary	0000000000000000000000000000000000001101101111100001111101111110111111100101101101011111111000000
ASCII	0 0 0 0 0 0 0 0 0 0 0 0 6 6 7 6 0 7 6 7 7 3 7 6 4 6 6 5 7 7 0 0

Table 3-14. SWIFT Traffic Speed Raw Data Speed Categorization.

Day	Time	Group #	ASCII Representation of Packet
15	44982	0	0 0 0 0 0 0 0 0 0 0 0 0 6 6 7 6 0 7 6 7 7 3 7 6 4 6 6 5 7 7 0 0
15	44982	1	7 0 7 7 3 7 7 4 7 7 0 6 0 7 7 7 7 7 7 6 0 7 7 0 7 7 0 6 6 0 7 6
15	44982	2	0 6 7 0 7 7 7 7 7 7 6 7 7 0 7 7 7 0 7 7 0 7 0 7 7 7 0 7 7 0 7 7
15	44983	3	0 0 7 0 6 0 0 6 0 0 7 6 7 0 7 7 7 7 7 7 6 7 7 7 7 7 7 7 7 7 7 7
15	45002	0	0 0 0 0 0 0 0 0 0 0 0 0 6 6 7 6 0 7 6 7 6 4 7 6 4 6 6 5 7 7 0 0
15	45002	1	0 0 7 7 3 7 7 4 7 7 0 6 0 7 6 7 7 7 7 7 0 7 7 0 7 7 7 6 6 7 7 6
15	45002	2	0 6 7 0 7 7 7 7 7 7 6 7 7 6 7 7 7 0 7 7 0 7 0 7 7 7 0 7 7 0 7 6
15	45002	3	7 0 7 0 6 0 0 6 0 0 7 6 7 0 7 7 7 7 7 7 6 7 7 7 7 7 6 7 7 7 7 7
15	45021	0	0 0 0 0 0 0 0 0 0 0 0 0 6 6 7 6 0 7 6 7 6 4 7 6 4 0 4 5 7 7 0 0
15	45022	1	7 0 7 7 3 7 0 4 7 7 0 6 7 7 6 7 7 7 7 7 0 7 7 0 7 7 0 6 6 7 7 6
15	45022	2	7 7 7 0 7 7 7 7 7 7 0 7 7 6 7 7 7 6 6 7 0 7 7 7 7 7 0 7 7 7 6 7
15	45022	3	0 0 7 0 7 0 0 6 0 0 7 6 0 0 7 7 0 7 7 7 6 7 6 7 7 7 6 7 7 0 7 7

Using Table 3-15 it was possible to associate each 0.5-milepost with the corresponding loop detector in order to compare field data observations with SWIFT traffic speed data. Furthermore, using the field observation time stamp, it was possible to search for a SWIFT observation that was observed after the field observation and within 20 seconds of the field observation (polling interval), in order to evaluate the SWIFT data accuracy.

Single Loop Speed Data Fidelity Field Test. The data collection exercise involved recording volume, occupancy and speed measurements from a dual loop detector station located along the westbound direction of I-520 at Evergreen point. In addition a radar gun was utilized to record the speeds of a selected number of vehicles. The loop detector and radar gun measurements were recorded for the median lane for approximately one hour from 1:30 PM to 2:45 PM on a typical weekday. In addition, the volume and occupancy measurements were utilized to estimate speeds using the G-factor and Kalman-filter techniques that will be described later in the results section. The objective of this field test was to evaluate the accuracy of the Kalman-filter technique, that was utilized as part of the SWIFT field operational test. Furthermore, this study also evaluated the accuracy of the G-factor technique, because it is a widely accepted and adopted technique.

Device Usability Field Test

The SWIFT participants rated the Seiko MessageWatch and Delco devices high in terms of ease to use, however, this was not the case for the PC devices. The device usability test attempted to validate the user perceptions and to identify any problems with the SWIFT devices.

The overall goal of the usability test was to identify usability deficiencies existing in the SWIFT devices and SWIFT information. Furthermore, an attempt was made to relate deficiencies to the design and implementation phases of the SWIFT architecture. This section describes the procedures utilized to conduct the device usability tests, while the results of the tests, and the major findings of the tests are described in the results section.

Table 3-15. Milepost Loop Detector Correspondence.

Milepost	Direction	Group ID	Loop ID
162.0	1	0	20
162.0	2	0	21
162.5	1	0	23
162.5	2	0	24
163.0	1	0	26
163.0	2	0	27
164.0	1	0	30
164.0	2	0	31
164.5	2	1	2
164.5	1	1	4
165.0	1	1	7
165.0	2	1	8
165.5	1	1	10
165.5	2	1	11
166.0	1	1	17
166.0	2	1	18
166.5	2	1	20
167.0	1	1	21
167.0	2	1	22
167.5	1	1	24
167.5	2	1	25
168.0	1	1	30
168.0	2	1	31
168.5	1	2	1
168.5	2	2	2
169.0	1	2	4
169.0	2	2	5
169.5	2	2	9
169.5	1	2	11
170.0	1	2	12
170.0	2	2	14
170.5	1	2	15
170.5	1	2	16
171.0	2	2	18
171.0	1	2	19
171.5	1	2	24
171.5	2	2	25
172.0	1	2	27
172.0	2	2	28
172.5	1	2	30
172.5	2	2	31
173.0	2	3	2
173.0	1	3	4

Usability testing suffers from a number of limitations, which are best described in the words of Rubin (1994): “Testing does not guarantee success or even prove that a product will be usable. Even the most rigorously conducted formal test cannot, with 100 percent certainty, ensure that a product will be usable when released." The limitations of this study, as with the case of any usability study, are:

- Testing is always an artificial situation.
- Test results do not prove that a product works. It only provides more confidence by reducing the risk that it will not work.
- Participants are rarely fully representative of the target population.

In spite of these limitations, usability testing, when conducted with care and precision, provides an almost infallible indicator of potential problems and the means to resolve them.

Rubin (1994) categorized usability tests into four categories, namely exploratory tests, assessment tests, validation tests, and comparison tests. Each of these tests has a slightly different purpose. The exploratory tests are conducted early in the development cycle with the objective of evaluating the effectiveness of preliminary design concepts. The assessment tests are conducted either early or midway into the product development cycle in order to evaluate the usability of lower-level operations and aspects of the product. The validation tests (also referred to as verification tests) are usually late in the development cycle and are intended to certify the product's usability. The comparison tests are not associated with any specific point in the product development life cycle; instead, they are used to compare different designs or products. The comparison test can be used in conjunction with any of the other three tests.

The usability test that was conducted for the SWIFT evaluation falls into the validation and comparison category because it was intended to certify the SWIFT device usability. In addition, the usability test compares the performance of the three devices in terms of their usability.

The methodology that was utilized can be summarized as follows:

- Prior to the test, benchmarks or standards for the tasks of the test were developed and identified
- The users were asked to perform tasks rather than simply commenting on screens, pages, etc.
- The test monitor did not interact much with the test participants
- Quantitative data were collected from the tests.

The SWIFT usability test involved three activities. The first activity was related to the usability of the SWIFT device and information. The second activity was a questionnaire intended to evaluate the impact that the SWIFT information had on the participant's travel behavior. The third and final task was a questionnaire on positive and negative operational features of the SWIFT devices. Tasks 2 and 3 were discussed in the first objective evaluation and as such are not described any further. Each participant was allocated 45 minutes to complete the device usability test. In addition, each participant was paid $25 to participate in the usability test.

Each of the three SWIFT devices required a device usability test; however, these device-specific tests were not identical because each SWIFT device displayed different types of information. The usability tests for the MessageWatch, navigation unit, and PC users are presented in Appendices A, B, and C, respectively.

The first part of the Seiko MessageWatch usability study was intended to evaluate the user's ability to use the basic functions of the watch (view, save, retrieve, delete messages, and to enable the beep mode), as demonstrated in Table 3-16. A concern that the SWIFT participants identified was the ability to decipher messages. Consequently, the ability to decipher traffic and non-traffic messages was also included in the test. The first part of the PC and Navigation usability tests were related to the basic functions of the devices and information, as demonstrated in Table 3-17 and Table 3-18. The tasks associated with the navigation unit usability test were related to reading traffic messages and using the navigational capabilities of the unit. The tasks associated with the PC device included the basic functions (displaying traffic incident information and using the navigational features) in addition to other functions, such as displaying traffic speed information and displaying bus information. Consequently, because each device displayed different types of information, it was extremely difficult, to compare the usability of the SWIFT devices.

The tasks that were required for each device were basic tasks that a typical user of the device should be able to do. The messages that the participants were asked to decipher were typical messages that were broadcast during the SWIFT field operational test. The message list was compiled to contain a number of difficult messages, average messages, and easy messages to interpret.

Table 3-16.   Seiko MessageWatch Performance Test.

Task	Question
a	View the third (3rd) message
b	Save the fifth (5th) message
c	View the time of the second (2nd) message
d	Delete the fourth (4th) message
e	Turn beep mode off and then turn back on

Table 3-17. Navigation Unit Performance Test.

Task	Question
a	"Read" a traffic message closest to your current location
b	Find the Bellevue library
c	Save the Bellevue library as destination #5
d	Recall the Bellevue library
e	Retrieve the Bellevue library's address, phone number, and estimated time of arrival
f	Change the location and destination radius to 50

Table 3-18. PC Performance Test.

Task	Question
a	Load up the Seattle-area map and enable communications
b	Display speed information for all lanes except HOV along I-5 between I-90 and I-520
c	Display full map area with traffic incident information and show traffic incident details
d	Display bus time points and locations for Route 243 for Saturday, May 17, 1997
e	Find the intersection of NE 12th Street and 106th Avenue NE
f	Locate the nearest Taco Bell to the above address

Prior to conducting the usability test on the test participants, the test was conducted on some SAIC employees in order to verify the test. Furthermore, the minimum number of key strokes per task was tallied, and the minimum time to conduct a task was recorded.

The steps required to complete each task are provided in Appendices D, E, and F.

Eight participants per device participated in the usability test. The test observer recorded the number of key strokes and time required by the participant to complete each task. If the participant was unable to complete a task, it was recorded as an incomplete task. In the case of the message-deciphering component (Seiko MessageWatchdevice only), the tasks were divided into sub-tasks, and the portion of the task that was deciphered correctly was recorded.

It should be noted at this point that in the case of the navigation unit and PC usability test, the participant would select items from menus requiring him or her to continuously press the mouse button (PC users) or to press a scroll button a number of times (Navigation users). For analysis purposes, the selection of an item was counted as a single stroke as opposed to a number of key strokes.

3.2.2. Results

This section summarizes the results of the field tests that were conducted in order to evaluate objective 2.

Data Stream Delay and Throughput Field Test

Table 3-19 summarizes the results of the delay analysis that was conducted. The results indicate that the propagation delay, from source to sink, was, on average, 21 seconds and 33 seconds for the traffic speed data stream and the traffic incident data stream, respectively. Therefore, the use of the Internet, as a means of communication, did not appear to be a source of major delays in the system. The results do indicate that some large delays (maximum delay 65623 seconds or 18 hours) were present between points E and F. A closer analysis indicated that a total of 151 data packets out of the 136425 packets from E to F experienced a delay of 600 seconds or greater (i.e. 0.1 percent of the sample). These large delays could have resulted from the procedure, which was used to estimate the delay (matching of packets) or could represent actual delays of data packets.

It is highly unlikely (a probability of 9.05E-28), but possible, that the 32 loop detector speed estimates that constitute a packet be identical for different data packets.

Table 3-19. Summary Results of Traffic Speed and Incident Data Streams.

Measure of Performance	Traffic Speed Data Stream			Traffic Incident Data Stream
	A-C	C-E	E-F	E-F
Avg. Delay (seconds)	2.16	0.78	17.48	33.03
Min. Delay (seconds)	1	0	0	0
Max. Delay (seconds)	24	2359	65623	8017

The delay distribution, for the speed data stream between points A and C, and between points C and E demonstrate minor variability, as illustrated in Figure 3-14 and Figure 3-15, respectively. Specifically, more than 99 percent of the data packets that traversed these measurement points experienced a delay less than 6 seconds. However, the distribution of delay measurements, between points E and F for the traffic speed data stream, demonstrates more variability, as illustrated in Figure 3-16. Specifically, 90 percent of the packets experienced a delay less than or equal to the mean delay (17.5 seconds), while 99.9 percent experienced a delay less than 40 seconds.

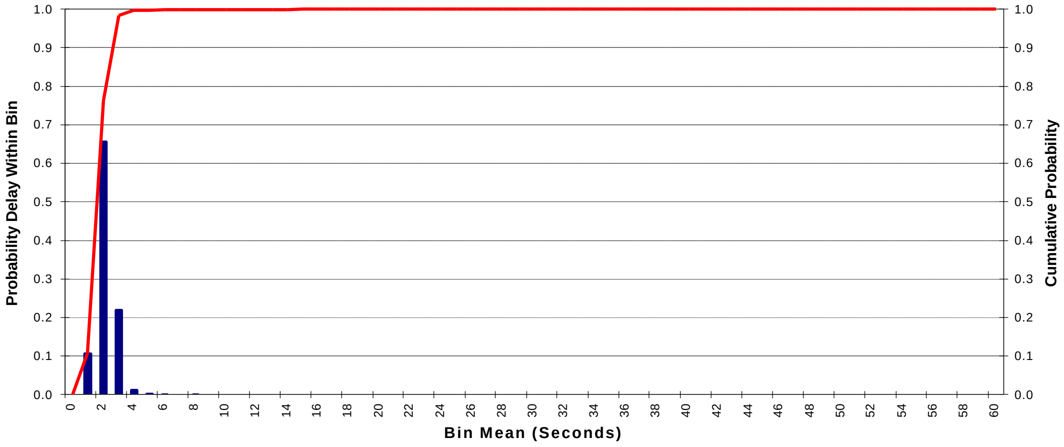


Figure 3-14. Packet Delay Distribution for Flow Between Points A and C.

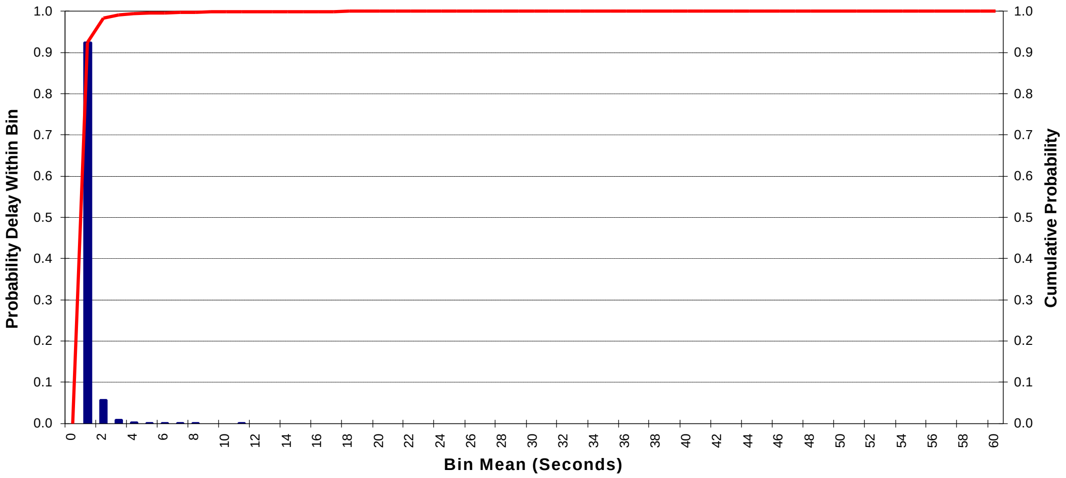


Figure 3-15. Packet Delay Distribution for Flow Between Points C and E.

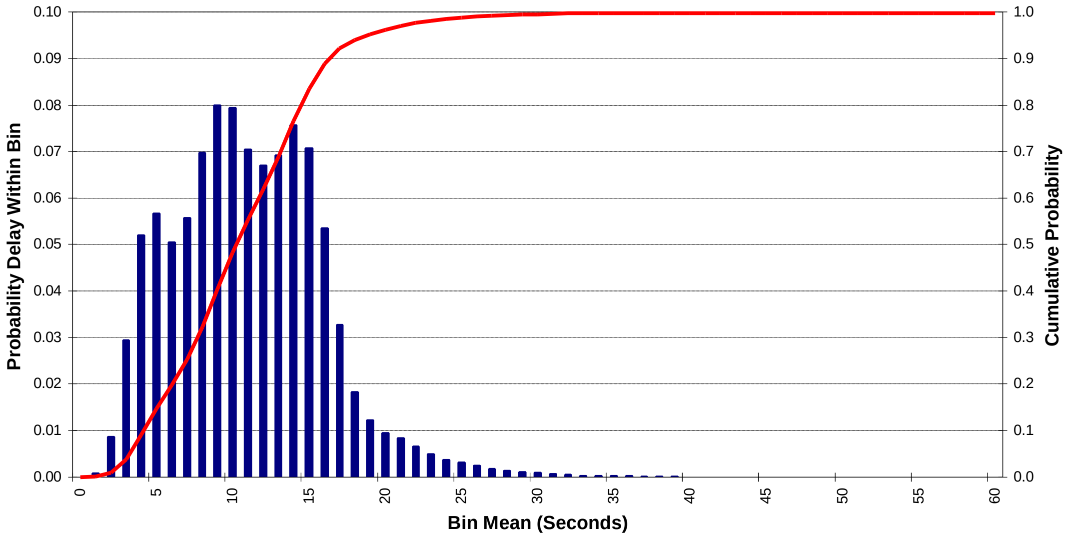


Figure 3-16. Packet Delay Distribution for Flow Between Points E and F for the Traffic Speed Data Stream.

The traffic incident data stream experienced the largest variability in terms of delay as illustrated in Figure 3-17. There appear to be a number of modes to the distribution that progressively reduce in intensity as the delay increases. It is not clear at this point why the traffic incident data stream experienced a different delay distribution from the traffic speed data stream. Figure 3-18 also demonstrates that 90 percent of the packets experienced a delay less than 70 seconds and that more than 99 percent of the packets experienced a delay less than 180 seconds.

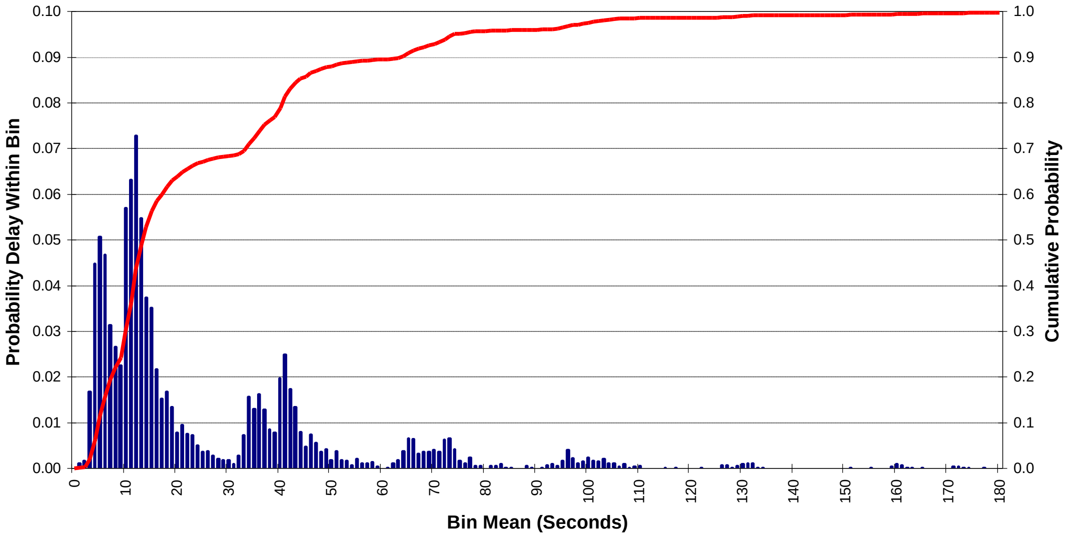


Figure 3-17. Packet Delay Distribution for Flow Between Points E and F for the Traffic Incident Data Stream.

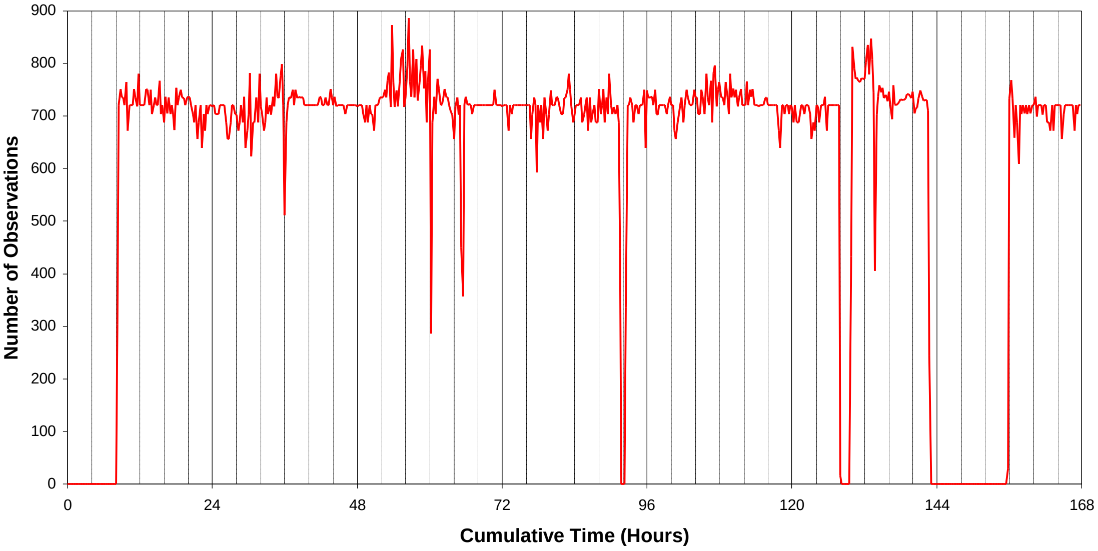


Figure 3-18. Packet Flow Rate Between Points C and E (Packets/15 Minutes).

Figure 3-19 to Figure 3-20 illustrate a throughput rate of 720 packets/15 minutes for the traffic speed data stream. Furthermore, these figures demonstrate two failures in the SWIFT system upstream of point E during the latter 2 days (between 120 and 168 hours). These failures resulted in problems downstream of point E (either at the Seiko server or at the PC Radio Receiver Module (RRM)) even after the system attained functionality.

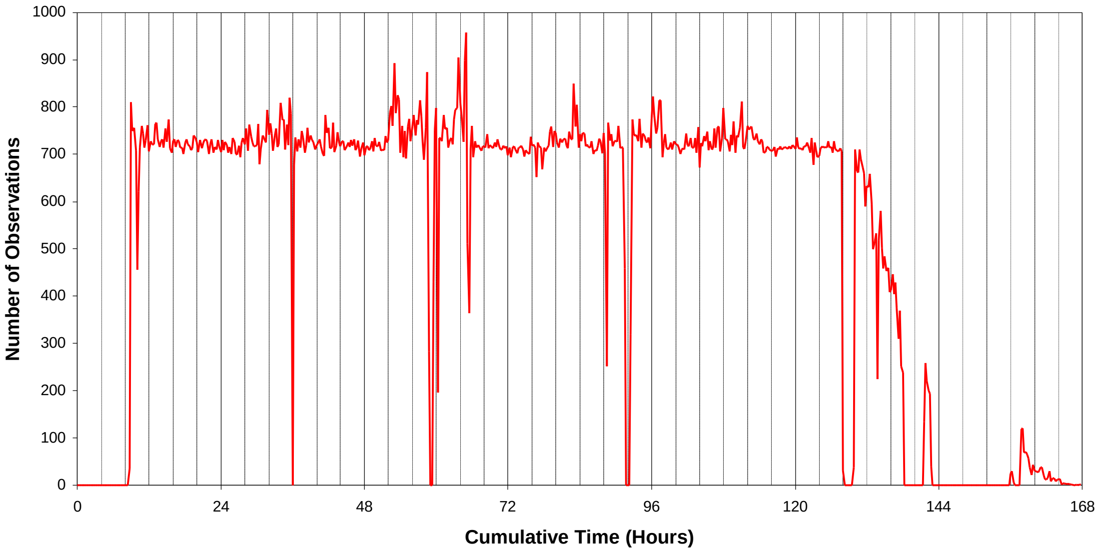


Figure 3-19. Packet Flow Rate Between Points E and F for Traffic Speed Data Stream (Packets/15 Minutes).

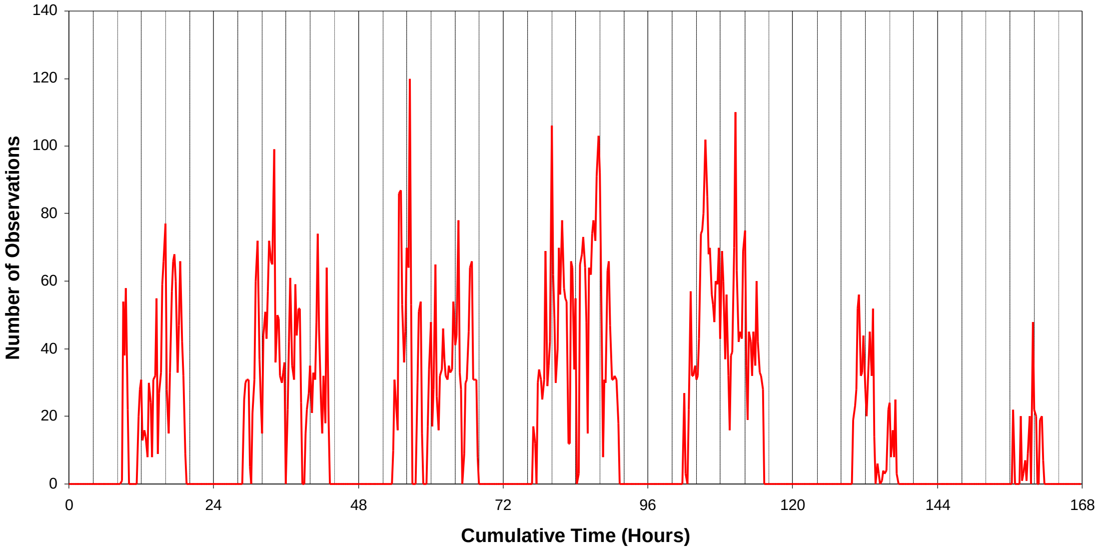


Figure 3-20. Packet Flow Rate Between Points E and F for Traffic Incident Data Stream (Packets/15 Minutes).

Because the incident information was only broadcast from 5:00 AM until 8:00 PM on weekdays and from 10:00 AM to 5:00 PM during weekends, packets were only observed during these time periods. This is illustrated in Figure 3-21. Furthermore, because the traffic incident data were not a continuous data stream, as was the case with the traffic speed data stream, one can observe large fluctuations in the data flow rate.

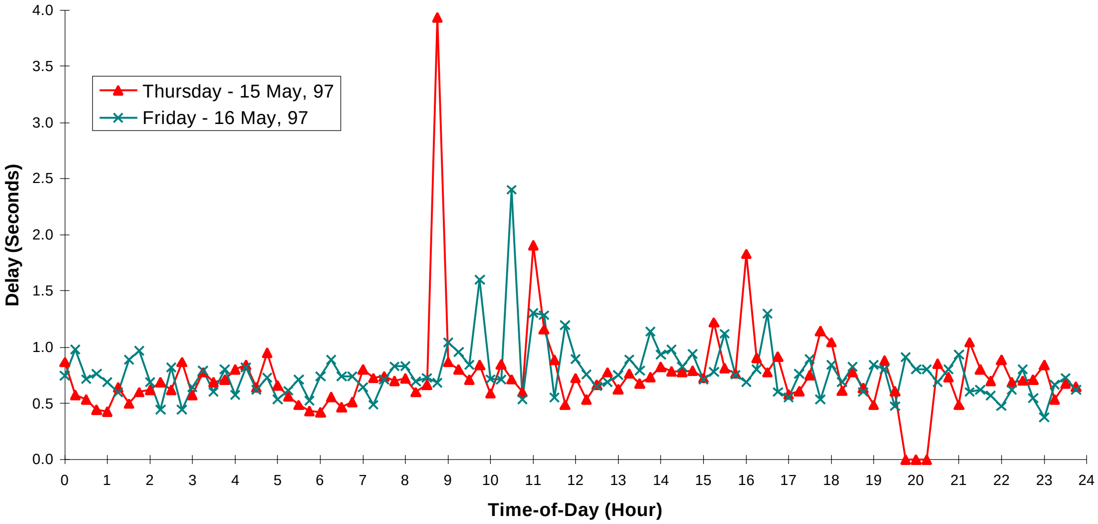


Figure 3-21. Delay Variation by Time-of-Day for Flow Between Points C and E.

In order to investigate whether delay varied as a function of the time-of-day, the average delay for each 15-minute interval was computed for the two consecutive days that were analyzed (May 15 and 16). Figure 3-21 illustrates how the 15-minute average delay varied between measurement points C and E as a function of the time-of-day for the two days under consideration. It appears that the delays experienced were similar for both days. In addition, there does appear to be more variability in the delay estimates between 8:00 AM and 4:00 PM. This appears to be the opposite case between points E and F, as illustrated in Figure 3-22 (larger delay during off-peak periods). The delay associated with the traffic incident data stream appears to experience larger variability when compared to the speed data stream (comparing Figure 3-23 to Figure 3-22).

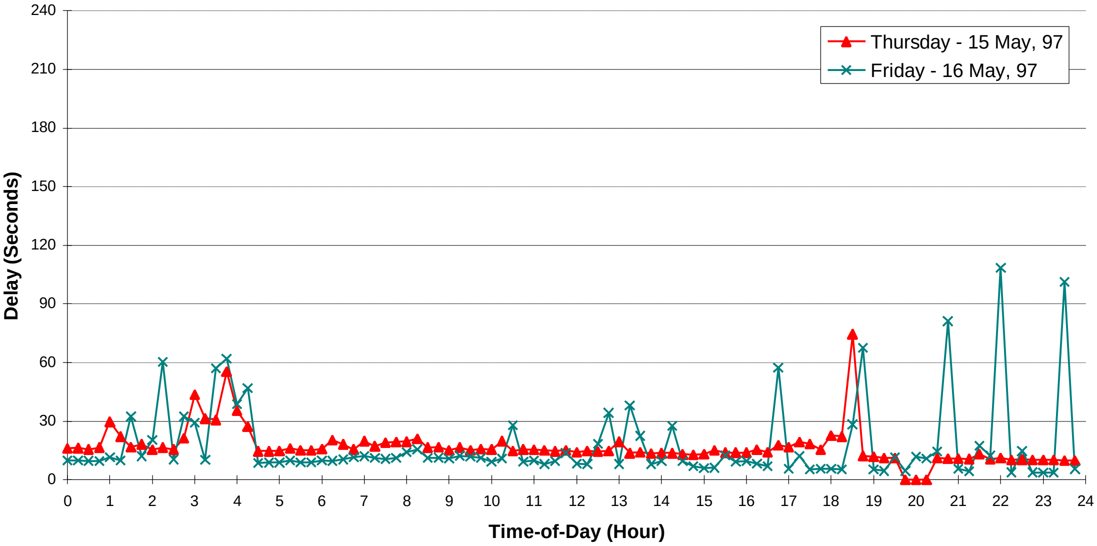


Figure 3-22. Delay Variation by Time-of-Day for Flow Between Points E and F for Traffic Speed Data Stream.

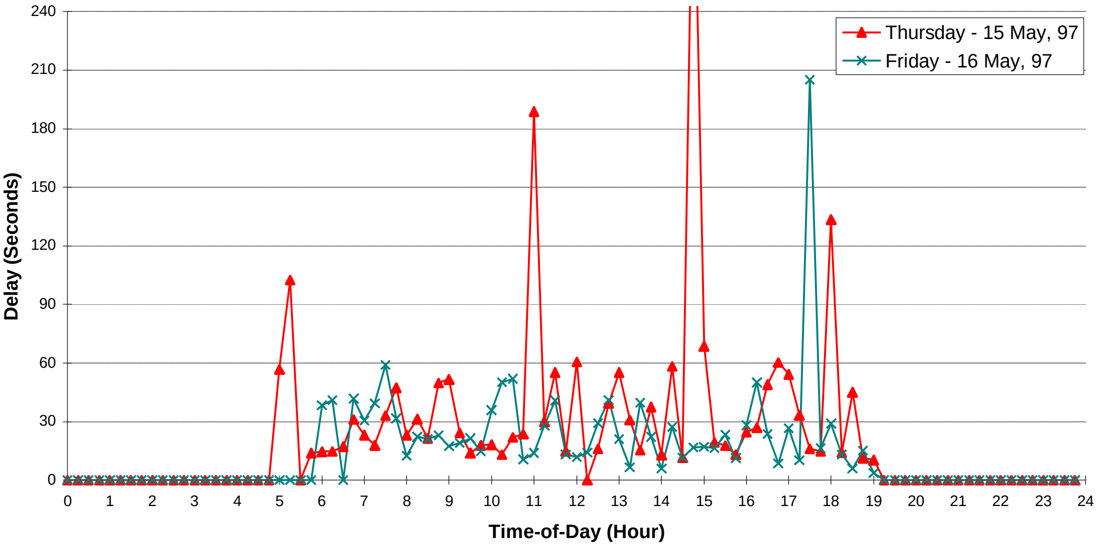


Figure 3-23. Delay Variation by Time-of-Day for Flow Between Points E and F for Traffic Incident Data Stream.

Incident Data Stream Delay Field Test

The previous field test examined the delay associated with the three data streams that were received by the PC device. The incident stream delay study estimates the delay associated with a single data stream (i.e., traffic incident data) for the three reception devices.

Table 3-20 summarizes the major findings of the study, as follows:

- The mean time to verify and input incident messages was less than a minute and a half (90 seconds)
- The PC devices had a higher reception rate than did the Seiko MessageWatches (98.5 versus 89.4 percent)
- The mean time required for the Seiko MessageWatch to display incident messages was 8 folds higher than that required by the PC (3 minutes versus 19 seconds)
- The mean time required for the Navigation unit to display incident messages was 3 folds higher than that required by the PC (60 seconds versus 19 seconds)
- The maximum transmission time for the various devices ranged from 13 minutes in the case of the PC, to 19 minutes in the case of the Seiko MessageWatch and navigation unit

Table 3-20. Summary Results.

	TWS	Time to PC		Time to MessageWatch		Time to Nav. Unit	
		Air	Total	Air	Total	Air	Total
Reception Probability (percent)	N/A	98.5		89.4		N/A	
Mean Time (seconds)	78.2	18.9	97.6	178.5	253.0	59.5	101.6
Minimum Time (seconds)	0.0	1.0	12.0	15.0	52.0	0.0	20.0
Maximum Time (seconds)	791.0	430.0	823.0	1135.0	1350.0	1164.0	1188.0

Incident Message Verification and Processing. Metro Traffic, which operated the TWS, received traffic incident information from a number of sources, including: police reports, state and local DOTs, special event operators, cellular phone calls and loop detector data from the University of Washington. Metro Traffic operators phoned state patrols three times every hour during peak traffic conditions and two times every hour during off-peak traffic conditions to collect incident information. Most of the data were received orally over the telephone and radio, and were read by traffic reporters, radio and television broadcasters. After receiving the information, the Metro Traffic operators verified incidents through a number of means, including: accessing WSDOT’s surveillance cameras on the World Wide Web (WWW), viewing traffic conditions on the WWW (loop detector data), and/or visually viewing traffic conditions from Metro Traffic. Metro Traffic was located on the top floor of the highest building in downtown Seattle.

As demonstrated in Table 3-20, the mean time to verify and process the incident data at the TWS was 78 seconds. Figure 3-24 illustrates the frequency and cumulative distribution of the time required to process and verify incidents at Metro Traffic. The figure demonstrates a distribution with a mode of 30 seconds and a median of 50 seconds. The mean as mentioned earlier was 78 seconds. The distribution also demonstrates that there is a 90 percent probability that the operators can verify and process an incident within 170 seconds (approximately 3 minutes).

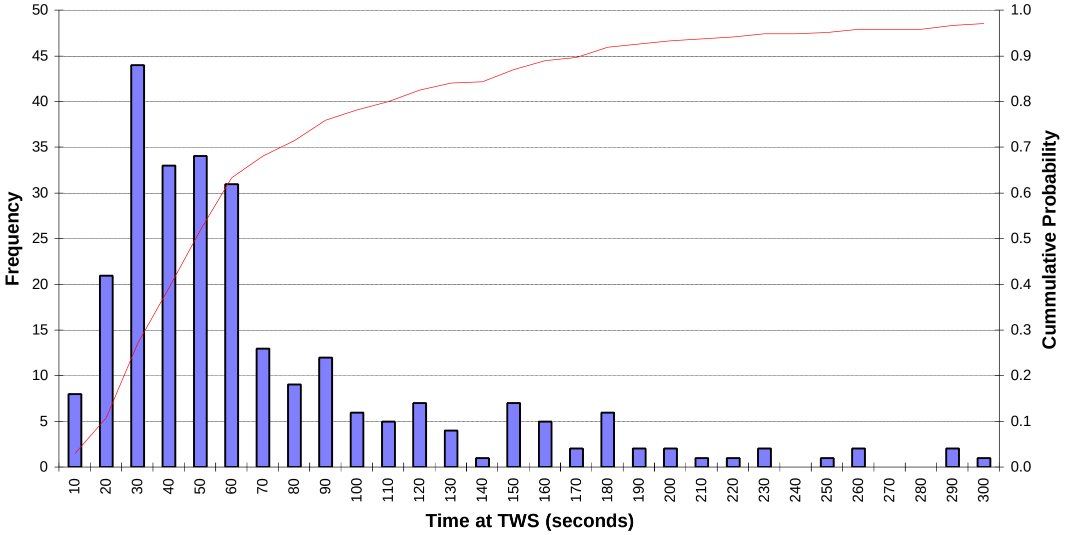


Figure 3-24. Time to Process and Verify Incident Reports at the TWS.

Data Stream Propagation Delay to PC Device. Figure 3-25 illustrates the frequency and conditional cumulative probability associated with the data stream propagation delay to the PC device. The conditional cumulative probability is the probability the propagation delay is less than *x* seconds given that the message is received by the device. The mean propagation delay was found to be 19 seconds with a mode of 10 seconds and a median of 20 seconds. Based on the results of Table 3-20 and Figure 3-25, the following conclusions can be made. First, on average there was a 98 percent probability that a message would be received by the PC device. Second, given that the message was received by the PC, there was a 90 percent probability that the PC would receive the message within 30 seconds of its origination.

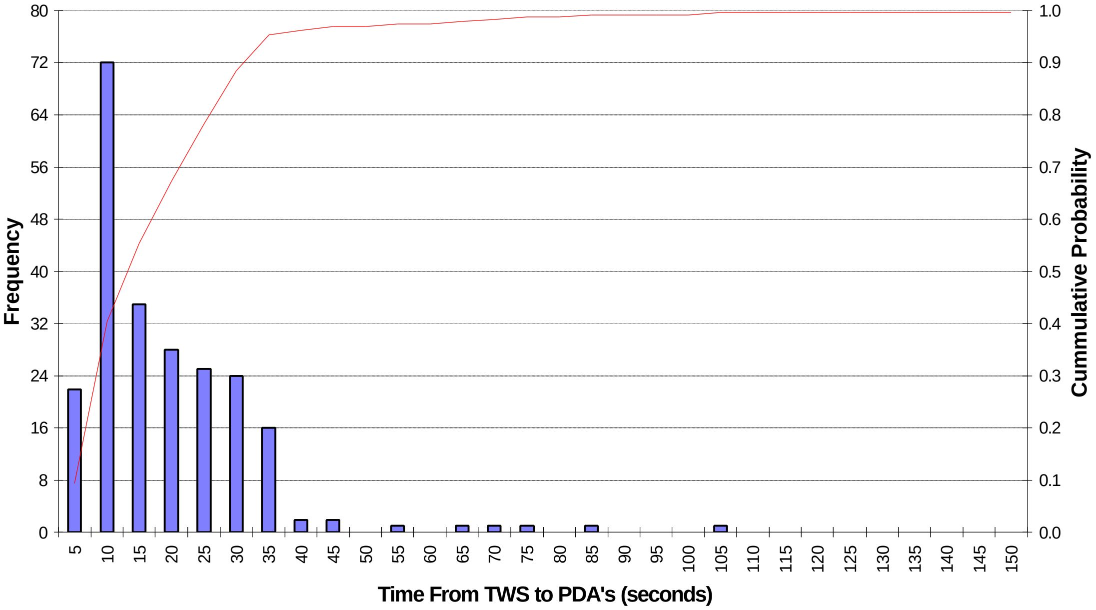


Figure 3-25. Transmission Time from TWS to PC's.

Figure 3-26 illustrates the impact of the message spacing (time interval between messages) on the propagation delay to the PC device. It is evident from Figure 3-26 that there is no correlation between the time interval between messages and the transmission duration to the PC device.

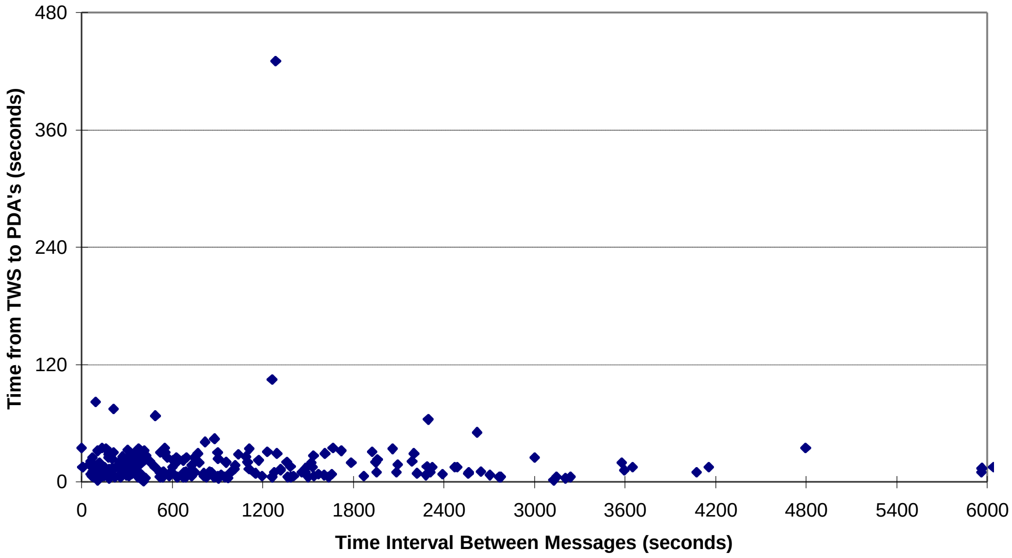


Figure 3-26. Transmission Time from TWS to PC's as a Function of Time Interval Between Incident Messages.

Data Stream Propagation Delay to Delco Navigation Device. Figure 3-27 illustrates the frequency and conditional cumulative distribution for propagation delay to the Delco navigation unit. The mean, mode and median propagation delays were found to be 60, 5 and 10 seconds, respectively. The mean propagation delay was much higher than the mode and median because a small number of transmission times exceeded 60 seconds (3 observations out of 32 observations). One of these observations was 1164 seconds. It is not clear at this point why the propagation delay was so high for a single observation.

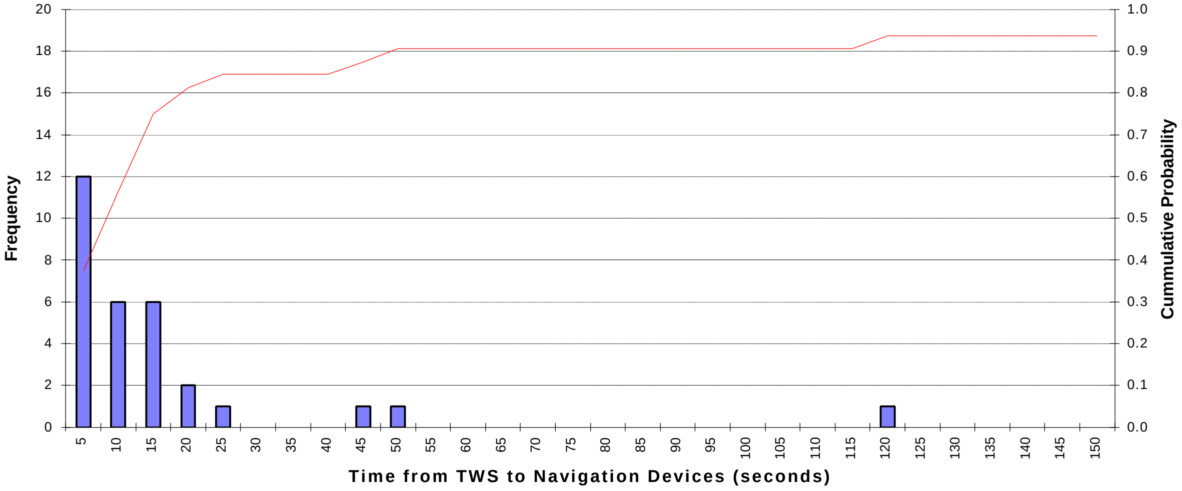


Figure 3-27. Transmission Time from TWS to Navigation Devices.

Again, as was the case for the PC devices, the message spacing had no impact on the propagation delay, as illustrated in Figure 3-28.

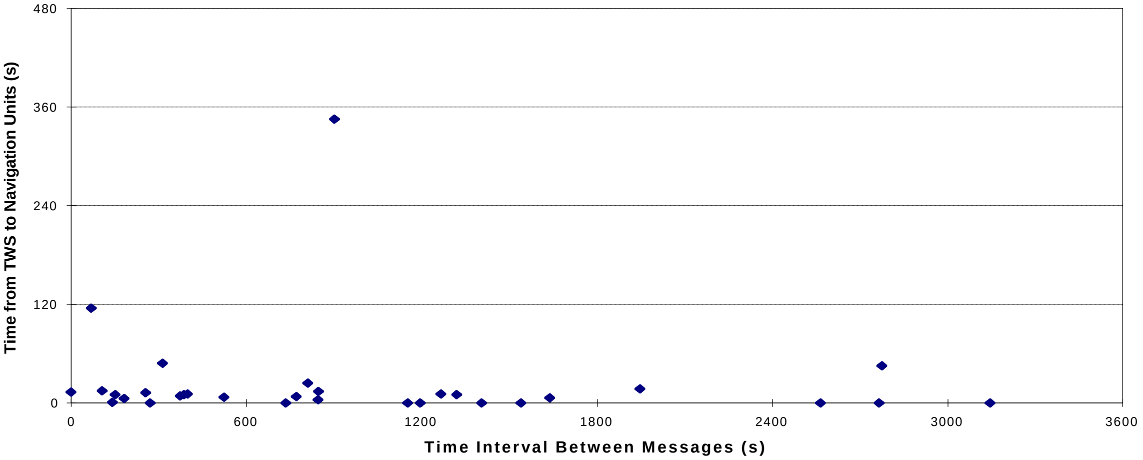


Figure 3-28. Transmission Time from TWS to Navigation Units as a Function of Time Interval Between Incident Messages.

Data Stream Propagation Delay to Seiko MessageWatch Device. Figure 3-29 illustrates the frequency and conditional cumulative probability distribution for the data stream propagation delay to the Seiko MessageWatch device. The mean, mode and median propagation delays were found to be 179, 105 and 120 seconds, respectively. The distribution also demonstrated that there was a 90 percent probability that the propagation delay to the Seiko MessageWatchdevice would be less than 360 seconds (6 minutes).

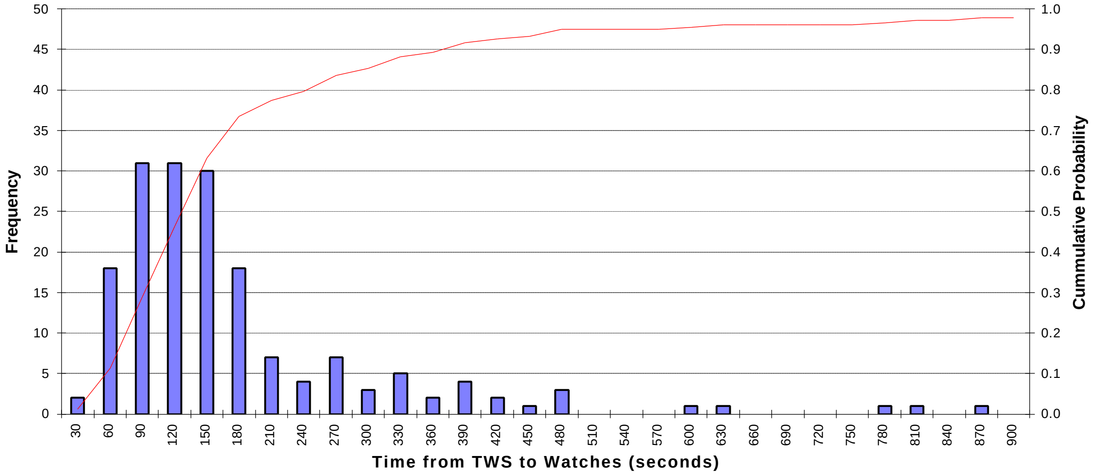


Figure 3-29. Transmission Time from TWS to MessageWatches.

Figure 3-30 illustrates the impact the message spacing had on the propagation delay to the Seiko MessageWatch device. The mean transmission time as a function of the message spacing is illustrated by the thick line while the 95 percent confidence limits are illustrated by the thin lines (assuming a normal distribution). Figure 3-30 clearly indicates that the propagation time was inversely correlated with the message spacing (i.e. closely spaced messages required longer propagation times). Furthermore, Figure 3-30 demonstrates that the variability about the mean increased as the message spacing decreased.

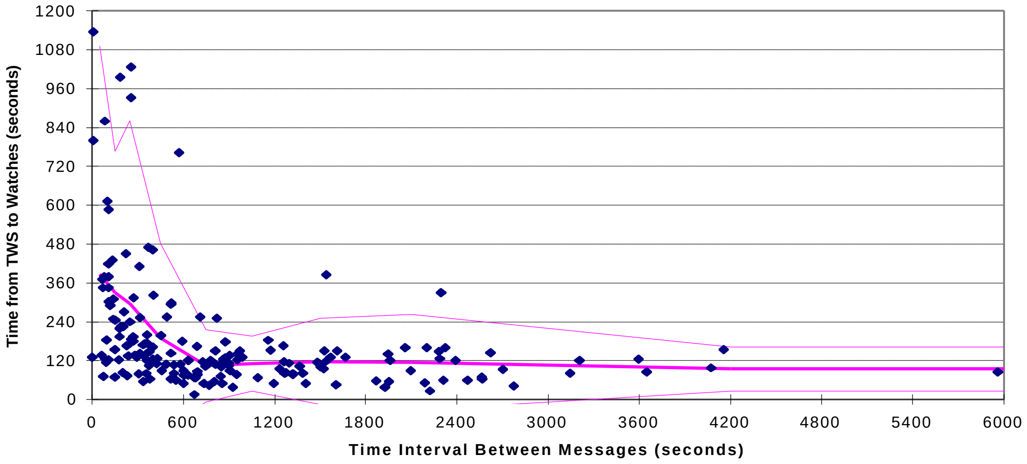


Figure 3-30. Transmission Time from TWS to MessageWatches as a Function of Time Interval Between Incident Messages.

The fact that the data stream propagation time to the PC and navigation devices were not impacted by the spacing of messages while it was to the Seiko MessageWatchcan be explained as follows. The Seiko MessageWatch was designed to check for information 0.13 milliseconds-seconds every 112 seconds (1.87 minutes) in order to allow a standard lithium battery to last for approximately a year to a year and a half. In addition, the SWIFT architecture was designed to send small packets of data with minimum error checking but with multiple broadcasts to the MessageWatches (3 broadcasts). These two architectural design requirements resulted in a message being sent 3 times every 5.5 minutes. Consequently, if a message was queued behind another message it would take any where between 5.5 and 11 (5.5+5.5) minutes before it could be received by the device. Figure 3-31 illustrates, for a sequence of 5 messages over 6 minutes, how the propagation time increased for the various messages from 115 seconds, for the first message, up to 1135 seconds for the fifth message. The first message only required 115 seconds because it was not queued, however, each subsequent message required a longer propagation time because of the queuing that resulted at the Seiko MessageWatchdevice.

These high delays associated with the Seiko MessageWatchdevice, that resulted from the architectural design, indicate that the users' concern with the timeliness of information was valid.

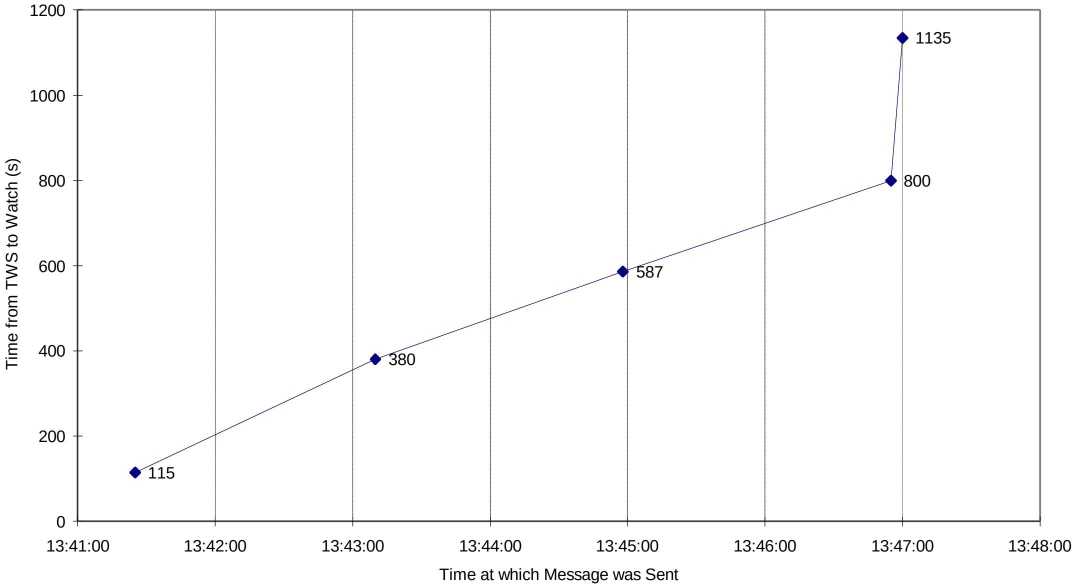


Figure 3-31. Example Illustration of Transmission Time for Incident Data from the TWS to MessageWatches.

SWIFT Data Fidelity Study

As described earlier, three data streams were broadcast as part of the SWIFT FOT. Two of these data streams included numeric data (transit and traffic speed data) while the third data stream included anecdotal data (traffic incident information). This study evaluates the fidelity of the two numeric data streams that were broadcast as part of the SWIFT FOT. An evaluation of the fidelity of the anecdotal data stream (incident data) was not possible because precise information on actual incident occurrence times, clearance times and incident severity were not available.

The next section presents the results and findings of the transit data fidelity test. In a similar fashion, the following section describes the traffic speed data fidelity results and findings. Because the SWIFT system broadcast traffic speed information as seven speed categories any inaccuracies within the speed estimates could be masked by the aggregation/categorization process. Consequently, further analysis quantifies the accuracy of the speed estimates derived from single loop detectors (majority of loop types in the Seattle area) relative to speed measurements from dual loop detectors and a radar gun.

Transit Data Fidelity. As described earlier, Metro Transit implemented an AVL system that was composed of a central computer, 255 signpost transmitters that were located throughout the 5000 square kilometer service area, an odometer sensor on each of the 1,150 buses in service, a Mobile Electronic Tracking System (METS) located on each bus, and a two-way radio system on each bus. The system's main computers were loaded with the latest bus schedules and routings, including the identity of each signpost transmitter on the route, and the distance between signposts. When the bus passed each battery-powered signpost, a small receiver on the bus captured the signpost signal and stored it in the memory of an on-board processor. This information, together with the latest odometer reading, was sent back to the central computer each time the bus was polled via the data radio system. Polling occurred nominally every 1 to 2 minutes during the peak period when up to 900 buses were in service, and more frequently during off-peak periods (5 to 15 seconds). Once the polling data were received by the central computer, it estimated the bus location on the network based on the location of the last signpost encountered and the odometer reading since the last signpost.

Tools were developed that searched for the nearest (shortest distance) SWIFT transit observation within a defined radius of the bus stop location (latitude and longitude). The corresponding absolute difference in time (SWIFT time stamp minus field observation time stamp) was computed for each of these observations. The resulting temporal and spatial location of each transit vehicle, within the SWIFT data stream, relative to the temporal and spatial field observation at the UW bus stop is illustrated in Figure 3-32. The x-axis represents the spatial difference in location (distance between the closest SWIFT observation and the corresponding field observation). The y-axis represents the absolute difference in time between the SWIFT observation and field observation. Ideally, the temporal and spatial deviation of the SWIFT observations should be minimum. Figure 3-33 illustrates that the majority of observations were within a 200m radius and a 2 minute temporal difference. A number of observations during the PM peak experienced relatively high temporal and spatial deviations. The temporal deviation exceeds the maximum update frequency (2 minutes) which could have resulted from the inaccuracy of the SWIFT data or due to the unavailability of data pertaining to some of the transit buses at certain polling intervals. The latter conclusion is more likely to be the cause of the data inconsistency because the SWIFT transit locations were both temporally and spatially offset. Data records that were either spatially or temporally offset were, most probably, a result of inaccuracies in SWIFT data. These inaccuracies in locating the buses are more evident for the downtown bus stop and the freeway stop, as illustrated in Figure 3-33 and Figure 3-34, respectively.

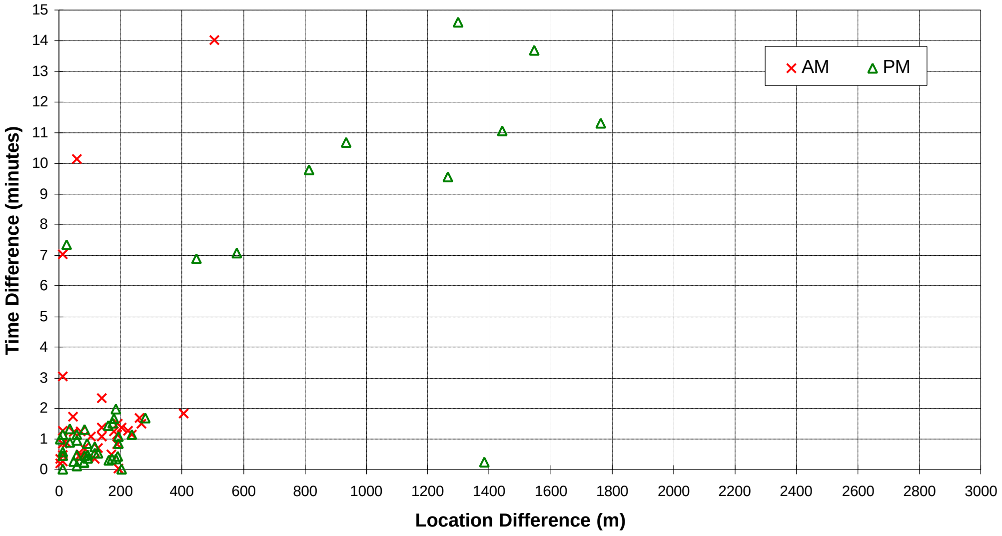


Figure 3-32. Temporal and Spatial Location of Buses at UW Bus Stop (SWIFT Versus Field Observations).

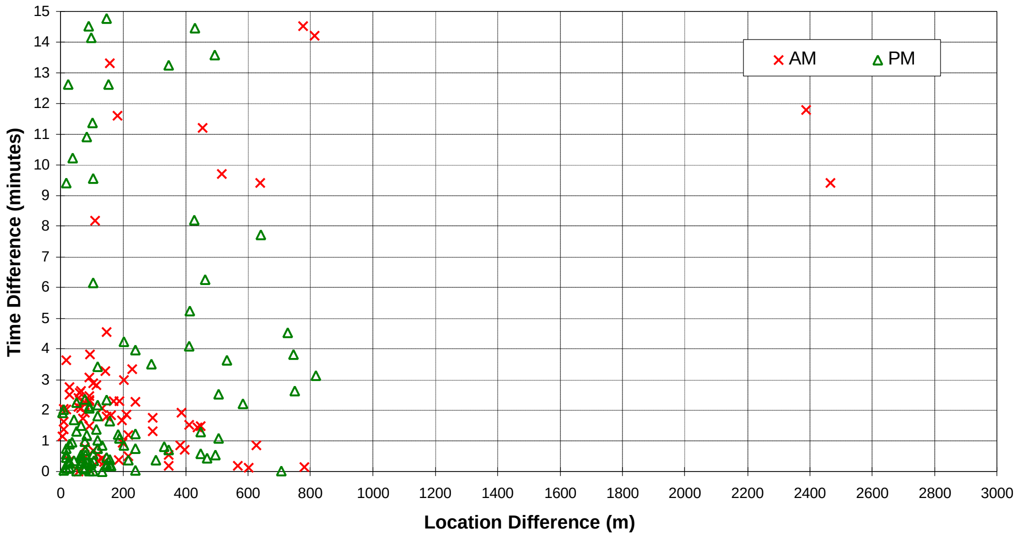


Figure 3-33. Temporal and Spatial Location of Buses at a Downtown Bus Stop (SWIFT Versus Field Observations).

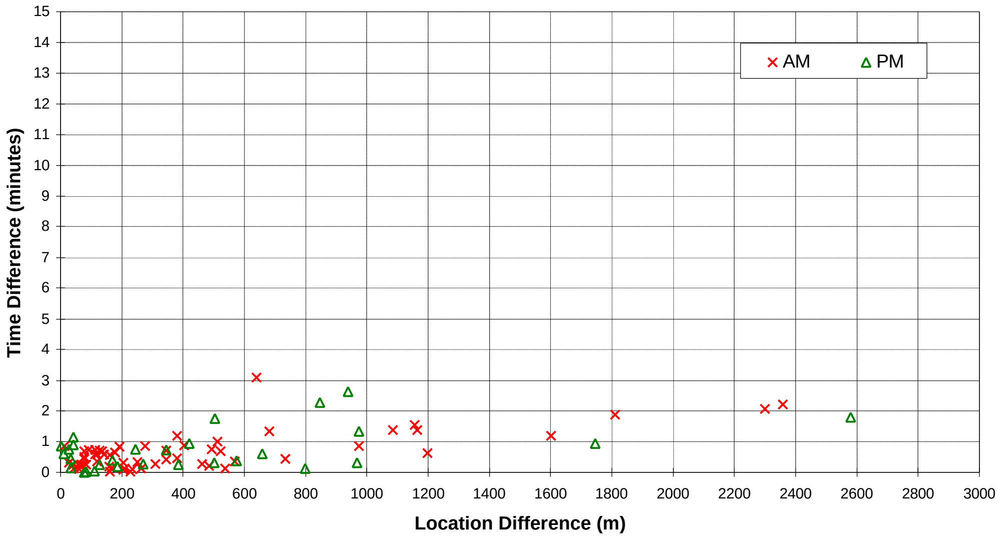


Figure 3-34. Temporal and Spatial Location of Buses at a Freeway Bus Stop (SWIFT Versus Field Observations).

The first evaluation of the SWIFT transit location data was to investigate if the data accuracy varied temporally by time-of-day (AM Versus PM peak). Utilizing Analysis of Variance (ANOVA) techniques, there was no evidence that the accuracy of data differed during the AM versus the PM peak at two of the bus stop locations, however, there was a statistical difference at the UW bus stop (5 percent level of significance), as demonstrated in Table 3-21. The temporal difference in transit location accuracy at the UW bus stop is also evident from the time/space illustration in Figure 3-32.

Table 3-21. Single-Factor ANOVA Results for AM and PM Peak Comparisons.

Bus Station Location	Statistical Significance Difference Between AM and PM (alpha = 5%)?
University of Washington - Hub Building	Yes
Downtown - University Station (Southbound)	No
Freeway - Evergreen Point (Westbound)	No

The second evaluation of the SWIFT transit location data was to investigate if the data accuracy varied spatially (freeway versus downtown versus urban bus stop). The results of the ANOVA analysis demonstrated that there was a statistical difference, at a 5 percent level of significance, in the SWIFT transit location data between the different sites, as demonstrated in Table 3-22. The freeway bus stop demonstrated the least accuracy for both the AM and PM peak conditions with an average error of 342 meters and 472 meters, respectively. It is speculated that the larger transit location error at the freeway bus stop could have resulted from the higher speeds at which the vehicles were traveling. Noteworthy is the fact that the buses were, on average, located to within half a kilometer of the bus stop regardless of the bus stop location.

Table 3-22. Single-Factor ANOVA Results Location Comparisons

Anova: Single Factor - PM

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
UW	46	15385	334	229674
Tunnel	101	20066	199	39449
Freeway	29	13683	472	332608

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1871492	2	935746.1	6.861	0.001	3.048
Within Groups	23593261	173	136377.2			
Total	25464754	175				

Anova: Single Factor - AM

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
UW	35	4516	129	13451
Tunnel	74	20175	273	169819
Freeway	29	9916	342	134587

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	794998.3	2	397499.1	3.228	0.043	3.063
Within Groups	16622590	135	123130.3			
Total	17417588	137				

Figure 3-35 illustrates how the density function and cumulative function of vehicle-location error varied during the AM peak at the UW bus stop (SWIFT spatial location versus field observations). The x-axis represents the bin size in 100 meter increments (e.g. a bin size of 1 represents an error less than 100 meters). Figure 3-35 demonstrates that approximately 40 percent of the SWIFT transit vehicle locations were within 100 meters of the field observations. Figure 3-35 also demonstrates that approximately 80 percent of the SWIFT vehicle locations were within 300 meters of the field observations. Furthermore, approximately 20 percent of the field observations were missing from the SWIFT data. During the PM peak the error in locating the transit vehicles was higher (as was found with the ANOVA testing) with approximately 30 percent of the field observations missing from the SWIFT data, as illustrated in Figure 3-36.

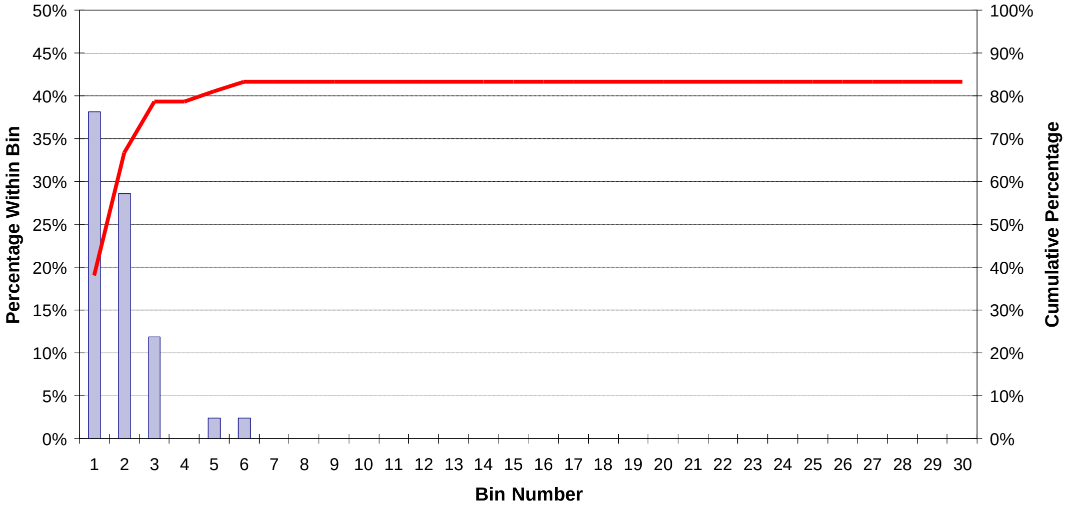


Figure 3-35. Distribution of Spatial Difference in Bus Location (UW Bus Station - AM).

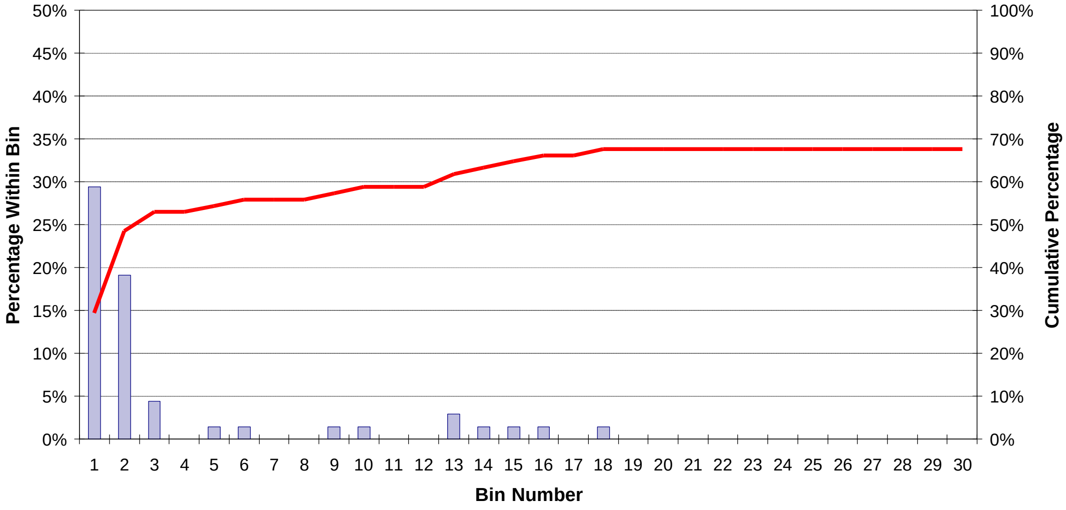


Figure 3-36. Distribution of Spatial Difference in Bus Location (UW Bus Station - PM).

In the case of the downtown bus stop, approximately 30 percent of the field observed transit vehicles were missing from the SWIFT data during the AM and PM peaks, as illustrated in Figure 3-37 and Figure 3-38, respectively. The majority of SWIFT observations were within a 1000 meter radius of the field observed buses.

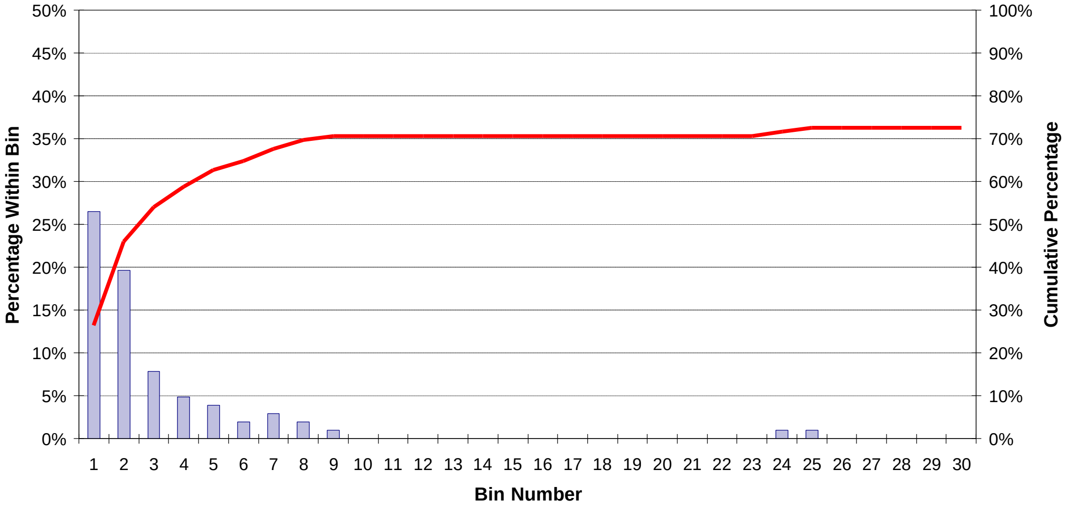


Figure 3-37. Distribution of Spatial Difference in Bus Location (Downtown Bus Station - AM).

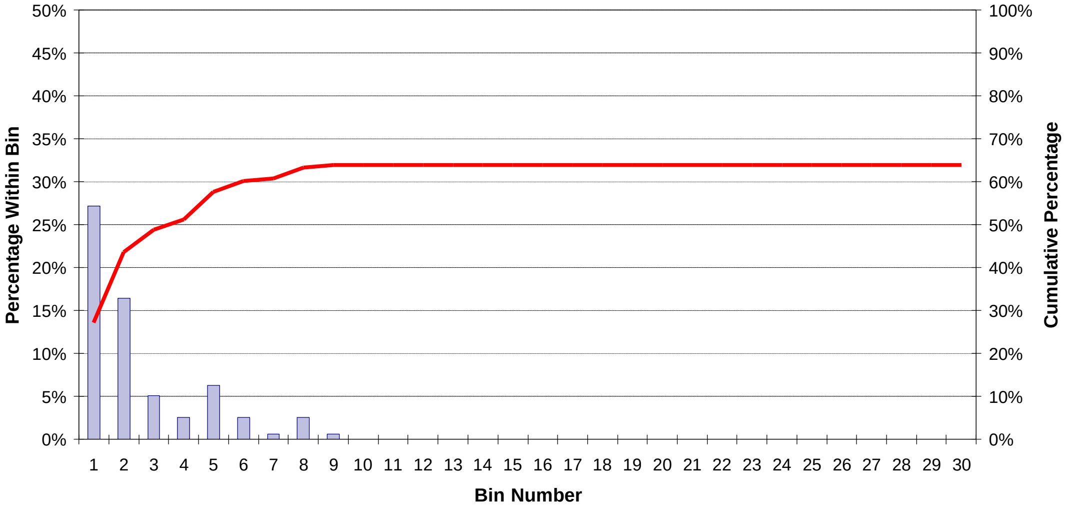


Figure 3-38. Distribution of Spatial Difference in Bus Location (Downtown Bus Station - PM).

In the case of the freeway bus stop, approximately 30 percent of the field observed transit vehicles were missing from the SWIFT data during the AM peak and approximately 40 percent during the PM peak, as illustrated in Figure 3-39 and Figure 3-40, respectively. Furthermore, approximately 10 percent of the observations were spatially offset by more than 1000 meters. It should be noted, however, that a spatial offset of 800 meters on a 105 km/h facility would be equivalent to a temporal offset of only 30 seconds. Consequently, the spatial offsets that were observed are not as bad as would appear at first glance.

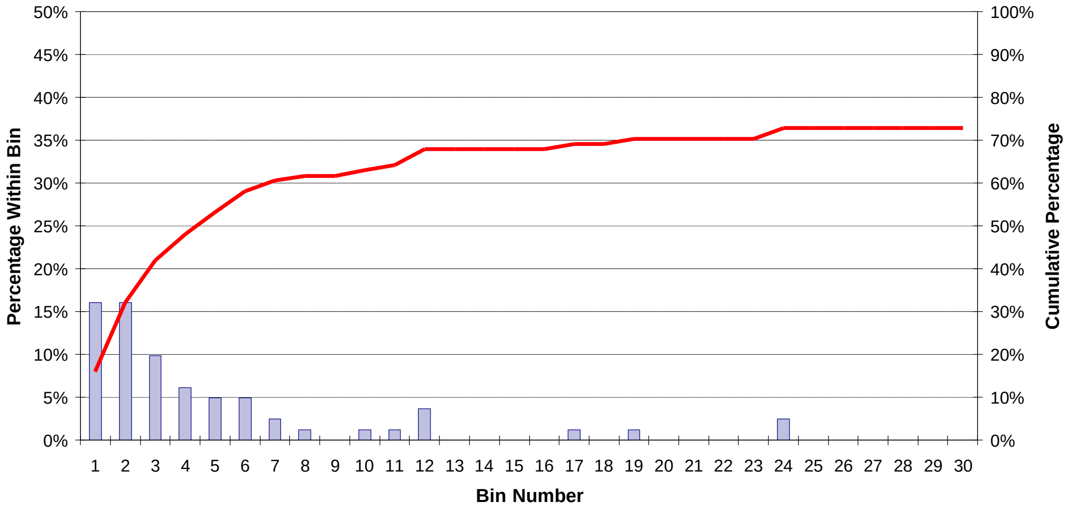


Figure 3-39. Distribution of Spatial Difference in Bus Location (Freeway Bus Station - AM).

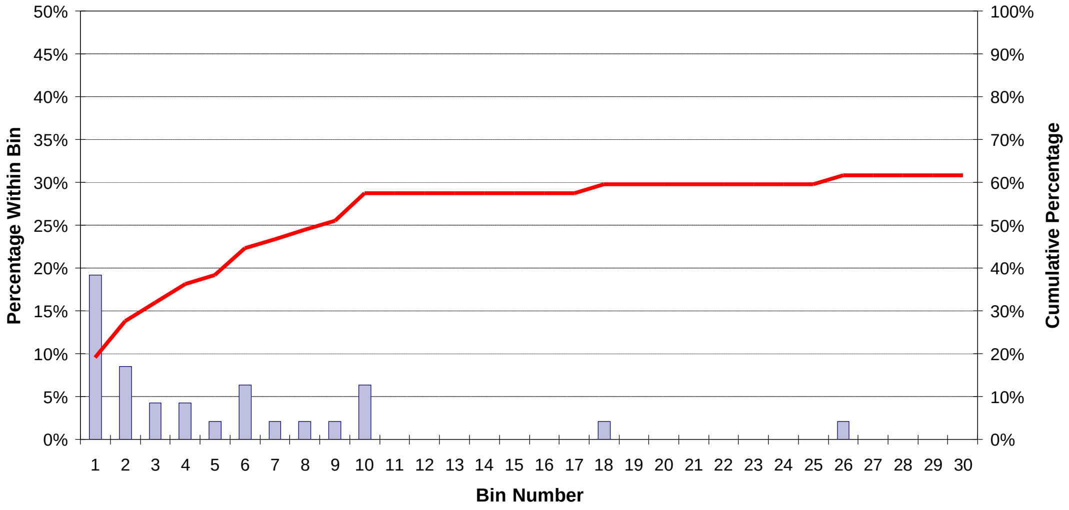


Figure 3-40. Distribution of Spatial Difference in Bus Location

(Freeway Bus Station - PM).

Traffic Speed Data Fidelity. The next step in the fidelity study was to evaluate the accuracy of the second SWIFT numeric data stream, namely; the traffic speed data. This section describes the field tests that were conducted in order to perform this evaluation together with the findings of the study.

Based on the nine test drives that were conducted in each direction along the 16-kilometer I-5 section, a total of 188 and 169 field observations were recorded in the Northbound and Southbound directions, respectively, as demonstrated in Table 3-23. The discrepancy in the number of observations by direction (188 versus 169) was caused by the fact that depending on where the first on-ramp and last off-ramp was located along the section the number of 0.5-mile segments would differ depending on where the first milepost mark and the last milepost mark were located along the driven section. Of these observations approximately 20 percent of the data were missing from the SWIFT system (0 category).

Table 3-23. Percentage Valid Traffic Speed Data Coverage.

	Northbound	Southbound
Number of Observations	188	169
Number of Valid SWIFT Observations	138	131
Number of Non-valid SWIFT Observations	50	38
Percentage Observations Non-Valid	20.7	22.5

It must be noted at this point, that the field observations represent a single observation from a statistical distribution while the SWIFT data represent mean observations over 20-second intervals across the non-HOV lanes. However, because the SWIFT data were displayed as categories as opposed to absolute values, it is implicitly assumed, in this study, that these categories encompass the confidence limits of a single observation. Consequently, the field observations are directly compared to the SWIFT traffic speed data for evaluation purposes.

Figure 3-41 illustrates considerable consistency between what the SWIFT system speeds that were broadcast to what was actually observed in the field. Specifically, 50 percent of the SWIFT valid estimates were in a category the was consistent with the field conditions for the northbound direction and 40 percent for the southbound direction. Furthermore, approximately 80 percent of the SWIFT valid observations were within 1 category difference for the northbound direction and 70 percent for the southbound direction. In some rare instances the SWIFT speed estimates were off by up to six (6) categories. Noteworthy, is the fact that the error distribution for the northbound direction appeared to be symmetric about the zero error, however, this was not the case for the southbound direction (skewed to the right). Specifically, the SWIFT speed estimates appeared to exceed what was observed in the field for the southbound direction.

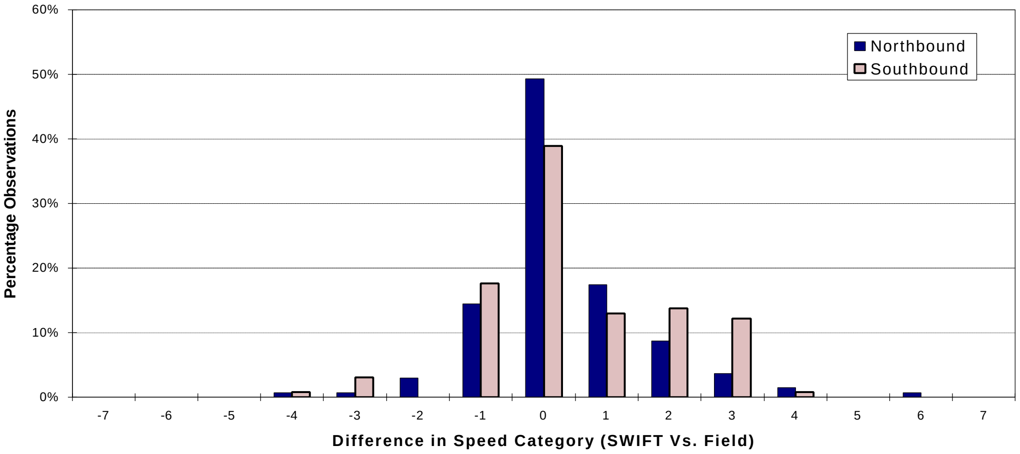


Figure 3-41. Distribution of Speed Estimate Difference Along I-5 (SWIFT Versus Field Observations).

In order to investigate why the SWIFT speed estimates inclined to be higher than what was experienced in the field along the southbound direction, the spatial variation in speed along each of the 18 segments (9 trips × 2 directions) are illustrated and discussed.

Figure 3-42 illustrates the spatial variation in speed along I-5 in the northbound direction for the first trip. The figure demonstrates a good match between the field observations and SWIFT speed estimates for uncongested conditions (high speeds). However, as the speeds that were experienced in the field decreased the SWIFT system tended to over-estimate the speed estimates compared to what was observed in the field. These findings are consistent for the remaining eight trips in the northbound direction along I-5, as illustrated in Figure 3-43 through Figure 3-50. The over-estimation of speeds by the SWIFT system is very evident for trip 8, as illustrated in Figure 3-49.

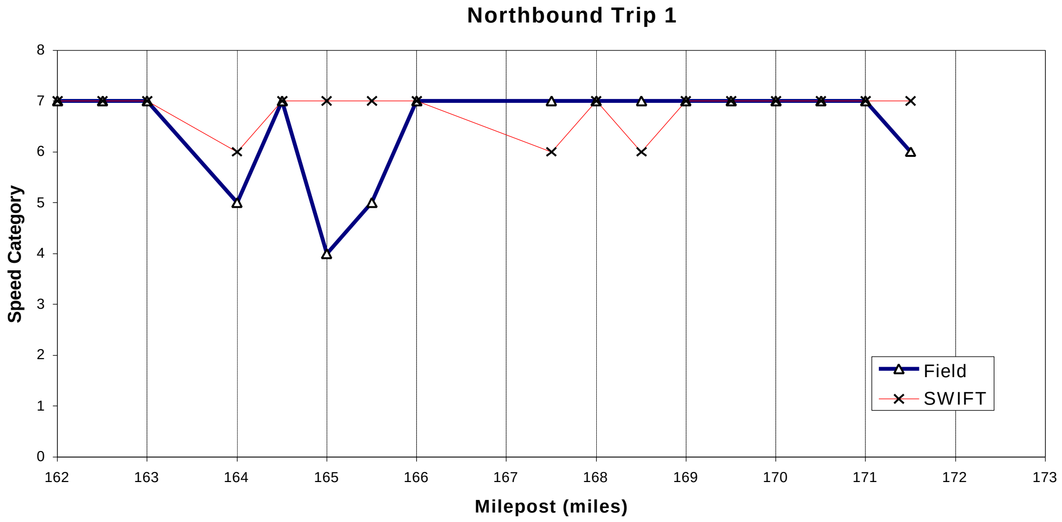


Figure 3-42. Spatial Variation in Speed Along I-5 (Northbound - Trip 1).

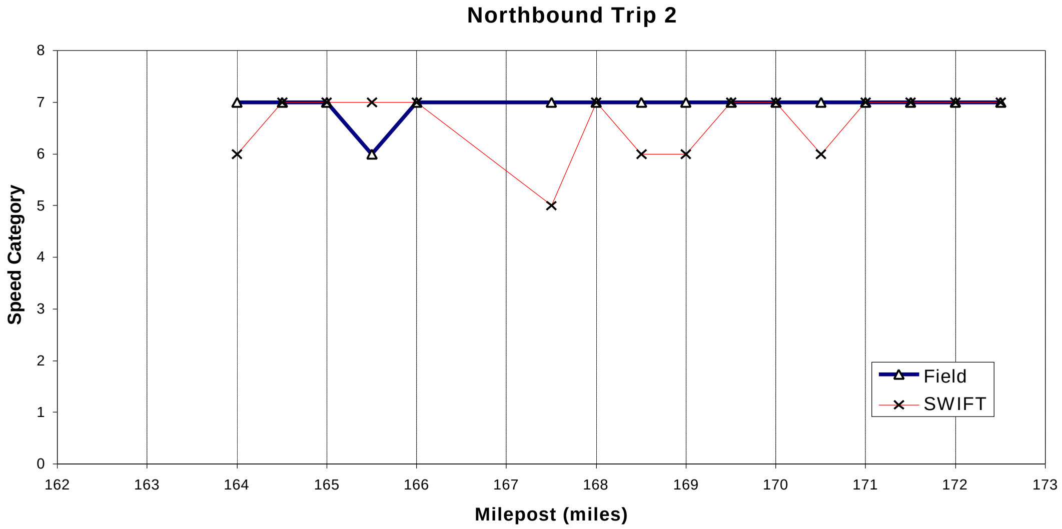


Figure 3-43. Spatial Variation in Speed Along I-5 (Northbound - Trip 2).

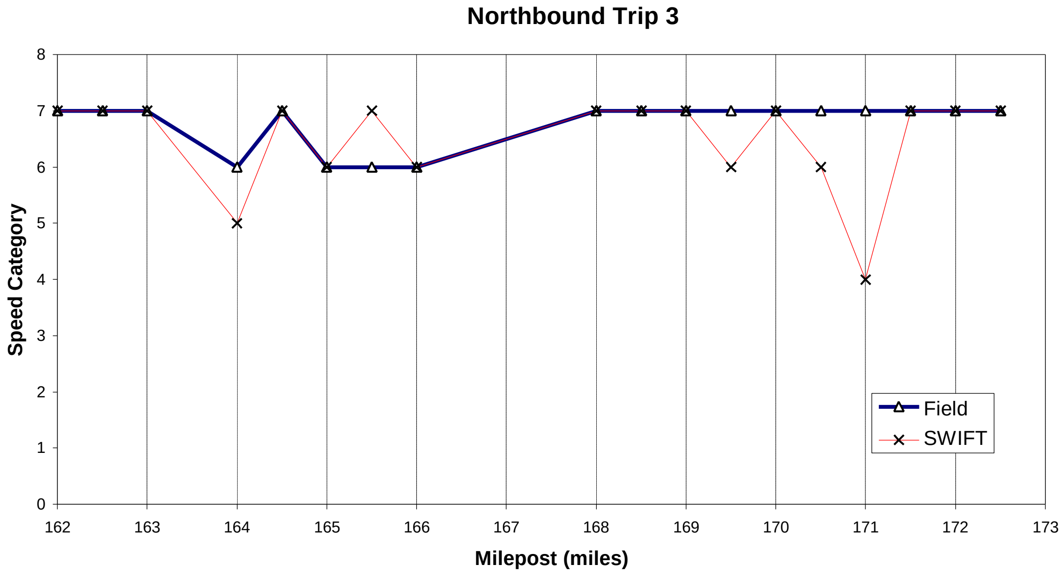


Figure 3-44. Spatial Variation in Speed Along I-5 (Northbound - Trip 3).

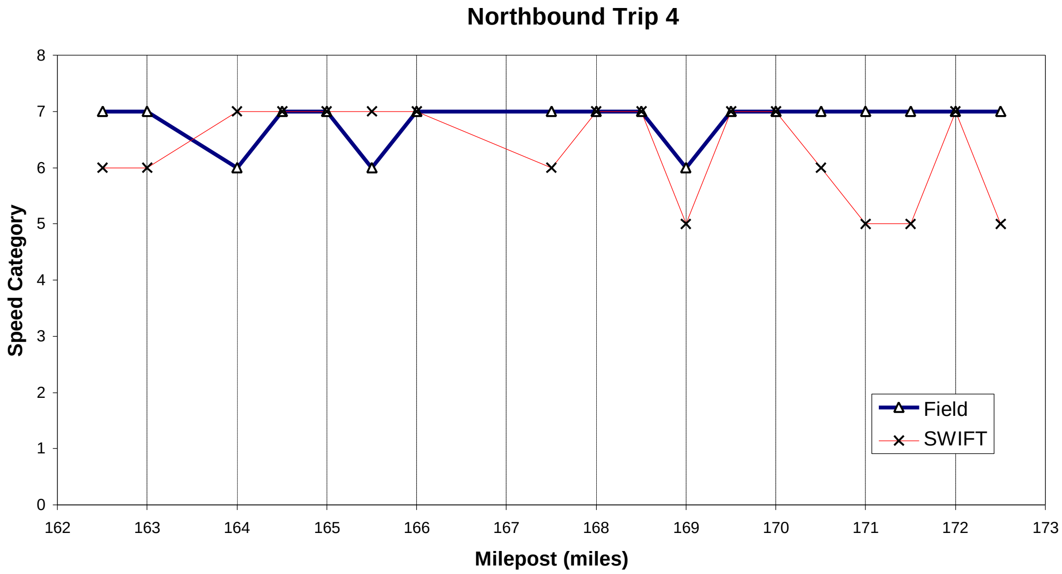


Figure 3-45. Spatial Variation in Speed Along I-5 (Northbound - Trip 4).

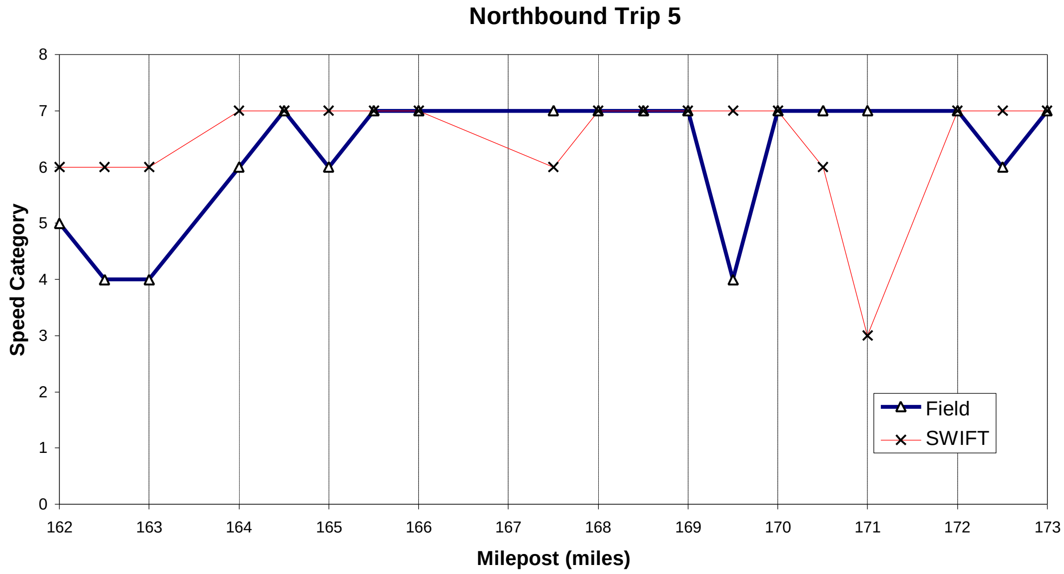


Figure 3-46. Spatial Variation in Speed Along I-5 (Northbound - Trip 5).

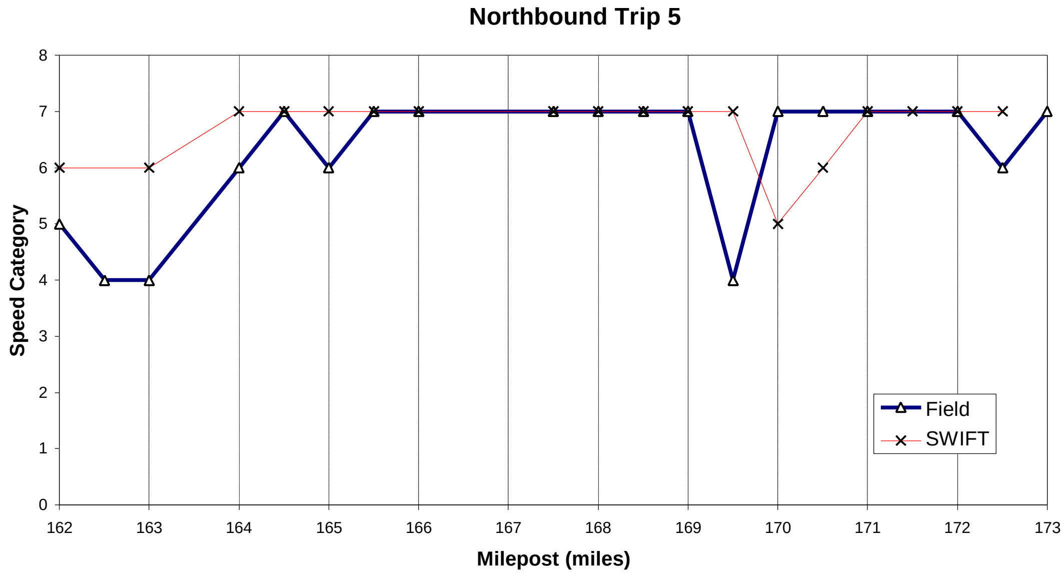


Figure 3-47. Spatial Variation in Speed Along I-5 (Northbound - Trip 6).

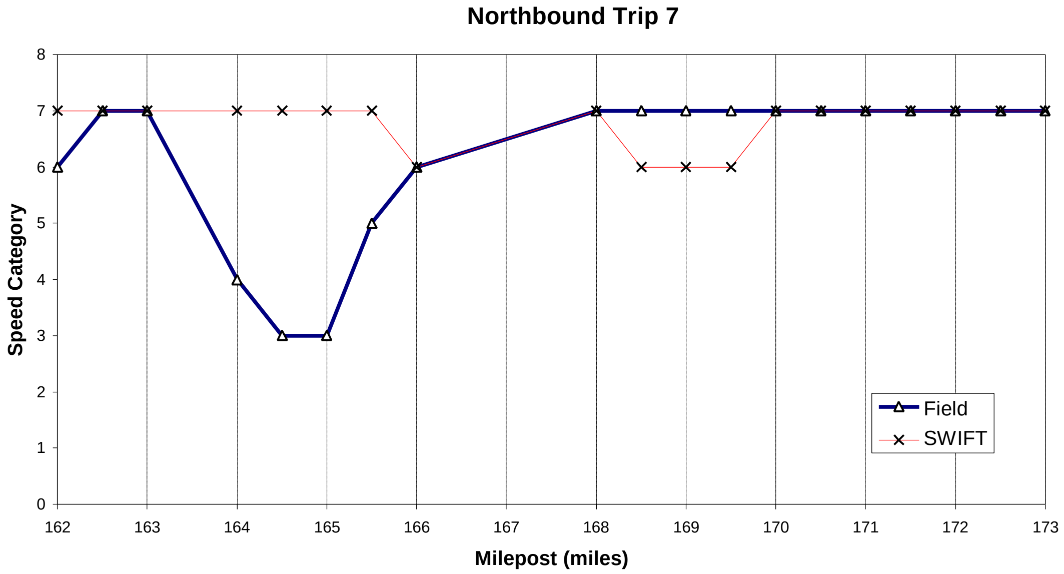


Figure 3-48. Spatial Variation in Speed Along I-5 (Northbound - Trip 7).

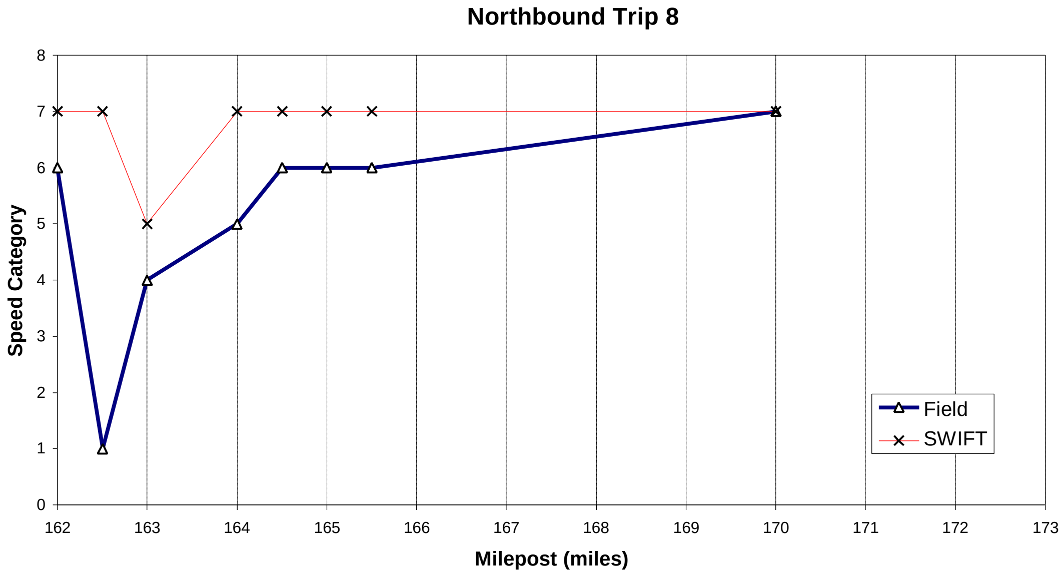


Figure 3-49. Spatial Variation in Speed Along I-5 (Northbound - Trip 8).

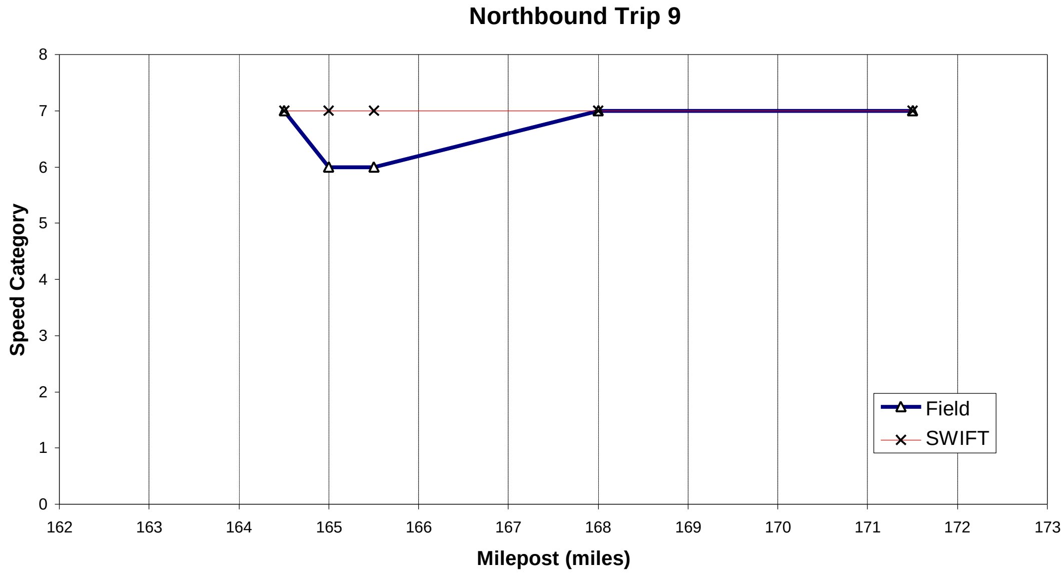


Figure 3-50. Spatial Variation in Speed Along I-5 (Northbound - Trip 9).

The southbound direction experienced more congestion at the time during which the test runs were conducted, as illustrated in Figure 3-51 through Figure 3-63. Specifically, trips 2 through 5 experienced speeds as low as category 3 (9 to 18 mph), as illustrated in Figure 3-52, Figure 3-53, Figure 3-54, and Figure 3-55. Consequently, because the SWIFT speed estimates tended over-estimate speeds for congested conditions and because the southbound direction experienced more congestion than did the northbound direction, the speed error for the southbound direction was skewed towards over-estimating speeds.

Figure 3-51. Spatial Variation in Speed Along I-5 (Southbound - Trip 1).

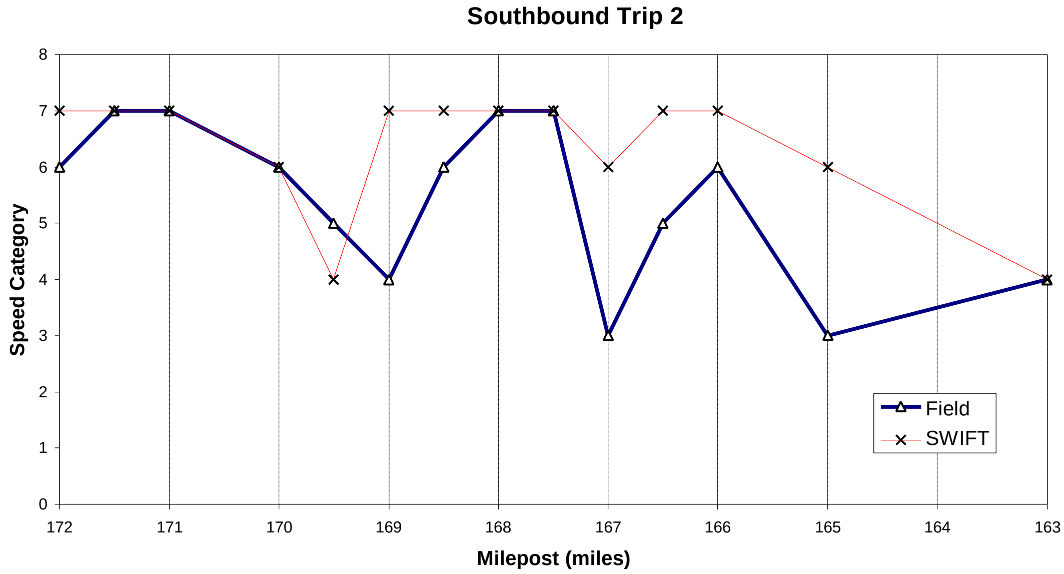


Figure 3-52. Spatial Variation in Speed Along I-5 (Southbound - Trip 2).

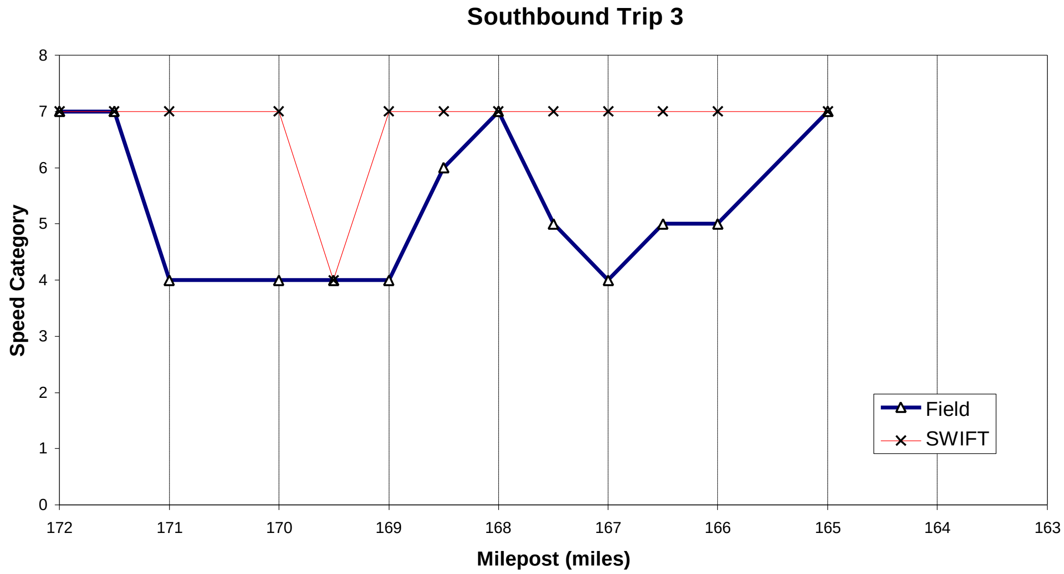


Figure 3-53. Spatial Variation in Speed Along I-5 (Southbound - Trip 3).

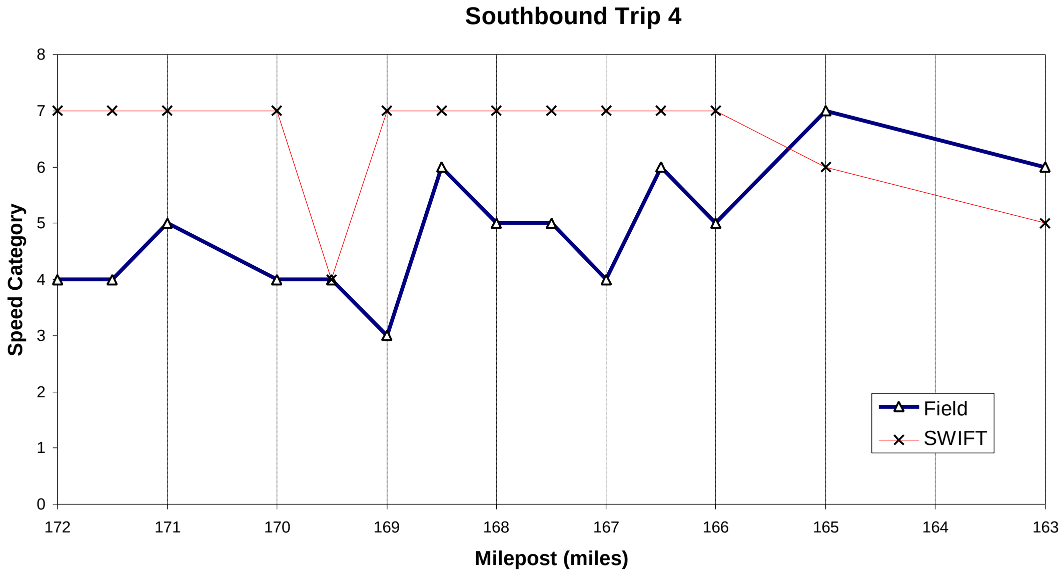


Figure 3-54. Spatial Variation in Speed Along I-5 (Southbound - Trip 4).

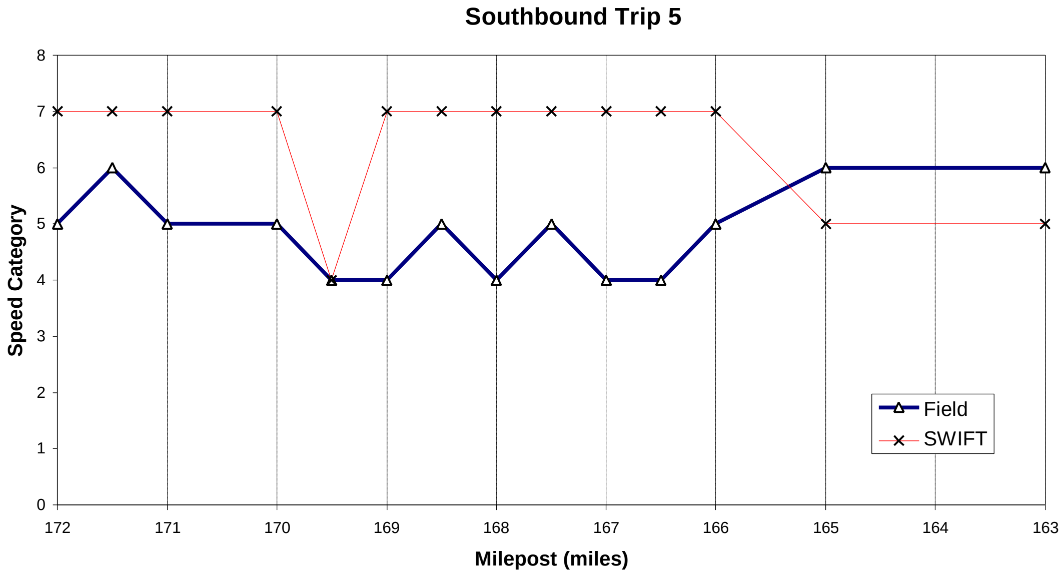


Figure 3-55. Spatial Variation in Speed Along I-5 (Southbound - Trip 5).

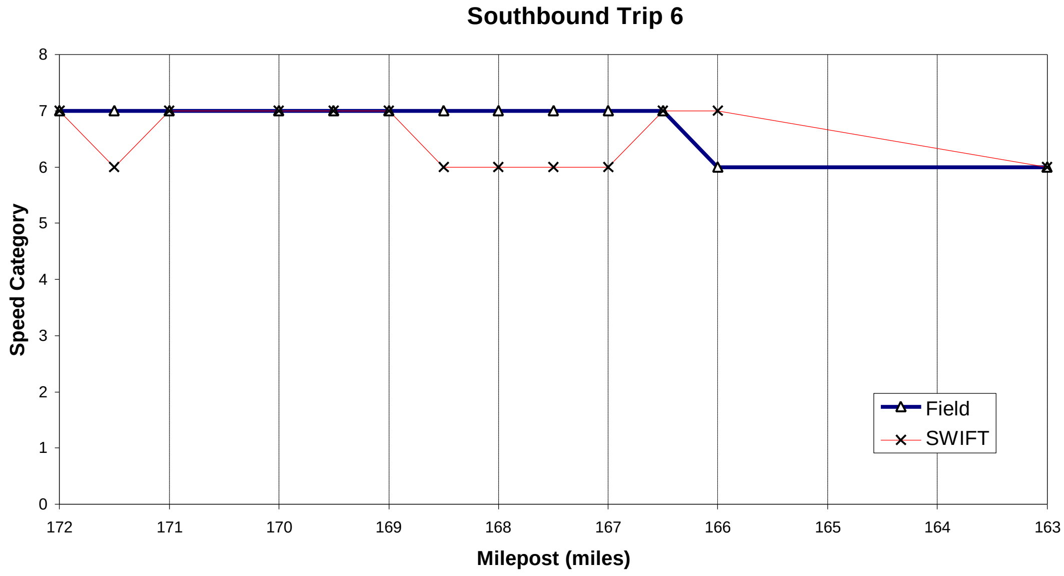


Figure 3-56. Spatial Variation in Speed Along I-5 (Southbound - Trip 6).

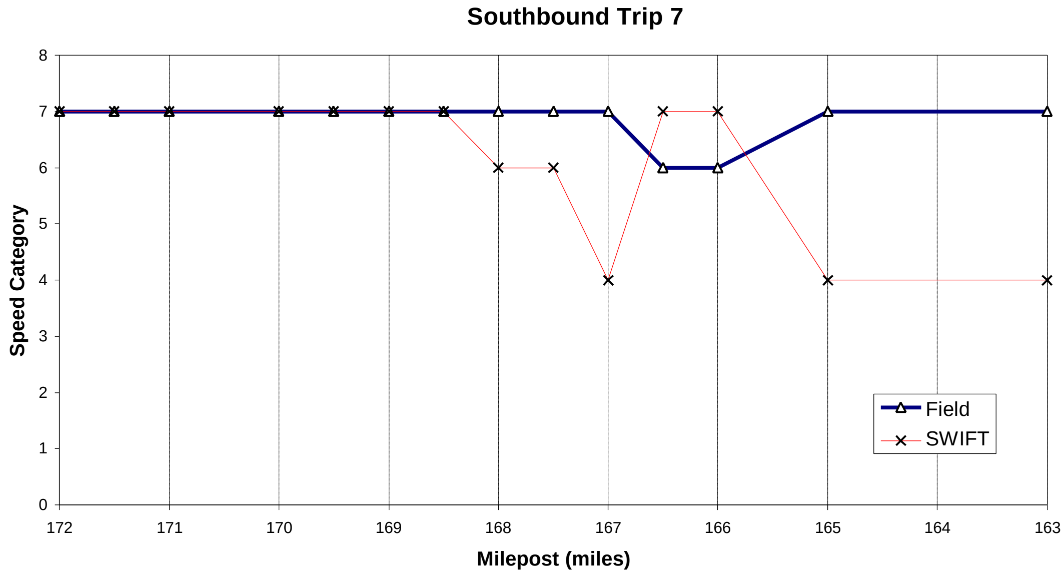


Figure 3-57. Spatial Variation in Speed Along I-5 (Southbound - Trip 7).

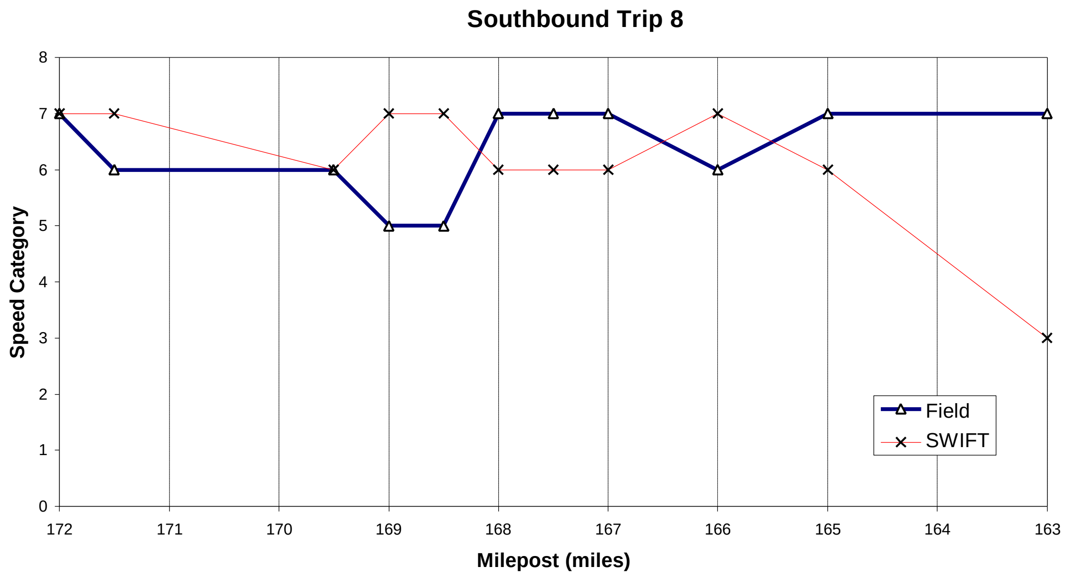


Figure 3-58. Spatial Variation in Speed Along I-5 (Southbound - Trip 8).

Figure 3-59. Spatial Variation in Speed Along I-5 (Southbound - Trip 9).

Evaluation of Single Loop Speed Estimator. As described in the previous section, the SWIFT speed data were broadcast as categories in order to minimize bandwidth utilization. Consequently, it is extremely difficult to identify whether speed estimate errors that were observed in the field operational test resulted from the categorization process or whether they resulted from some inherent error in the speed estimation procedure. This section attempts to evaluate the speed estimation procedure that was utilized as part of the SWIFT field operational test.

Unfortunately, the speed measurements that were gathered along the I-520 section during the analysis period did not experience congestion with speeds only varying from 80 km/h (50 mph) to 125 km/h (80 mph). Consequently, it was not possible to evaluate the accuracy of the G-factor and Kalman-filter techniques for various levels of traffic conditions. Ironically, the previous section demonstrated that the SWIFT speed category estimates were least accurate for low speeds.

The most common traffic detector used today is a presence-type detector which detects the presence and passage of vehicles over a short segment of roadway. When a vehicle enters the detection zone, the sensor is activated and remains activated until the vehicle leaves the detection zone. The detector remains on for a distance of travel equivalent to the length of the vehicle plus the length of the detection zone. The detection zone, which does not necessarily equal the physical length of the detector, is numerically determined through calibration. The inductance loop detectors that are currently installed in the Seattle area are examples of presence type detectors. Inductance loop detectors act as an inductor in an oscillating inductor-capacitor (L-C) circuit. L-C circuits oscillate at a resonant frequency that depends on the value of the capacitance and inductance. A large metalic object that travels over the detector (within the detection zone) changes the value of the inductance, resulting in a change in the resonant frequency. The change in resonant frequency produces an electric current giving what may be thought of as a “1” signal. Alternatively, when there is no vehicle over the detection zone no signal is produced and it may be thought of as giving a “0” signal. The loop detector is scanned at regular intervals (60 times per second in the case of the Seattle loop detectors) generating a pictorial output depicted in Figure 3-60.

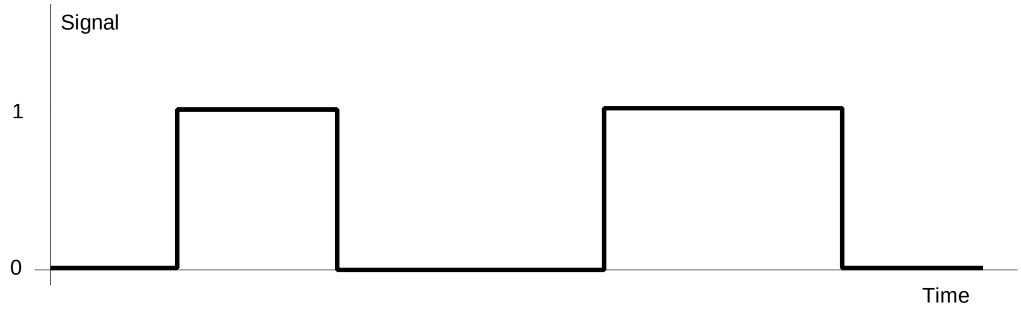


Figure 3-60. Output signals for a Loop Detector.

The classical steady-state traffic flow relationship states that the traffic flow rate equals the product of the traffic density and the traffic space mean speed, as demonstrated in Equation 1 (Lighthill and Witham, 1955).

$$q = k \times u \tag{1}$$

a. Where:

b. q = Hourly flow rate (veh/h/lane)

c. k = Traffic density (veh/km/lane)

d. u = Traffic space mean speed (km/h)

It is important, at this point, to demonstrate the difference between space-mean-speeds and time-mean-speeds. This distinction will be relevant when the radar gun speeds are compared to the loop detector speeds. The mean or average speed of individual vehicles is referred to as time-mean-speed and is computed using Equation 2. If, instead, the average travel time rate were computed first and then the average speed computed from the average travel time rate, the final speed is referred to as the space mean speed, as demonstrated in Equation 3. Wardrop (1952) derived the equation relating time-mean-speed and space-mean-speed as shown in Equation 4. Studies have shown that the difference between time-mean-speed and space-mean-speed are in the order of 1 to 5 percent (May, 1990).

$$\bar{u}_{TMS} = \frac{\sum_{i=1}^{N} u_i}{N} \tag{2}$$

$$\bar{u}_{SMS} = \frac{d}{\sum_{i=1}^{N} t_i / N} \tag{3}$$

$$\bar{u}_{TMS} = \bar{u}_{SMS} + \frac{s_{SMS}^2}{\bar{u}_{SMS}} \tag{4}$$

Where:

$\bar{u}_{TMS}$ = Time-mean-speed

$\bar{u}_{SMS}$ = Space-mean-speed

N = Number of observations

d = Distance traveled (detection zone plus vehicle length)

t_i = Travel time for vehicle “i” to traverse distance “d”

u_i = Speed of vehicle “i” along distance “d”

s_{SMS}^2 = Space-mean-speed variance

Single loop detectors measure occupancy, which is defined as the percentage of time a detector is occupied over a specified time interval (O_i). Occupancy ranges from 0, meaning that the detection zone was never occupied during the time interval, to 1, meaning that the detection zone was occupied 100 percent of the time interval. Single loop detectors also measure the traffic volume that passes the detection zone, which is defined as the number of activations for a specified time interval (N_i). The measurement time interval is usually 20 seconds (as was the case for the Seattle area loop detectors) or in some instances can be 30 seconds.

The flow rate over a 20-second time interval can be easily computed using Equation 5. The computation of traffic density from occupancy measurements is not straightforward because it depends on a variable parameter (average vehicle length), as demonstrated in Equation 6. The detection length is a constant parameter that is calibrated, however, the average vehicle length over a time interval is a function of the traffic composition (percentage trucks, buses, etc.). Furthermore, the average vehicle length can vary from one time interval to another.

$$q_i = \frac{3600}{T} \times N_i \tag{5}$$

$$k_i = \frac{1000}{l_v + l_D} \times O_i \tag{6}$$

Where:

q_i = Hourly flow rate for time interval “i” (km/h/lane)

T = Time interval duration (20 seconds for WSDOT loop detectors)

N_i = Number of activations for time interval “i” (unitless)

k_i = Traffic density for time interval “i” (veh/h/lane)

l_v = Average vehicle length (meters)

l_D = Length of detection zone (meters)

O_i = Occupancy for time interval “i” (unitless and ranges from 0 to 1)

Using the steady-state traffic flow relationship (Equation 1) the speed over a time interval can be computed using Equation 7. Hall and Persaud (1988) have assumed the average vehicle length to be constant allowing the vehicle speed to be equal to a constant (“G” factor) multiplied by the volume to occupancy ratio. The constant is a parameter that is derived through calibration. This approach is referred to as the G-factor technique.

$$u_i = 3.6 \times \left(\frac{l_v + l_D}{T} \right) \times \frac{N_i}{O_i} \tag{7}$$

Dailey (1997) has demonstrated that the use of a constant multiplied by an error free volume to occupancy ratio has a bias because it neglects the speed variance (s_s), as demonstrated in Equation 8. In order to address the variability of the observations, Dailey (1997) developed a Kalman filter technique that estimates the mean traffic speed using volume to occupancy data from single inductance loops. The algorithm, which is based on the statistics of the measurements from a traffic management system, produces an estimate of speed and provides a reliability test for the speed estimate. This Kalman filter technique was utilized during the SWIFT field operational test in order to estimate the traffic speed.

$$u_i = 3.6 \times \left(\frac{l_v + l_D}{T} \right) \times \frac{N_i}{O_i} \times \left(\frac{s_s^2}{u_i^2} + 1 \right) \qquad (8)$$

The following paragraphs describe the accuracy of the G-factor and Kalman filter speed estimation techniques by comparing these speed estimates to speeds measured by a dual loop detector. The use of two closely spaced loop detectors (dual loops) allows for the direct measurement of speed without having to estimate the vehicle length. Specifically, knowing the distance between the detection zones of the two detectors (through calibration) and using the time difference between actuations the speed of the vehicle is directly computed. While the use of dual loop detectors allows for the direct measurement of speed, it is more costly because it requires two loop detectors as opposed to one.

Figure 3-61 illustrates a scatter plot of dual loop detector speed measurements (x-axis) versus speed estimates using the G-factor technique (y-axis). The line of perfect correlation (45° line) is also drawn in order to visually demonstrate how the two speed estimates compare. It is clearly evident that the G-factor technique under-estimated vehicle speeds when compared to the dual loop detector speed measurements.

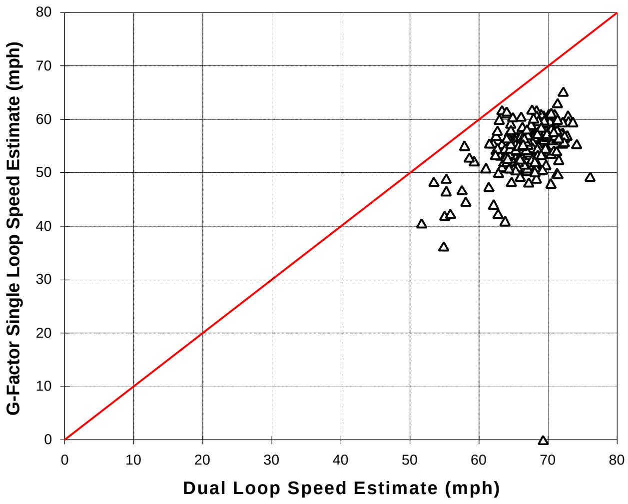


Figure 3-61. Speed Estimate Comparison
(WSDOT Algorithm Versus Dual Loop Speed Counts).

Figure 3-62 illustrates how the Kalman-filter speed estimates compared to the dual loop measurements. The observations are closely aligned around the line of perfect correlation. Comparing Figure 3-61 to Figure 3-62 it is evident that the Kalman-filter estimates were more accurate than the G-factor estimates.

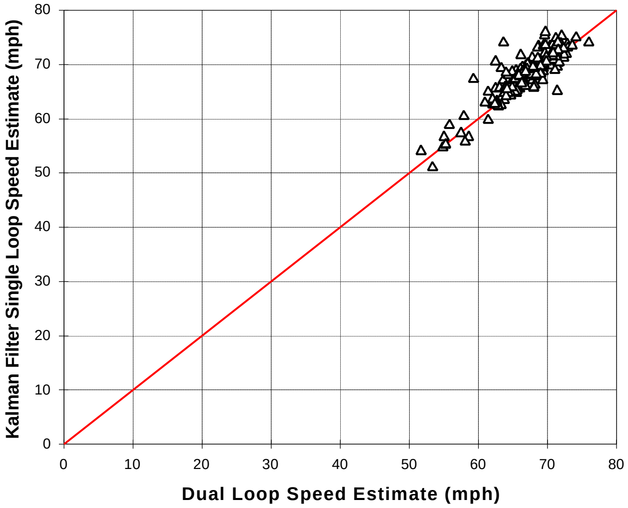


Figure 3-62. Speed Estimate Comparison (Kalman Filter Versus Dual Loop Speed Counts).

Figure 3-63 illustrates the speed error distribution (relative to dual loop detector measurements) for the G-factor and Kalman filter techniques. As was concluded earlier, the G-factor technique tended to under-estimate the speeds by 12 mph on average. The Kalman filter technique, on the other hand, tended to over-estimate the traffic speed (2 mph on average). The over-estimation of speeds using the Kalman filter technique was less evident in Figure 3-62.

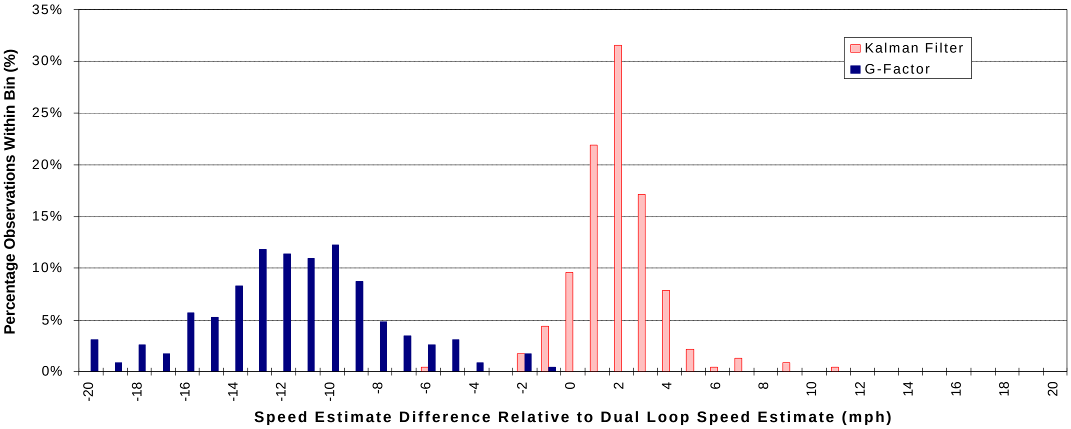


Figure 3-63. Speed Error Distribution Relative to Dual Loop Speed Estimate.

Figure 3-64 illustrates how accurate the Kalman filter technique estimated the vehicle length. Clearly, there was no systematic error in the vehicle length estimation because the observations appear to be symmetrically scattered around the line of perfect correlation. However, there does appear to be a larger error in estimating the vehicle length versus the vehicle speed as demonstrated by the larger amount of scatter about the line of perfect correlation (comparing Figure 3-64 to Figure 3-62). Figure 3-64 demonstrates that the average vehicle length ranged from 18 feet to 36 feet with an average vehicle length of 26 feet. Because the G-factor speed estimates were computed using a calibrated vehicle length of 21 feet the speeds were under estimated relative to the dual loop detector speed measurements.

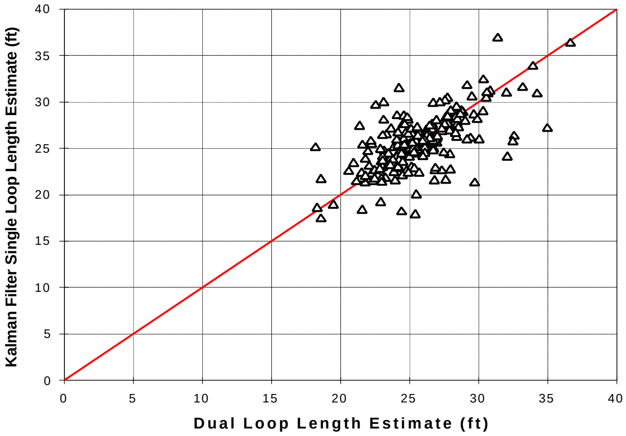


Figure 3-64. Vehicle Length Estimate Comparison (Kalman Filter Versus Dual Loop Speed Counts).

For completeness, Figure 3-65 and Figure 3-66 illustrate how the flow and occupancy measurements from a single loop (one loop from the two loops that comprise the dual loop detector) compare to the flow and occupancy measurements averaged across both loop detectors. Clearly, both figures demonstrate some random error (scatter around the line of perfect correlation), however, there does not appear to be any systematic error (non-symmetric around the line of perfect correlation).

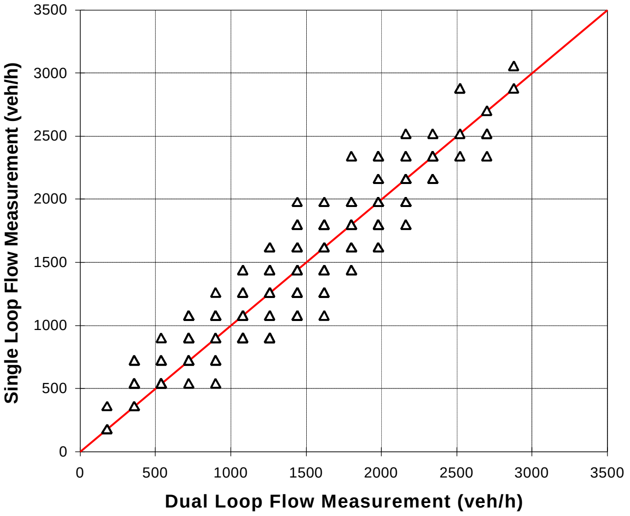


Figure 3-65. Flow Estimate Comparison (Kalman Filter Versus Dual Loop Speed Counts).

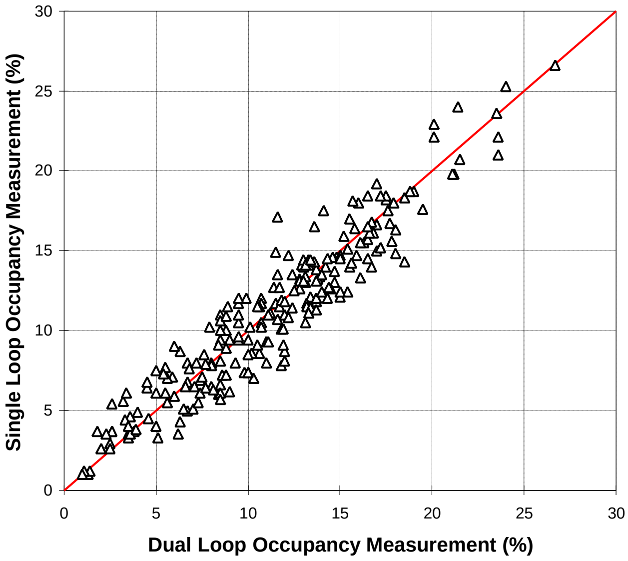


Figure 3-66. Occupancy Estimate Comparison (Kalman Filter Versus Dual Loop Speed Counts).

The next step in the analysis was to compare the speed measurements that were obtained from the radar gun to the dual loop speed measurements, the G-factor single loop speed estimates and the Kalman filter speed estimates. Figure 3-67 illustrates the temporal variation in the dual loop detector speed measurements, the single loop detector speed estimates (G-factor and Kalman filter) for the median lane, and the radar gun measurements for the shoulder and median lane. Figure 3-67 illustrates lower radar gun speed measurements on the shoulder lane compared to the median lane. This finding is consistent with what has been found in other studies (Carter *et al.*, 1995). Consequently, only median lane radar gun measurements were utilized for comparison purposes in order to be consistent with the loop detector measurements and estimates. The radar gun being a Doppler radar device measures the speed vector component along the radar path. So if for example the reading were taken at an angle of 30 degrees, the speed would be under-estimated by 1/cos30. Consequently, it appears that the radar gun measurements were made at an angle to the traffic and thus the lower measurements.

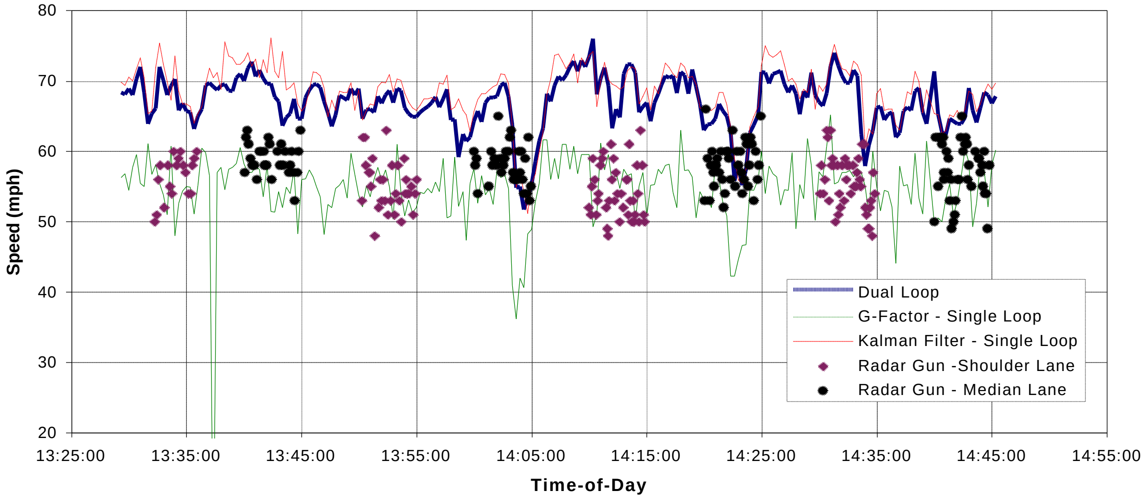


Figure 3-67. Variation in Speed Estimates Over Analysis Period.

Figure 3-68, Figure 3-69, Figure 3-70, and Figure 3-71 illustrate the temporal variation in speed estimates along the median lane for each of the time periods during which radar gun measurements were available. The radar gun mean and standard deviation estimates for each 20-second time interval were computed by including radar measurements within the 20-second interval. An average standard deviation for each of the four analysis periods was then computed and used to estimate the 95 percent confidence limits assuming a normal distribution. It must be acknowledged at this point, that because it was not possible to measure the speed of all vehicles in the lane (using the radar gun), these statistics only represent sample means and standard deviations. Clearly, a sample size equal to the entire population would give more confidence, however, because this was not possible the sample mean and confidence limits were utilized instead. Furthermore, it must be noted that the radar gun mean speeds were time-mean-speeds as opposed to space-mean-speeds. As described earlier time-mean-speeds are 1 to 5 percent higher than space-mean-speeds.

Figure 3-68 clearly indicates that the radar gun measurements were more similar to the G-factor speed estimates. Again, this is attributed to the fact that was at an angle to the traffic when the radar gun measurements were made.

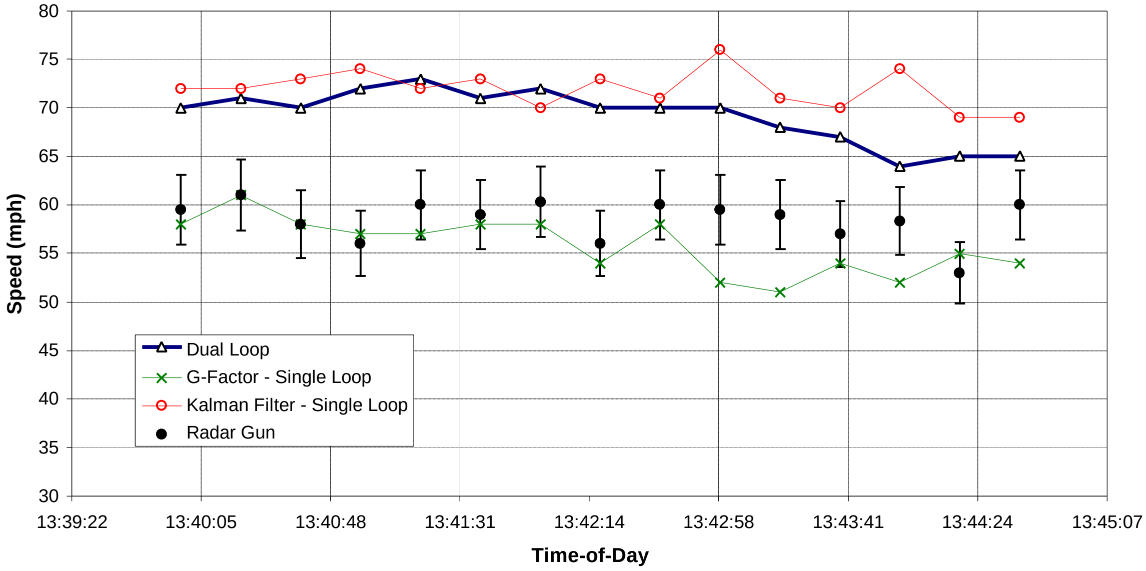


Figure 3-68. Variation in Speed Estimates Over Portion 1 of Analysis Period.

Figure 3-69 again demonstrates a good fit between the radar gun and G-factor speed estimates for speeds in the 55 to 60 mph range. However, at lower speeds the radar gun speed measurements were found to be more similar to the dual loop detector measurements and Kalman filter speed estimates. The same conclusions were found for the other two time periods, as illustrated in Figure 3-70 and Figure 3-71.

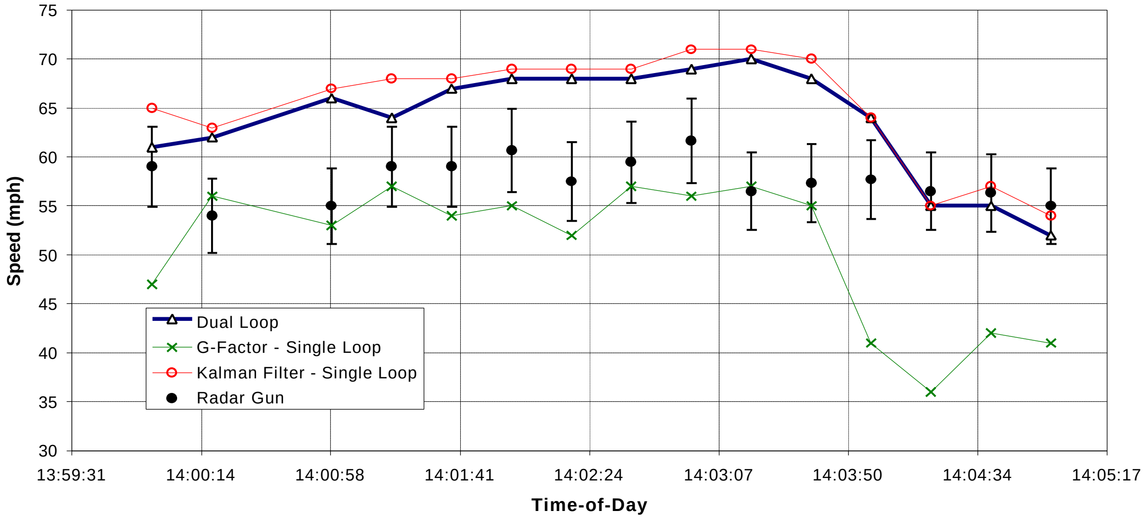


Figure 3-69. Variation in Speed Estimates Over Portion 2 of Analysis Period.

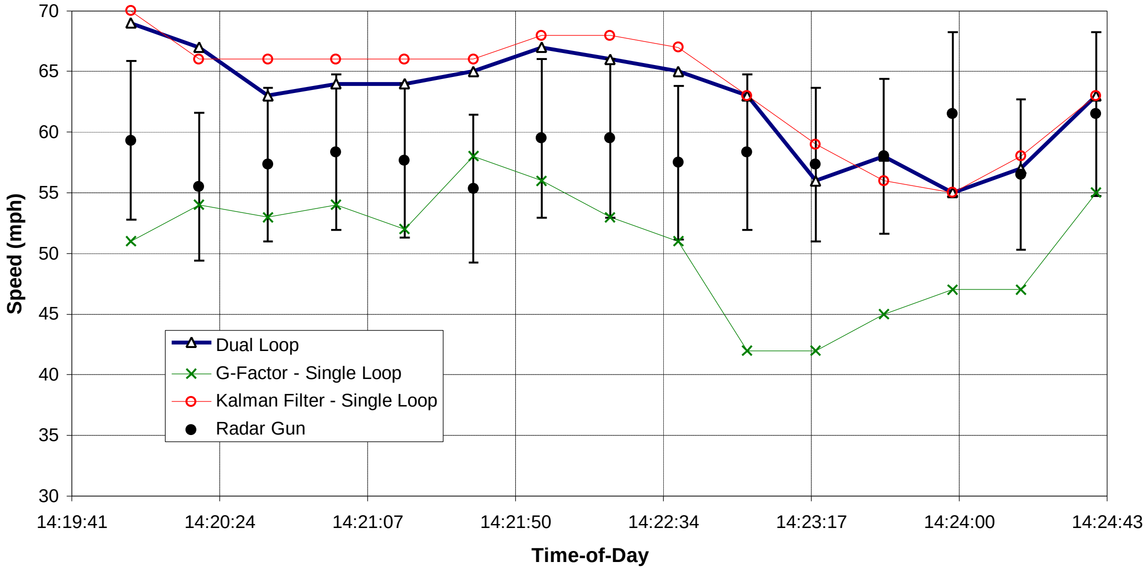


Figure 3-70. Variation in Speed Estimates Over Portion 3 of Analysis Period.

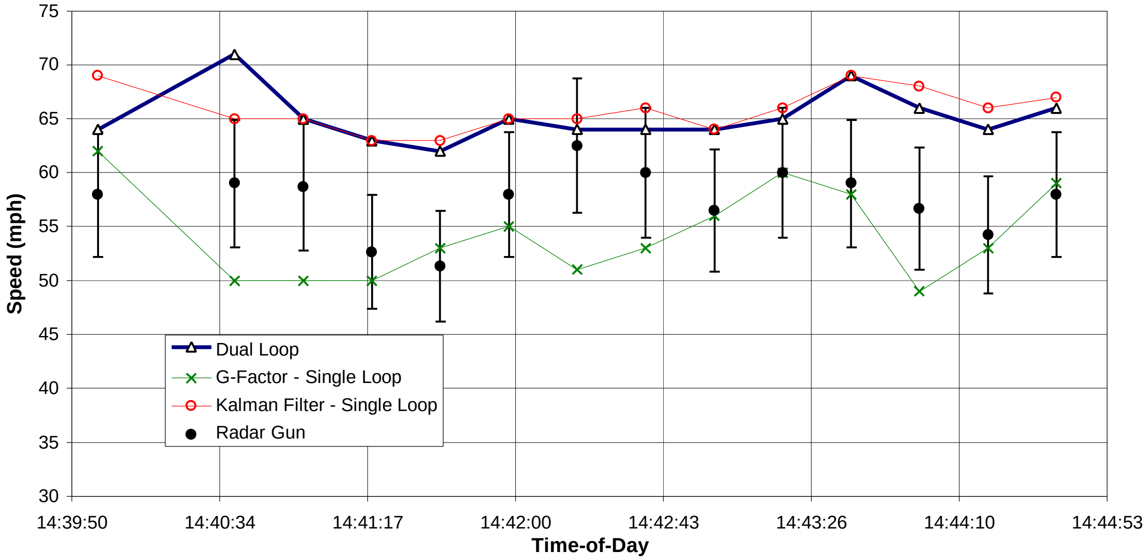


Figure 3-71. Variation in Speed Estimates Over Portion 4 of Analysis Period.

Figure 3-72 and Figure 3-73 clearly demonstrate that the “G” factor that was used in the G-factor technique was not calibrated adequately and thus resulted in a systematic error in the speed estimates.

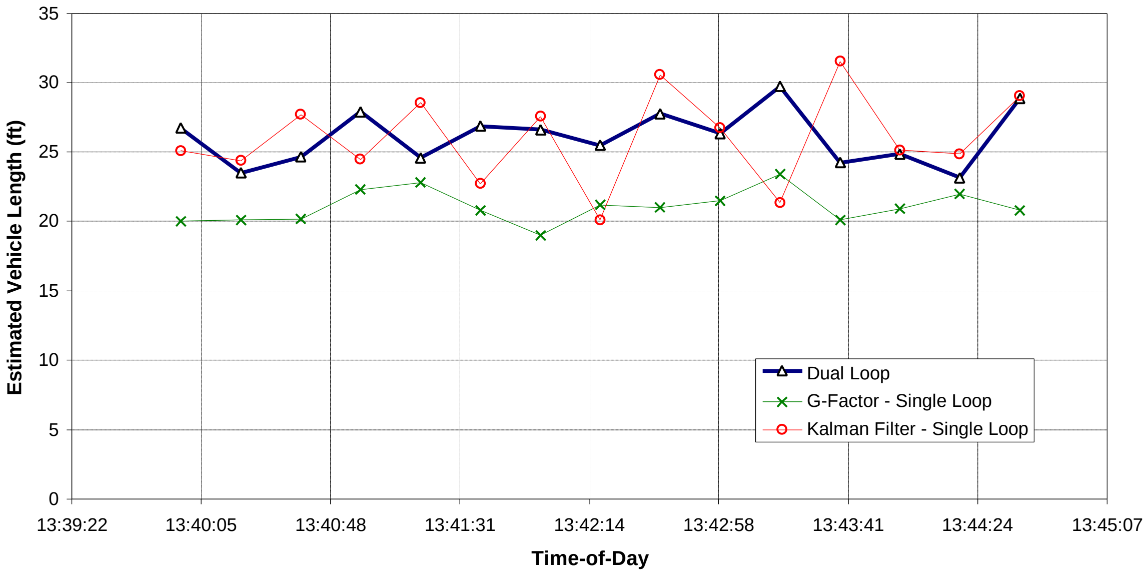


Figure 3-72. Variation in Vehicle Length Estimates Over Portion 1 of Analysis Period.

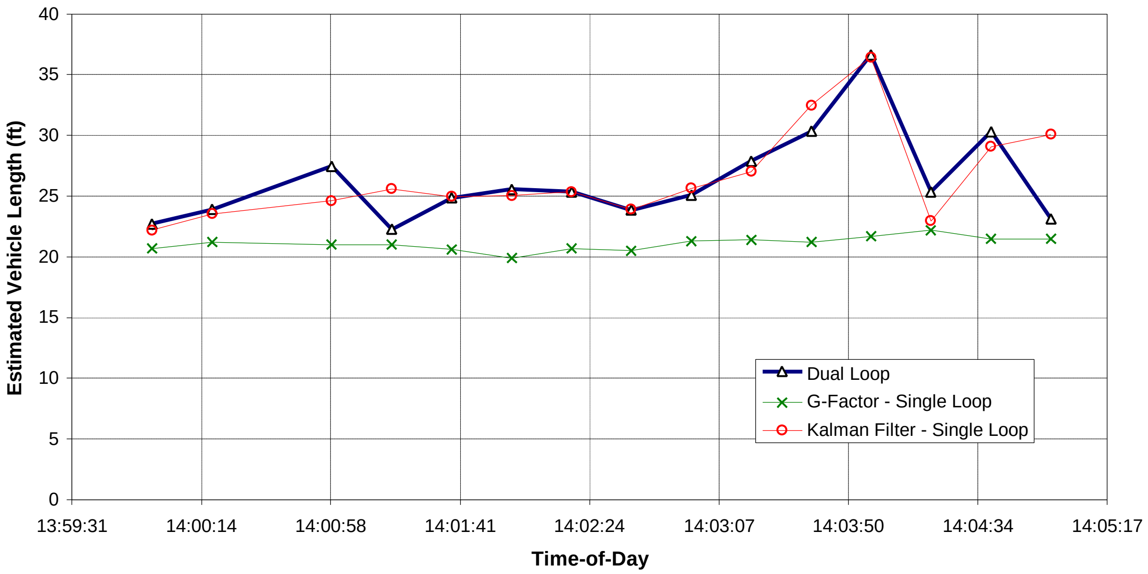


Figure 3-73. Variation in Vehicle Length Estimates Over Portion 2 of Analysis Period.

Device Usability Field Test

This section describes the results of the device usability field test that was conducted in order to evaluate how easy it was for the test participants to utilize the various SWIFT reception devices. The procedures that were utilized in order to evaluate the usability of the devices was described earlier in the methodology section. Consequently, only the results are reported here.

Table 3-24 demonstrates that the hardest tasks to complete were to delete a message and to enable/disable the beep mode (Tasks D and E). Specifically, only 63 percent of the participants were able to delete a message or disable the beep mode. All tasks required a small number of key strokes ranging from 3 to 5 key strokes, with an average duration ranging from 3.6 seconds to 9.1 seconds. Overall, the participants were able to complete 85 percent of the tasks within 4.2 keystrokes and 6.2 seconds.

Table 3-24. Summary Results for Seiko MessageWatch Usage.

	Task A	Task B	Task C	Task D	Task E	Overall
Percent Task Completed (percent)	100	100	100	63	63	85.0
Mean Number of Key Strokes	3.0	6.1	3.1	5.0	4.2	4.2
COV of Number of Key Strokes	0.00	0.06	0.11	0.00	0.11	0.06
Minimum Number of Key Strokes	3.0	6.0	3.0	5.0	4.0	4.2
Mean Task Duration (seconds)	3.6	9.1	3.9	8.2	7.3	6.2
COV of Task Duration	0.25	0.43	0.27	0.40	0.93	0.5
Minimum Task Duration	2.4	5.8	3.4	6.5	3.8	4.4

In terms of deciphering the traffic messages, the usability test results indicate that the Seiko MessageWatch users were able to decipher, on average, 91 percent of a message, as demonstrated in Table 3-25. The fact that the message was within the user's coverage profile did not have a significant bearing on the participant's ability to decipher the message (95.4 versus 90.5 percent). The non-traffic messages were deciphered consistent with the traffic messages (88.8 versus 91.3 percent). Interestingly, a service that was used was much more likely to be deciphered than a service that was not used (99.2 versus 33.3 percent). Based on these results it appears that the device users were able to understand most of the messages.

Table 3-25. Summary Results of Seiko MessageWatch Message Deciphering.

	Percent Message Deciphered (%)
Traffic Messages	
Total	91.3
Within Coverage Area	95.4
Outside Coverage Area	90.5
Non-Traffic Messages	
Total	88.8
Service Used	98.3
Service Not Used	33.3

For the navigation unit, only 25 percent of the participants were able to change the location and destination radius (Task F), as demonstrated in Table 3-26. Furthermore, those who completed the task required 45 key strokes and 180 seconds as opposed to a minimum of 5 key strokes and

19 seconds. The higher number of key strokes and time required to complete the task demonstrate that even those who completed the task experienced major difficulty in doing so. In addition, Table 3-26 shows that 63 percent were able to find a location (Task B) and retrieve the location's address and phone number (Task E). The remaining tasks (including displaying a traffic message, saving a location, and recalling a saved location) were successfully performed (88 percent of participants completed the task). Overall, on average, the participants were able to complete 71 percent of the tasks. In addition, on average, 15 key strokes and 28 seconds were required to complete a task.

Table 3-26. Summary Results for Navigation Unit Usage.

	Task A	Task B	Task C	Task D	Task E	Task F	Overall
Percent Task Completed (percent)	100	63	88	88	63	25	70.8
Mean Number of Key Strokes	2.8	47.6	8.7	9.3	8.4	45.0	15.2
COV of Number of Key Strokes	0.6	0.4	0.4	0.2	0.4	0.9	0.5
Minimum Number of Key Strokes	2.0	20.0	4.0	5.0	5.0	5.0	6.8
Mean Task Duration (seconds)	6.5	45.7	20.5	10.4	17.2	178.9	27.7
COV of Task Duration	0.7	0.6	0.3	0.3	0.3	1.2	0.6
Minimum Task Duration	2.0	14.6	11.8	8.5	9.1	19.2	10.9

The results of the PC usability test indicate that traffic information-related tasks were completed by 88 percent of the participants or higher, as demonstrated in Table 3-27. However, yellow page information tasks were less successful (38 and 63 percent completed for Tasks E and F, respectively). Overall, on average, the participants were able to complete 77 percent of the tasks. In addition, on average, 16 key strokes and 79 seconds were required to complete a task.

Table 3-27. Summary Results for PC Usage.

	Task A	Task B	Task C	Task D	Task E	Task F	Overall
Percent Task Completed (percent)	100	88	88	88	38	63	77.1
Mean Number of Key Strokes	12.5	25.6	9.9	14.6	8.0	25.6	16.3
COV of Number of Key Strokes	0.60	0.94	0.39	0.65	0.13	0.99	0.62
Minimum Number of Key Strokes	4.0	9.0	4.0	9.0	7.0	12.0	7.5
Mean Task Duration (seconds)	62.9	100.6	44.7	83.9	53.4	117.7	78.9
COV of Task Duration	0.24	0.79	0.44	1.00	0.16	0.65	0.55
Minimum Task Duration	6.0	20.9	11.4	31.5	34.3	21.8	21.0

Because the Seiko MessageWatch only displayed incident information, it was difficult to compare the usability of the Seiko MessageWatchto the other user devices. In comparing the navigation unit to the PC, it appeared that it was harder to complete a task using the navigation unit versus the PC (71 versus 77 percent completion rate, respectively). However, the navigation unit required a smaller number of key strokes (15 versus 16) and less time (28 versus 79 seconds) to complete a task. The low success rate in completing tasks together with the large number of key strokes and time required to complete a task appear to be the major contributing factors to user dissatisfaction with the PC device.

3.3. Objective 3: Assess System Availability and Reliability from User's Perspective

The first two objectives of the *SWIFT Architecture Study* were to evaluate the system when it operated at full functionality. Objective 3 evaluates the system availability and reliability from the system user's perspective, while objective 4 evaluates the system availability and reliability from the system's perspective.

3.3.1. Test Methodology

The user perspective on system performance was evaluated through questionnaires and focus groups that were conducted as part of the *SWIFT Consumer Acceptance Study*. An overview of the test methodology is provided in this section.

User Questionnaires and Focus Groups

The questionnaire portion of the *SWIFT Architecture Study* focused primarily on capturing the experiences and perceptions of system users during the course of their use of a particular SWIFT device. Some of the questions within the questionnaires were tailored towards a specific SWIFT devices and user types (e.g. automobile, ride share, or transit), while most others were common across devices and user types. These questionnaires were administered to SWIFT users on four occasions:

- Before beginning SWIFT use (user profile questionnaire)
- At the end of one month of use
- At the end of six months of use
- At the end of twelve months of use

The *SWIFT Architecture Study* provided the *SWIFT Consumer Acceptance Study* with questions to be included in the evaluation questionnaires. The *SWIFT Consumer Acceptance Study* then compiled the questions, coordinated, administered and conducted the questionnaires. The questionnaire results were provided to the *SWIFT Architecture Study* in order to conduct its analysis.

The next method to be utilized in evaluating the SWIFT architecture was through the organization of focus groups. While the conduct of these focus groups was mainly targeted towards the needs of the *SWIFT Consumer Acceptance Study*, some of the discussions were directed to also serve the needs of the *SWIFT Architecture Study*. Each focus group included approximately eight users. Separate focus groups were conducted for each SWIFT device. Focus group activities were conducted at various times during the operational phase of the test, with the first activity beginning during the second month of the field operational test.

3.3.2. Results

This section summarizes the findings of the questionnaires and focus groups that relate to the user's perception of the system reliability and availability.

User Questionnaires and Focus Groups

System Availability. In the second SWIFT user survey, device users were asked to indicate their level of agreement with the statement that such factors as terrain, weather, time-of-day, and location impacted the receipt of messages on their SWIFT device. Figure 3-74 presents a summary of the results. In general, users of the SWIFT PC devices perceived a greater level of problems associated with system availability than did other device users. PC device users appeared to perceive the highest level of impact while inside buildings or while in and around high rise buildings and as a result of terrain patterns. Users of the Delco devices perceived the highest level of problems in receiving messages while in parking garages.

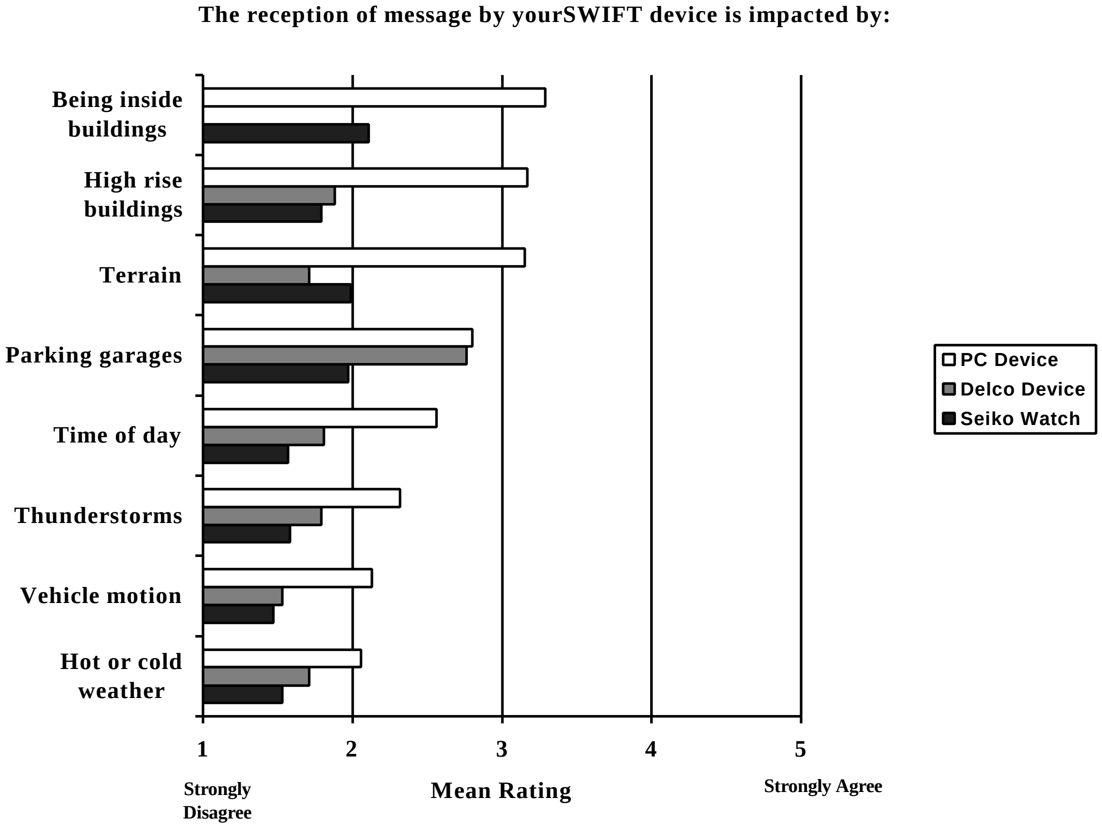


Figure 3-74. System Availability.

Seiko MessageWatch users reported the following as weak signal areas: Black Diamond, Everett, Tenino, and Bellingham. However, Tenino and Bellingam were both out of the SWIFT coverage area. Several participants reported encountering paging problems from within their work facility.

Participants in the first focus group meetings for Delco device users reported receiving very few messages. This was consistent with the early problems encountered with the system. These system problems were fixed with an upgrade that was issued by Delco in October 1996. PC device users identified the following weak signal areas: Bainbridge Island, West Seattle, High Point, White Center, Capitol Hill, Enumclaw, Boeing Field, Boeing Access Route near Alboro and the Swift Alboro Exit on I-5. Several participants reported that they were unable to receive a signal from within their work facility. The transit users reported that while riding on the bus, the signal intermittently went on- and off-line, and the bus icons would disappear from the screen. Users also reported loss of signal when traveling through the bus tunnel.

Device Problems. The most frequently encountered problem for Seiko MessageWatch users was that messages were cryptic or hard to read, as illustrated in Figure 3-75. However, the frequency of this problem was relatively low. Among the most important improvements the users requested was to include the creation of an alphanumeric display capability, provide a different band type and provide more message storage capability.

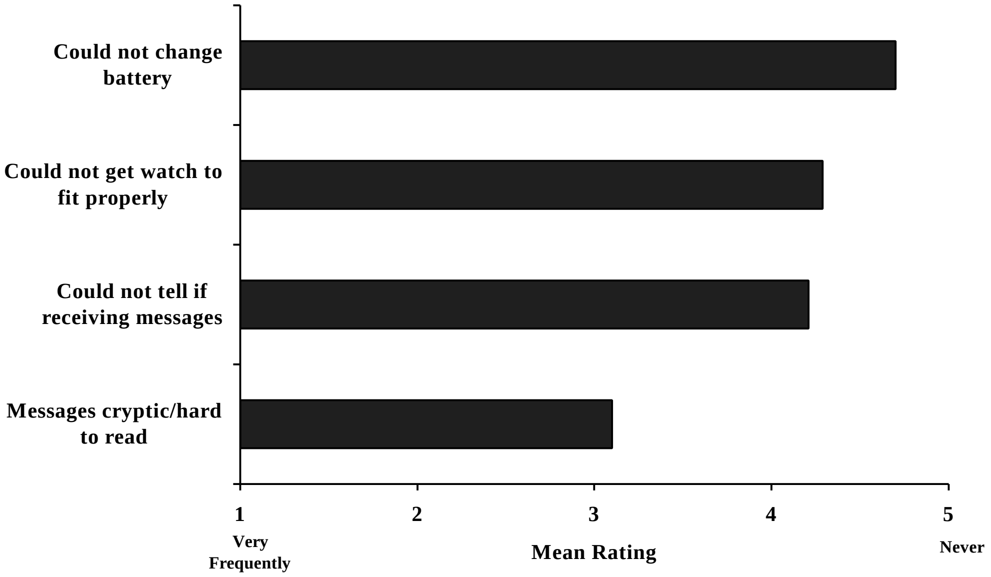


Figure 3-75. Frequency of Problems Encountered with Seiko MessageWatch Device.

Figure 3-76 summarizes the frequency of problems encountered by Delco Device users. Users were asked to indicate the frequency of times they encountered problems on a five point scale with a value of one (1) indicating “very frequently” and five (5) indicating “never”. The results indicate that the frequency of problems encountered was very low. Users reported that the most frequently encountered problems were associated with the message filtering feature and reading the display in direct sunlight.

In terms of improving the Delco devices, the results indicate that users placed a high degree of importance on receiving congestion related information, alternative route information, route specific information, and a graphic map display. Lesser importance was placed on providing only a single "traffic" message when the car is started and providing travel time under perfect conditions.

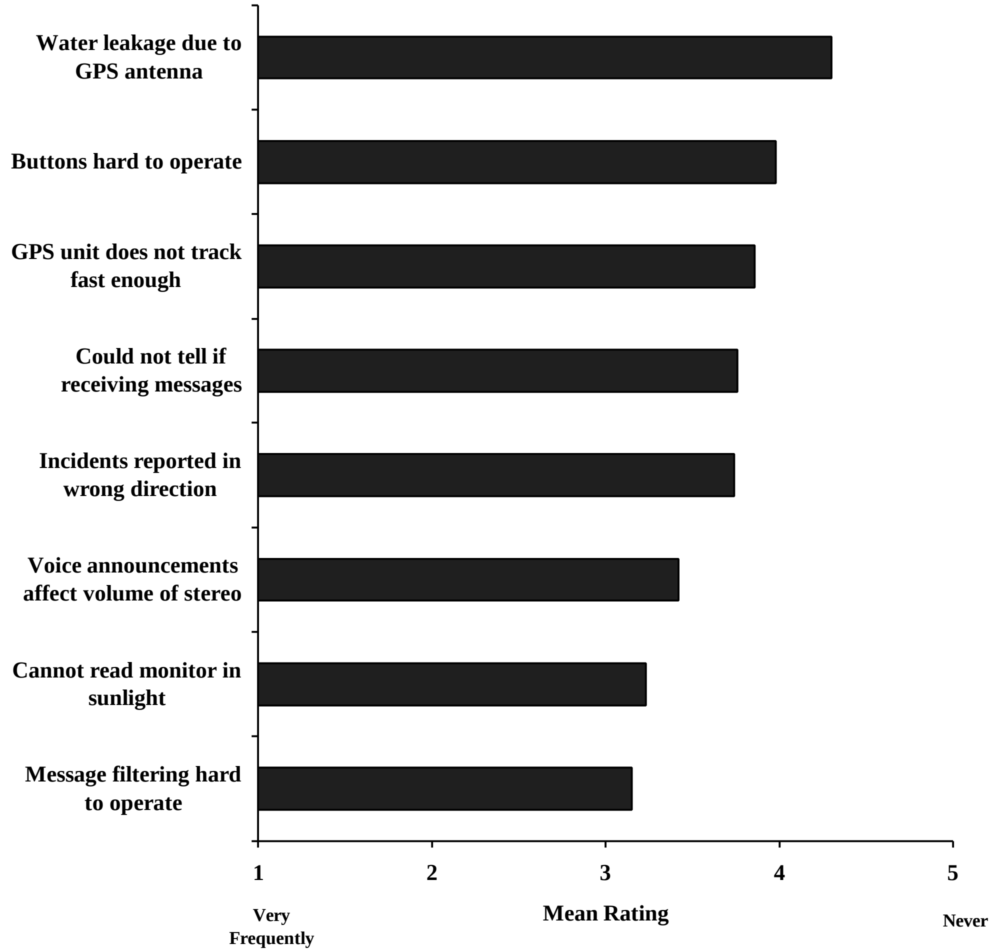


Figure 3-76. Frequency of Problems Encountered with Delco In-vehicle Device.

SWIFT PC users generally reported infrequent encounters with "General Protection Default" errors. Among Dauphin users, the most frequently encountered problems included environment/news feature not working, slow speed operation, loss of signal or weak signal. Among IBM Thinkpad users the most frequently encountered problems included loss of signal, difficulty connecting with the remote Radio Receiving Module (RRM) and bus information off-line. Toshiba users reported the most frequent problems with environment/news feature not working, loss of signal, and difficulty connecting with the RRM.

Figure 3-77 summarizes the frequency of problems encountered by PC device users with the RRM. Device users reported that the RRM was cumbersome to carry. In addition, users of the Toshiba device reported that the RRM failed to connect with the computer more frequently than the users of other devices. It must be noted at this point that the RRM that was utilized in the FOT was envisioned as a beta version of a final product.

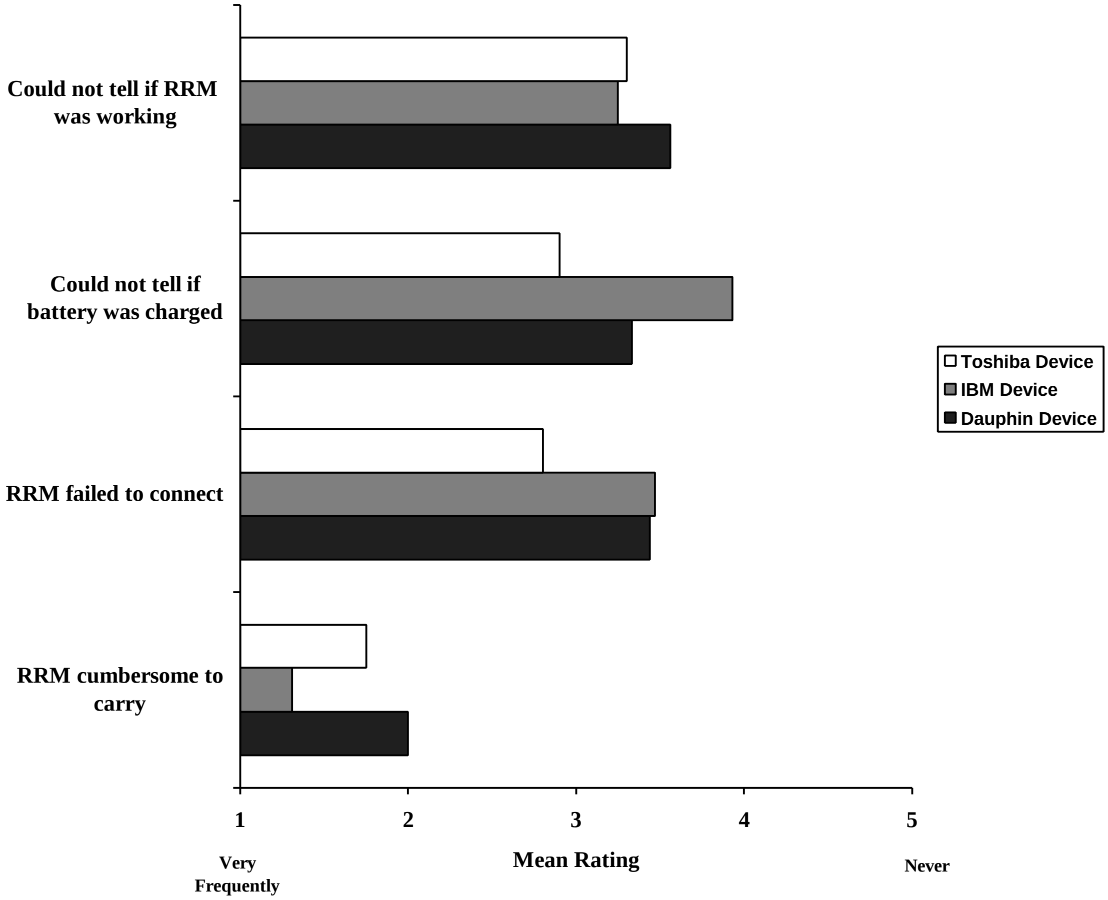


Figure 3-77. Frequency of Problems Encountered with Radio Receiving Module (RRM).

3.4. Objective 4: Assess System Availability and Reliability from System's Perspective

Objective 4 attempts to evaluate how the user's perceptions of the system availability and reliability compare to how the system actually operated during the field operational test.

Furthermore, an attempt is made to identify locations and sources of failures within the system. An explicit attempt is made to distinguish observed failures to the design, implementation, and/or operation phase. In doing so, two field tests were conducted. The first field test quantified the number of failures and location of failures along the system architecture over a typical two-week analysis period. In addition, a listing of the major failures that occurred during the one-year field operational test is provided and the sources of these failures are described. The second field test was the FM sub-carrier coverage field test that was conducted as part of the *SWIFT Communications Study*.

3.4.1. Methodology

System Availability and Reliability Field Test

As described earlier, the SWIFT system was decomposed into nodes and links in order to isolate problem areas within the SWIFT architecture. The three data streams that propagated the SWIFT system included two continuous data streams, namely: the transit data stream and the traffic speed data stream. The third data stream (traffic incident information) was an intermittent data stream. These data streams followed different paths within the system architecture, as illustrated in Figure 3-78 and described in Table 3-28. Specifically, the loop detector speed data originated at the WSDOT node (upstream of link C) and propagated to the UW, the Metro Traffic, the Seiko Server nodes before being transmitted via the FM sub-carrier (C-D-E path). The traffic incident data originated at the Metro Traffic node traversing the Seiko node before being broadcast (E and F paths). Finally, the transit data stream originated at the Metro Transit node, traversing the UW node and the Seiko server before finally ending up at the PC reception device (A-B path).

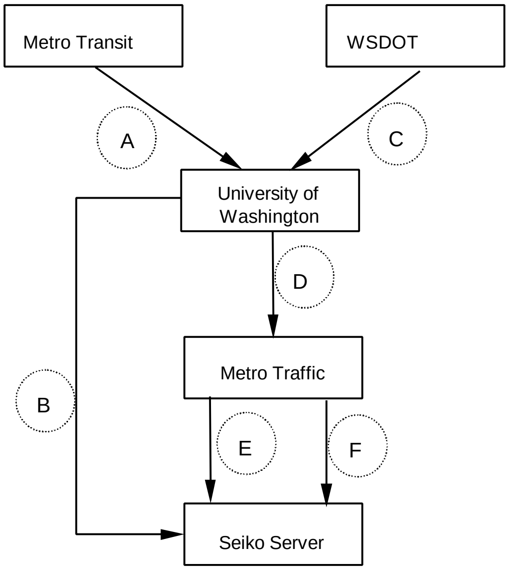


Figure 3-78. Architectural Link Notation for System Reliability Analysis.

Table 3-28. Architectural Link Description.

Link	Upstream Node	Downstream Node	Data Stream
A	Metro Transit	UW	Transit Data
B	UW	Seiko Communications	Transit Data
C	WSDOT	UW	Traffic Speed Data
D	UW	Metro Traffic Control	Traffic Speed and Incident Data
E	Metro Traffic Control	Seiko Communications	Traffic Speed and Incident Data Stream to PC
F	Metro Traffic Control	Seiko Communications	Traffic Incident Data Stream to Watches

In order to identify failures along the SWIFT system, the University of Washington developed a tool that checked the status of the architectural links every 15 seconds. Specifically, the tool checked, if any data packets were observed during the last 15-second interval. Because link F (traffic incident data stream) was traversed by an intermittent data stream, as opposed to a continuous data stream, not observing data packets within the a 15-second interval would not necessarily be an indication of some failure along the link. Consequently, because the status of link F could not be ascertained conclusively, it was not included in the reliability analysis that is described in this section.

Status data were collected for a two-week period from May 5 through May 18. A sample of the status data records that were collected is demonstrated in Table 3-29. These records, that were collected every 15 minutes, included the date, the time at which the record was collected and the status of each of the links over the 15-second interval. A status of 1 meant that data traversed the link in the last 15-second interval, while a status of 0 meant that no data traversed the link in the last 15-second interval.

In addition the time at which the data packets and the contents of the data packets that passed a number of measurement points along the SWIFT architecture were collected for a week (May 12 through May 18). From these data the delay along the system was computed as described in the evaluation of objective 2. These delay estimates allowed for the comparison of system propagation delays while the system was not operating at full functionality versus operating at full functionality.

It must be noted at this point, that the data collection exercise was deliberately conducted during the latter quarter of the FOT in order to ensure that the system had fully overcome any problems associated with the initial setup and development phase.

FM Sub-Carrier Coverage Field Test

The user questionnaires and focus group reports suggested that there were several areas around and within Seattle where SWIFT message reception problems existed. The objectives of the coverage field test were to determine if the user-reported problem areas were valid and to determine the cause of any problems. More information on this field test can be found in the *SWIFT Communications Study*.

The coverage field test was conducted during the week of July 29, 1997 at nine problematic sites within the Seattle area. A number of tools were utilized to measure the coverage/performance of the SWIFT system at the test sites. These tools included:

- Six Seiko MessageWatches
- Two remote Radio Receiver Modules (RRM)

Table 3-29. Sample Status Data.

		Link Status					
Date	**Time**	**A**	**B**	**C**	**D**	**E**	**F**
05/15/97	0:00:05	1	1	1	1	1	0
05/15/97	0:00:20	1	1	1	1	1	0
05/15/97	0:00:35	1	1	1	1	1	0
05/15/97	0:00:50	1	1	1	1	1	0
05/15/97	0:01:05	1	1	1	1	1	0
05/15/97	0:01:20	1	1	1	1	1	0
05/15/97	0:01:35	1	1	1	1	1	0
05/15/97	0:01:50	1	1	1	1	1	0
05/15/97	0:02:05	1	1	1	1	1	0
05/15/97	0:02:20	1	1	1	1	1	0
05/15/97	0:02:35	1	1	1	1	1	0
05/15/97	0:02:50	1	1	1	1	1	0
05/15/97	0:03:05	1	1	1	1	1	0
05/15/97	0:03:20	1	1	1	1	1	0
05/15/97	0:03:35	1	1	1	1	1	0
05/15/97	0:03:50	1	1	1	1	1	0
05/15/97	0:04:05	1	1	1	1	1	0
05/15/97	0:04:20	1	1	1	1	1	0
05/15/97	0:04:35	1	1	1	1	1	0
05/15/97	0:04:50	1	1	1	1	1	0
05/15/97	0:05:05	1	1	1	1	1	0
05/15/97	0:05:20	1	1	1	1	1	0
05/15/97	0:05:35	1	1	1	1	1	0
05/15/97	0:05:50	1	1	1	1	1	0
05/15/97	0:06:05	1	1	1	1	1	0
05/15/97	0:06:20	1	1	1	1	1	0
05/15/97	0:06:35	1	1	1	1	1	0
05/15/97	0:06:50	1	1	1	1	1	0

- A Seiko TREQ Monitor to measure the reception characteristics at a site. These characteristics included the Radio Signal Level (RSL), the Bit-Error-Rates (BER), and the Packet Completion Rate (PCR)
- A spectrum analyzer in order to measure the Radio Signal Level (RSL) and the “noise-floor” at the transmitters channel. The “noise-floor” was utilized to compute the Signal Noise Ratio (SNR) for each of the transmitters.

3.4.2. Results

System Availability and Reliability Field Test

This section evaluates the reliability of the SWIFT system components by computing failure rates for the various architectural links. In addition, this section evaluates the impact of system failures on data packet propagation delays. Finally, the major causes of system component failures over the entire FOT are discussed together with a description of the major malfunctions that occurred during the FOT.

Link Reliability Results. Figure 3-79 illustrates the status of links A through E from 12:00 AM to 12:00 PM on May 14. The status flag for each of the links was offset in order to facilitate the presentation of the results. Specifically, the status for link A ranged from 8 to 9 (8 being down and 9 being up), for link B ranged from 6 to 7 (6 being down and 7 being up), for link C from 4 to 5 (4 being down and 5 being up), for link D from 2 to 3 (2 being down and 3 being up) and for link E from 0 to 1 (0 being down and 1 being up). As mentioned in the previous section, the transit data followed the path A-B, while the traffic speed data followed the path C-D-E, and the traffic incident data stream traversed link E.

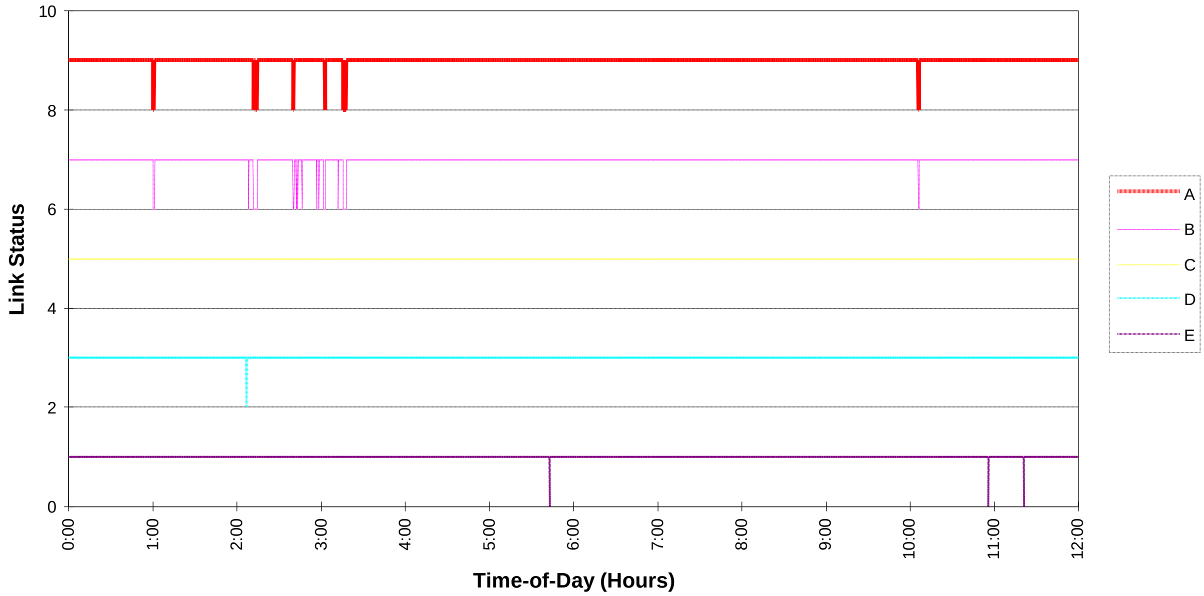


Figure 3-79. SWIFT Architectural Link Status for May 14 (12:00 AM to 12:00 PM).

Figure 3-79 illustrates some failures that occurred along link A which resulted in no data being observed at the downstream link (link B) for the same time intervals. A failure in a link can be caused because of a problem with the upstream node, the downstream node or the link itself. The flow along links C, D and E experienced minor failures, as illustrated in Figure 3-79. Noteworthy, is the fact that the failure on link D between 2:00 and 3:00 AM did not result in an absence of data along link E because the data stream along link E also includes the traffic incident data stream that was injected into the system at the Metro Traffic node.

Figure 3-80 illustrates the status of the SWIFT architectural links for the latter half of May 14 (12:00 PM to midnight). As was the case in Figure 3-79, a failure in upstream links results in no data being observed at downstream links. The same trend is observed on May 15, as illustrated in Figure 3-81 and Figure 3-82. Figure 3-44, illustrates some intermittent operation along link C between 7:30 and 8:30 PM. This problem results in no data being observed at the two downstream links (links D and E) during the same interval.

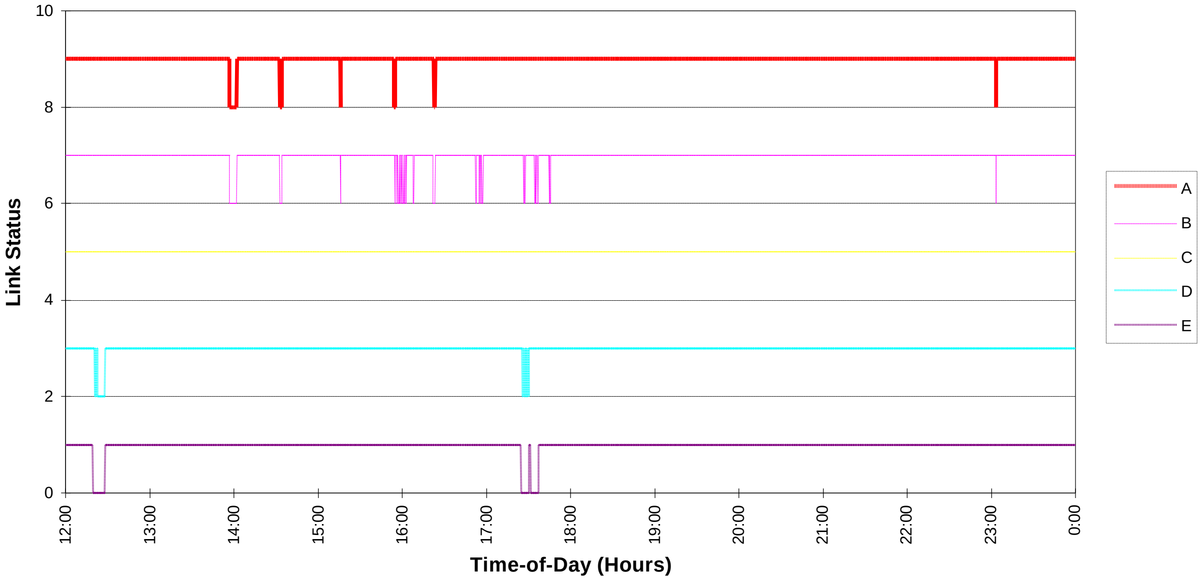


Figure 3-80. SWIFT Architectural Link Status for May 14 (12:00 PM to 12:00 AM).

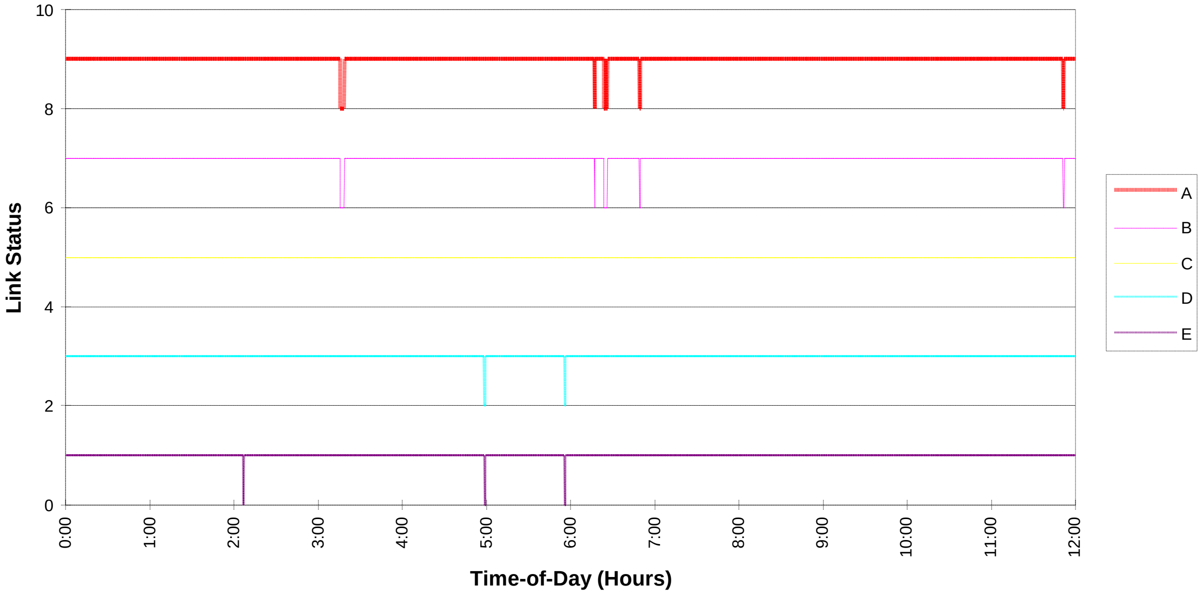


Figure 3-81. SWIFT Architectural Link Status for May 15 (12:00 AM to 12:00 PM).

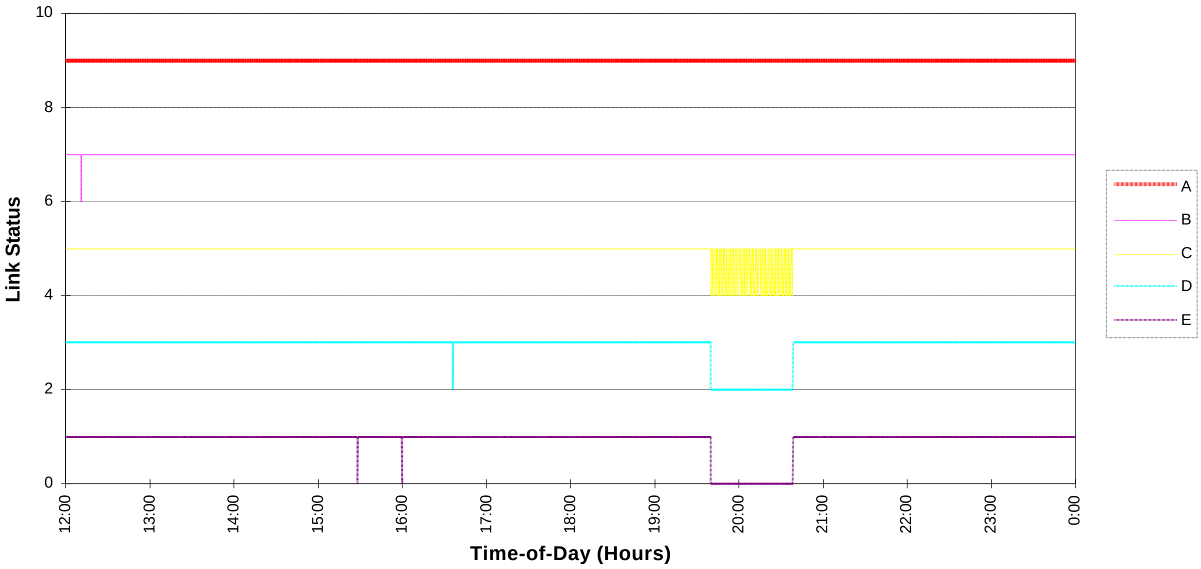


Figure 3-82. SWIFT Architectural Link Status for May 15 (12:00 PM to 12:00 AM).

In terms of overall results during the two-week analysis period the SWIFT system was operating at full functionality for over 90 percent of the time, as demonstrated in Table 3-30. Specifically, the transit data stream only experienced a failure rate of 3.9 percent with the majority of failures occurring along link A. The traffic speed data stream experienced most of its failures along link D (9.6 percent of the time). It is unclear at this point whether the UW or Metro Traffic nodes or both contributed to these failures or that the failures are a result of problems along the link. A review of the failure logs reveals that most failures within the system were a result of some problem at either the upstream or downstream node of the corresponding link. The causes of failures of the different nodes are discussed in more detail later. This field test also demonstrated that dividing an ATIS system into nodes and links facilitates identifying problem areas within the system.

Table 3-30. Reliability of SWIFT Architectural Links and Nodes.

	Link A	Link B	Link C	Link D	Link E
Number of Observations with no Data Flow	2194	3156	146	7925	8576
Percent Time with no Data Flow (percent)	2.7	3.9	0.2	9.8	10.6
Loss of Data on Link (percent)	2.7	1.2	0.2	9.6	0.8

Delays Associated with System Failures. Figure 3-83 and Figure 3-84 illustrate how, for link D, the average propagation delay over a 15-minute interval varied as a function of the time-of-day for a single day during the analysis period. The solid lines in Figure 3-83 and Figure 3-84 correspond to the status of link D (1 being up and 0 being down). The dashed lines in Figure 3-83 and Figure 3-84 correspond to the propagation delay along link D. These figures clearly indicate that the propagation delay did not increase abnormally following a link failure. Analysis of the results for the other links and other days within the study period revealed similar conclusions.

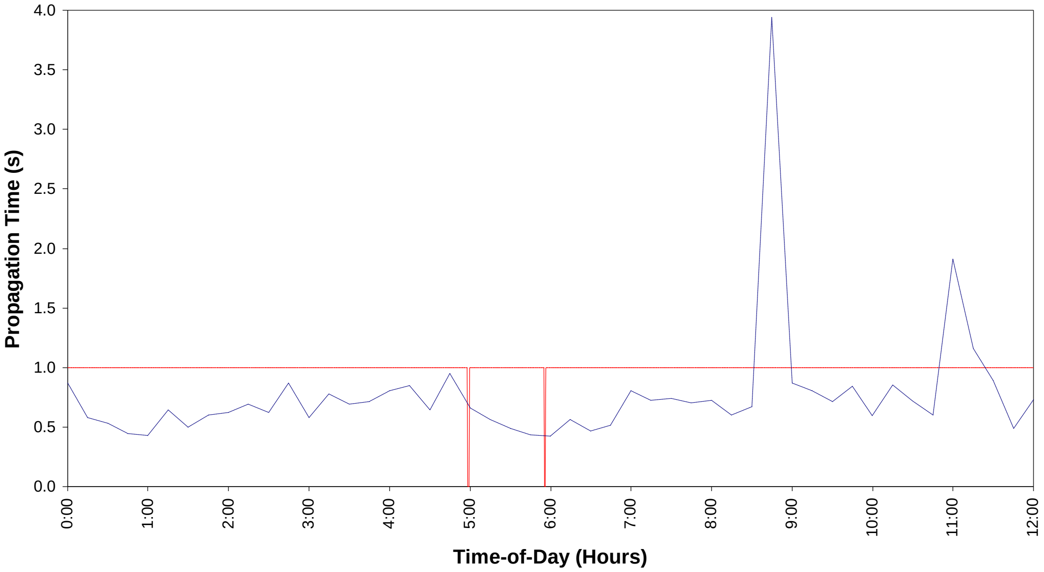


Figure 3-83. Status and Propagation Delay Along Link D for May 15 (12:00 AM to 12:00 PM).

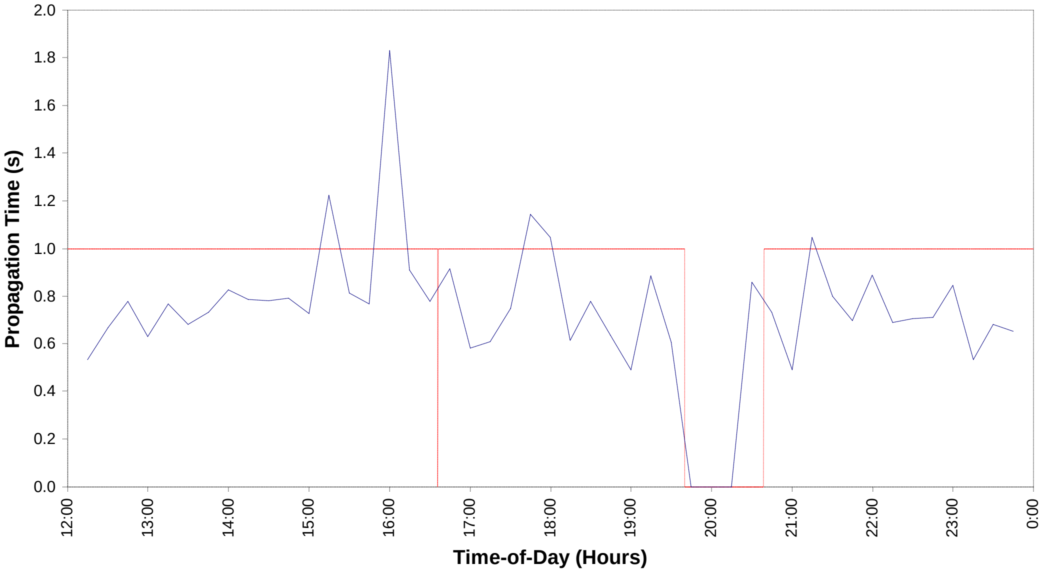


Figure 3-84. Status and Propagation Delay Along Link D for May 15 (12:00 PM to 12:00 AM).

Major Causes of Failure. A record of system failures from December 1996 until September 1997 was maintained. Any failures prior to December 1996 were attributed to the initial setup of the system and thus were not included. A study of the failure logs, which is summarized in Table 3-31, revealed the following:

- The majority of failures in the system were a result of failures within the architectural nodes as opposed to failures in the connecting links.
- Diverse weather conditions caused major problems at the data originating nodes (Metro Transit and WSDOT). For example, the extreme snow storms that occured during the FOT resulted in buses altering their routes which in turn resulted in the failure of the AVL system tracking the buses. In addition, these winter storms resulted in a loss of loop detector data from WSDOT.
- Computer malfunctions was the major contributor to failures within the system.
- The data ports at Seiko Communications caused most failures at the Seiko node. These failures required human intervention (re-setting of ports).
- The remote Radio Receiver Module (RRM) was the major contributor to reception problems for the PC receiver devices.
- The FM sub-carrier signal was weak in concrete structures, tunnels, underground garages and at locations with changes in the topology.

A number of major malfunctions in the system occurred during the SWIFT FOT. These include the following:

- Delco navigational units were receiving messages from Minneapolis/St. Paul.
- Delco navigational units were reversing the direction of incidents (e.g. northbound incidents were displayed as southbound).
- Traffic speed values were inadvertently being altered at the TWS at Metro Traffic Control (January 1997).
- Truncated incident messages were being received by the Seiko MessageWatch devices (January 1997).
- The Differential Global Positioning System (DGPS) signal failed (January 1997).

FM Sub-Carrier Coverage Field Test

The coverage field test demonstrated that the SWIFT devices were unable to receive messages at a number of locations due to significant multi-path interference. This problem manifested itself as a low reception rate and a sensitivity of reception to the antenna orientation for in-building locations even when the signal was strong.

The RSL measurements that were made as part of the coverage test demonstrated that the coverage maps that were produced by Seiko were reliable. However, the field-testing did demonstrate that, because of the significant multi-path signal interference, the coverage maps were not a sufficient indicator of message delivery success.

The overall conclusion was that the HSDS system performed well in most locations, however, its major problem was related to multi-path signal interference given the mountainous terrain in and around Seattle.

Table 3-31. Causes of Failure at SWIFT Architectural Nodes.

Node	Major Causes of Failure
Metro Transit	• Automatic Vehicle Location (AVL) system down • Internet problems • General Maintenance
WSDOT	• Data not sent to WSDOT server because of malfunctions in the loops or severe weather conditions • WSDOT server problems
University of Washington	• Problems with T1 leased line (US West) • UW server malfunction at Metro Transit or WSDOT • UW server failure at the University of Washington • Power outage
Metro Traffic Control	• Loading/updating profile data • Maintenance work on the Traffic Work Station (TWS) • Training of employees
Seiko Communications	• Port malfunctions • Stations off the air • Server problems • Internet problems
PC Reception Device	• Problems with the Radio Reception Module (RRM) • Weak signals in concrete structures, tunnels, underground parking garages, and West Seattle • Problems recharging devices
Delco Navigation Device	• Not receiving traffic, news and pager messages • Wrongly reporting northbound messages as southbound and vice versa • GPS problems (wrongly locating vehicle) • Problems with voice module

4. DISCUSSION

Four objectives were identified for the evaluation of the SWIFT system architecture. These objectives included the following:

- Objective 1: Evaluate the system when operating as intended from the user's perspective.
- Objective 2: Evaluate the system when operating as intended from the system's perspective.
- Objective 3: Evaluate the system when it did not operate as intended from the user's perspective.
- Objective 4: Evaluate the system when it did not operate as intended from the system's perspective.

The previous section described the methodologies that were utilized in order to evaluate these objectives together with the results and findings of these evaluations. This section analyzes the findings of the previous section and discusses how the user perceptions agreed with the actual system performance. In addition, this section attempts to identify the source of any architectural limitations that occurred during the SWIFT FOT. Finally, this section also discusses the issue of expanding the SWIFT system architecture, as it existed in the field operational test, in terms of the number of system users, the coverage area of the system, and the number of reception devices.

4.1. Overview of SWIFT Architecture Study Findings

The purpose of the *SWIFT Architecture Study* is to determine how well the various SWIFT components worked singularly and collectively. The*SWIFT Architecture Study* considers the architecture in terms of how it was designed, how this design was implemented, and how the implemented design operated in the field. This distinction is intended to separate any deficiencies in the original design from problems introduced during the system implementation. Similarly, deficiencies in the way the system was operated are distinguished from those related to design and implementation. The objective of this section is to discuss these issues.

The latter issues are especially critical for the*SWIFT Architecture Study*, as the effort will consider two further architecture deployment stages which relate to the extent to which the SWIFT architecture can be expanded within Seattle with respect to the number of users and the system scope, and the extent to which the system architecture can be implemented elsewhere in North America. The objective of the next section is to discuss the system expandability and transferability issue.

4.1.1. Seiko MessageWatch Device Findings

Because the Seiko MessageWatch, only received traffic incident and rideshare information as part of the SWIFT field operational test, the discussion will be focused on these types of data. As was described in the previous section, the Seiko MessageWatchdevice 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, by the device users, in terms of data timeliness (based on questionnaires). A closer analysis of the system demonstrated that the delay associated with the Seiko MessageWatch device is a result of a problem in the system design. Because the watch was designed to remain in "sleep mode" and only check for messages for 0.13 seconds every 1.87 minutes and because three broadcasts were required, the system could experience excessive delays when messages were closely spaced (the field test demonstrated delays of up to 20 minutes).

In terms of data accuracy, the duration of the 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). Clearly, the procedure that was utilized to forecast the incident duration lacked scientific rigor. Research has been conducted, and continues to be conducted, in the area of Incident Management in order to develop techniques that estimate incident duration's more accurately based on historical incident data. The use of such techniques could potentially improve the accuracy of incident duration estimates. 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.

4.1.2. Delco In-Vehicle Navigation Device Findings

Because the Delco in-vehicle navigation device only received traffic incident information as part of the SWIFT FOT, the discussion will only be focused on this data stream.

The questionnaire results indicated that the Delco 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 questionnaire 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 problem in the system implementation that resulted in the device reversing the direction of incidents (e.g. northbound indicated as southbound).

The questionnaire results indicated that the 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.

4.1.3. PC-Device Findings

Because the PC device received all data streams as part of the SWIFT field operational test, the discussion will deal with all data streams.

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 bear in mind that the PC-device users had different travel characteristics than did the other device users.

The questionnaires and focus groups also 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, and personal paging. 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 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 field data.

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 that 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 technology.

The field tests and questionnaire results indicated problems with the RRM. These problems are attributed to the design of the system. These problems were associated with the RRM not receiving the SWIFT signal. These problems appeared to be caused by the lazy RRM batteries that were not able to maintain an electric charge early in the FOT due to non-use before the start of the FOT.

4.2. System Expandability and Transferability

This section discusses the SWIFT system in terms of its expandability and transferability.

4.2.1. System Expandability

Most of ITS FOTs, such as SWIFT, demonstrate the viability of deploying specific ITS services, and provide some initial indicators as to their likely acceptance by the public. However, these FOT's generally involve only modest deployment levels of the given services. Consequently, some concern often exists as to what extent the deployed technology can be expanded in order to service either a larger geographic area, a larger number of customers, or a different geographic area. These issues will be briefly discussed below.

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 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, as indicated next.

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 the Washington DOT 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 addition of additional and/or faster computers should be able to accommodate these requirements at a moderate cost. The need for increased data communications 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 constraints. 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.

4.2.2. System Transferability

The remaining component that requires evaluation is the opportunities that exist for transferring the SWIFT system to other sites. The issue of the transferability of the SWIFT architecture is discussed in some detail in this section.

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 is evident 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 media does not require any infrastructure installations. All these factors grouped together clearly indicate that the SWIFT architecture is extremely flexible in terms of system transferability.

4.3. Limitations of the Study

The *SWIFT Architecture Study* evaluated how the SWIFT components operated both individually and collectively. In addition, the*SWIFT Architecture Study* evaluated the delay and capacities within the SWIFT system, the accuracy of the data that were broadcast, the usefulness of the SWIFT information, and the impact of SWIFT data on user travel behavior for conditions that were observed in the field operational test. An attempt was made to relate any architectural limitations to either the architectural design, the implementation of the design or the operation of the system.

However, this study fell short of quantifying the impact of an ATIS system similar to SWIFT on the traffic conditions (e.g. congestion, travel time, vehicle fuel consumption, vehicle emissions, and accident risk). Furthermore, the study did not evaluate the SWIFT system for conditions that were not observed in the field operational test (e.g. higher levels of market penetration).

Ultimately, the objective of the SWIFT evaluation should be to study what impact an ATIS system similar to SWIFT has on traffic conditions, because the main reason for applying ATIS systems is to reduce congestion and improve travel conditions. Consequently, it is recommended that a simulation study be conducted using the findings from the SWIFT evaluation in order to answer the following questions:

- What impact does an ATIS system like SWIFT have on a number of Few Good Measures (FGM’s) (i.e. travel time, vehicle fuel consumption, vehicle emissions and accident risk)?
- What is the relationship between the market penetration of an ATIS system like SWIFT and the FGM’s?

5. CONCLUSIONS

This section summarizes the conclusions of the *SWIFT Architecture Study* based on the four objectives that were identified.

5.1. Objective 1: System Operating as Intended from the User's Perspective

This section summarizes the conclusions of the *SWIFT Consumer Acceptance Study* and the device usefulness field test for conditions when the SWIFT system operated at full functionality.

5.1.1. Perceptions of Importance of Traveler Information

Results indicate that users tended to place a high degree of importance on congestion and incident 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, bus location information, and rideshare matching information was rated very low in importance. This is consistent with the auto dependence reported by the group and suggests that information concerning non-auto options would not be used by the auto dependent group. Since users of the PC device were recruited from among transit users, this group generally rated transit information higher than other device user groups, however the importance of this information was not as high as congestion and incident related information.

5.1.2. Perceptions of SWIFT Traveler Information Usefulness

Users tended to view the messages they received from the SWIFT system 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 unit and Personal Computer experienced problems in receiving personal paging messages and these problems were reflected in respondent ratings.

The map based display provided by the Personal Computer resulted in generally higher ratings for that 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. Delco in-vehicle navigation unit respondents reported difficulty in understanding the time when a message applied over other device users.

Generally speaking device users 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. Seiko MessageWatch user respondents expressed a desire for improved timeliness of messages as a top priority. Delco in-vehicle navigation unit respondents endorsed a need to develop route specific messages and Personal Computer respondents expressed a desire to cover more roads as a high priority improvement.

5.1.3. Perceptions of Device Usability

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

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.

Delco in-vehicle navigation unit

Respondents reported a generally high level of satisfaction with the physical characteristics of the devices. 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.

Personal Computer

The IBM and Toshiba personal computers were rated similarly. In general, respondents were dissatisfied with the size and weight of the devices and the design of the communications connection. Respondents rated highly the information display, in particular, the map information provided. Respondents generally endorsed the need for a smaller, lighter, and more portable device with an easier communications connection.

The results indicated that users were extremely dissatisfied with the Dauphin device both in terms of its physical and operational characteristics. The Dauphins were replaced by the laptops during the FOT because of their limited black and white display.

5.1.4. Perceptions of SWIFT Device Usefulness

The device usefulness field test indicated that the Delco in-vehicle navigation device was highly used by the test participants before starting a trip (62 percent selected frequently, 27 percent selected often and 11 percent selected sometimes). However, there appeared to be no obvious trend with regards to referring to the Seiko MessageWatch and PC devices prior to starting a trip. The questionnaires demonstrated that the SWIFT participants were clearly making use of their respective devices for travel planning. The results indicate that most users were consulting their devices to make travel related decisions at least weekly. The results indicate 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 unit found their devices to be convenient, comfortable, safe and easy to use. Respondents from the PC device user group generally rated their devices lower in these areas.

5.1.5. 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. These conclusions were generally consistent with the findings of the device usefulness field test.

5.2. Objective 2: System Operating as Intended from the System’s Perspective

5.2.1. System Delay and Throughput

The field tests demonstrated that decomposing an ATIS into architectural nodes and links facilitates the evaluation of system delay and throughput and allows for the identification of system bottlenecks. However, estimation of the delay associated is not as simple a process as would appear at first glance for the following reasons: (1) data are fused and manipulated as they proceed through the system, and (2) data management becomes critical because of the large amount of data that propagates through the system.

Data stream delays were minor (on average less than 30 seconds) in comparison with the other components of the system (e.g. time required to detect and verify an incident), thus demonstrating the feasibility of the Internet as an ATIS backbone. The field tests did demonstrate that data delays within SWIFT were both data stream specific and device specific. Specifically, the architectural design of the Seiko MessageWatch resulted in queuing of messages at the Seiko MessageWatch when messages were closely spaced (less than 5.5 minutes). This queuing resulted in delays up to 20 minutes with an average delay of 4 minutes.

5.2.2. Data Fidelity

Transit Data Fidelity

The accuracy of the SWIFT transit data was found to be sensitive to the bus stop location. Specifically, the data appeared to be less accurate along high speed roadways (freeway sections). However, accuracy of the SWIFT transit data appeared to be insensitive to the time-of-day.

The major problem with the transit location data was the high percentage of missing data (on average 30 percent of the data were missing), however, the data were accurate to within 500 meters on average. These findings explain why the SWIFT participants rated the bus location information low in terms of its reliability and availability, but did not rate it low in terms of its accuracy.

Traffic Speed Data Fidelity

On average 80 percent of the loop detectors operated at full functionality (20 percent failure rate) during the field tests. Furthermore, on average 75 percent of the valid SWIFT speed estimates were within one category of what was observed in the field. However, the accuracy of the SWIFT speed data appeared to be sensitive to the level of congestion. Specifically, SWIFT over-estimated speed during congested conditions.

It must be noted that the speed data that were broadcast as part of the SWIFT field operational test were based on speed estimates from single loop detectors using a Kalman-filter technique. The Kalman-filter method overcomes the systematic bias that is inherent in the standard G-factor method. Consequently, an evaluation of both techniques was conducted, however, because observations were only available during uncongested conditions, it was not possible to generalize the conclusions for congested conditions.

In general, the Kalman-filter technique demonstrated a small systematic error in that it tended to over-estimate speeds slightly (2 mph). However, the G-factor speed estimates were found to be very sensitive to the adequacy of the vehicle length calibration. Incorrect calibration resulted in large systematic speed estimate errors (up to 12 mph).

5.2.3. Device Usability

Overall the MessageWatch appeared to be usable (85 percent of participants completed the required tasks) and the messages were decipherable (89 percent of non-traffic messages and 91 percent of traffic messages were deciphered). Non-traffic messages were easily decipherable if service was used, otherwise messages were less decipherable (99 percent deciphered for services used and 33 percent for services not used).

PC and Delco in-vehicle navigation devices appeared to be equally usable (77 and 71 percent of tasks completed). In addition, the PC and Delco devices required a comparable number of key strokes to complete a task (16 and 15 key strokes). However, the PC required longer time to complete a task when compared to the navigation device (79 seconds versus 28 seconds). The longer time to complete tasks explains why the users rated the PC device low in terms of its usability.

Deleting messages and enabling/disabling the beep mode were the hardest tasks for MessageWatch users (only 63 percent of participants completed the tasks), while changing the location and destination radius was the hardest task for Delco device users (only 25 percent of participants completed the task). Yellow page functions were the hardest tasks for the PC users (38 and 63 percent of participants completed the tasks).

5.3. Objective 3: System not Operating as Intended from the User's Perspective

5.3.1. Perceptions of System Reliability

Users generally found the devices to be reliable. Seiko MessageWatch users perceived the highest reliability rates followed by Delco in-vehicle navigation unit users, and Personal Computer users. In focus group discussions Personal Computer users expressed a concern with the signal connection particularly in the receipt of general information messages.

5.3.2. Perceptions of System Availability

Participants generally perceived that the system was available. Terrain and being inside buildings appeared to have the greatest impact on receipt of messages for Personal Computer users. Users of the Delco in-vehicle navigation unit reported problems in receiving messages while in parking garages. Users of the Seiko MessageWatch reported few problems in the receipt of messages.

5.4. Objective 4: System not Operating as Intended from the System's Perspective

5.4.1. System Reliability and Availability

This study has demonstrated that breaking down an ATIS into architectural nodes and links allows for the isolation of problem areas within the system. Furthermore, this study demonstrates that the Internet is a viable means for communication within an ATIS.

In general the SWIFT system was reliable (10 percent failure rate). Most failures within the SWIFT system occurred between the University of Washington and Metro Traffic Control (9.6 percent of the time). The majority of failures within the system were a result of failures at the architectural nodes as opposed to failures along the connecting links.

The major causes of SWIFT system failure included:

- Diverse weather conditions which caused major problems at the data originating nodes (Metro Transit and WSDOT). This occured when some major snow storms resulted in Metro Transit buses altering their routes and consequently the system was unable to track the buses.
- Computer malfunctions.
- Data port failures at the Seiko node that required human intervention (re-setting of ports).
- Problems with the PC RRM.
- Topography and building influence on the FM sub-carrier signals.

5.4.2. FM Sub-Carrier Coverage

In general the FM sub-carrier reception was good except for a limited number of locations where the SWIFT devices were unable to receive messages due to significant multi-path interference. This problem manifested itself as a low reception rate and a sensitivity of reception to the antenna orientation for in-building locations even when the signal was strong.

The RSL measurements that were made as part of the coverage test demonstrated that the coverage maps that were produced by Seiko were reliable. However, the field-testing did demonstrate that, because of the significant multi-path signal interference, the coverage maps were not a sufficient indicator of message delivery success.

The overall conclusion was that the HSDS system performed well in most locations, however, its major problem was related to multi-path signal interference given the mountainous terrain in and around Seattle.

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APPENDIX A: MESSAGEWATCH USABILITY TEST

SEIKO MESSAGE WATCH USABILITY FIELD TEST
Instructor's Score Sheet

SWIFT USER'S NAME____

Date______________________

6.1. Part 1: Performance Test

a. View the third (3rd) message

b. Save the fifth (5th) message

c. View the time of the second (2nd) message

d. Delete the fourth (4th) message

e. Turn beep mode off and then turn back on

Question	Duration	Number of key strokes	Solved? (yes=1, no=0)	Comments
1.a				
1.b				
1.c				
1.d				
1.e				

Please read out loud the following messages and identify if any of the traffic messages are within your travel profile.

a.

b.

c.

d.

e.

f.

g.

h.

I.

j.

k.


SEIKO
MessageWatch
Su Mo Tu We Th Fr Sa
93- 103
SU 42- 13
TIME
MESSAGE

l.


SEIKO
MessageWatch
Su Mo Tu We Th Fr Sa
SUn Ind
2
TIME
MESSAGE

m.


SEIKO
MessageWatch
Su Mo Tu We Th Fr Sa
42° H46
80P L38
TIME
MESSAGE

n.


SEIKO
MessageWatch
Su Mo Tu We Th Fr Sa
26° 4300
107 [2]
TIME
MESSAGE

o.


SEIKO
MessageWatch
Su Mo Tu We Th Fr Sa
FOr H50
rAIn L37
TIME
MESSAGE

SEIKO MESSAGE WATCH USABILITY FIELD TEST
Instructor's Score Sheet

SWIFT USER'S NAME__________________________________

Date______________

SWIFT Message-Deciphering Answer Sheet

2a. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2b. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2c. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2d. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:
2e. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2f. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2g. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2h. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:
2I. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2j. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2k. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2l. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:
2m. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2n. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:	2o. Correct:______________________ Mistakes:_____________________ Did not Know: _________________ Within Coverage Area:__________ Comments:___________________	

SEIKO MESSAGE WATCH USABILITY FIELD TEST
Instructor's Score Sheet

SWIFT USER'S NAME_______________________________ **Date**_______________

6.2. Part 2: Oral Questions

a. What mode of travel do you most frequently use for work travel?_______
b. Number of alternative routes of travel available on your trip to work______
c. Number of alternative routes of travel available on your trip home_____
d. Do you do any work related travel?_____
e. Before you leave for travel, how often does SWIFT traveler information influence

Do you refer to your device?	The time you leave?	Your route choice?	Your means, or mode, of transportation?
____Frequently	____Frequently	____Frequently	____Frequently
____Often	____Often	____Often	____Often
____Sometimes	____Sometimes	____Sometimes	____Sometimes
____Rarely	____Rarely	____Rarely	____Rarely
____Never	____Never	____Never	____Never

6.3. Part 3: Feature Demonstration

Please demonstrate three (3) positive operational features of your SWIFT device:
Feature #1_______________________________
Feature #2_______________________________
Feature #3_______________________________
Please demonstrate three (3) negative operational features of your SWIFT device:
Negative Feature #1_______________________________
Negative Feature #2_______________________________
Negative Feature #3_______________________________

APPENDIX B: NAVIGATION UNIT USABILITY TEST

NAVIGATION UNIT USABILITY FIELD TEST
Instructor's Score Sheet

SWIFT USER'S NAME____

Date________________________

6.4. Part 1: Performance Test

a. "Read" a traffic message closest to your current location
b. Find the Bellevue Library
c. Save the Bellevue Library as Destination #5
d. Recall the Bellevue Library
e. Retrieve the Bellevue Library's Address, Phone Number, and Estimate Time of Arrival
f. Change the location and destination radius to 50

Question	Duration	Number of key strokes	Solved? (yes=1, no=0)	Comments
1.a				
1.b				
1.c				
1.d				
1.e				
1.f				

NAVIGATION UNIT USABILITY FIELD TEST
Instructor’s Score Sheet

SWIFT USER’S NAME_______________________________ **Date**_______________

6.5. Part 2: Oral Questions

a. What mode of travel do you most frequently use for work travel?_______
b. Number of alternative routes of travel available on your trip to work______
c. Number of alternative routes of travel available on your trip home_____
d. Do you do any work related travel?_____
e. Before you leave for travel, how often does SWIFT traveler information influence

Do you refer to your device?	The time you leave?	Your route choice?	Your means, or mode, of transportation?
____Frequently	____Frequently	____Frequently	____Frequently
____Often	____Often	____Often	____Often
____Sometimes	____Sometimes	____Sometimes	____Sometimes
____Rarely	____Rarely	____Rarely	____Rarely
____Never	____Never	____Never	____Never

6.6. Part 3: Feature Demonstration

Please demonstrate three (3) positive operational features of your SWIFT device:
Feature #1_______________________________
Feature #2_______________________________
Feature #3_______________________________
Please demonstrate three (3) negative operational features of your SWIFT device:
Negative Feature #1_______________________________
Negative Feature #2_______________________________
Negative Feature #3_______________________________

APPENDIX C: PERSONAL COMPUTER USABILITY TEST

PORTABLE COMPUTER USABILITY FIELD TEST
Instructor's Score Sheet

SWIFT USER'S NAME____

Date_____________________

6.7. Part 1: Performance Test

a. Load up the Seattle-area map and enable communications
b. Display speed information for all lanes except HOV along I-5 between I-90 and I-520
c. Display full map area with traffic incident information and show traffic incident details
d. Display bus time points and locations for Route 243 for Saturday, May 17, 1997
e. Find the intersection of NE 12th Street and 106th Avenue NE
f. Locate the nearest Taco Bell to the above address

Question	Duration	Number of key strokes	Solved? (yes=1, no=0)	Comments
1.a				
1.b				
1.c				
1.d				
1.e				
1.f.				

PORTABLE COMPUTER USABILITY FIELD TEST
Instructor's Score Sheet

SWIFT USER'S NAME______________________________ **Date______________**

6.8. Part 2: Oral Questions

a. What mode of travel do you most frequently use for work travel?_______
b. Number of alternative routes of travel available on your trip to work______
c. Number of alternative routes of travel available on your trip home_____
d. Do you do any work related travel?_____
e. Before you leave for travel, how often does SWIFT traveler information influence

Do you refer to your device?	The time you leave?	Your route choice?	Your means, or mode, of transportation?
____Frequently	____Frequently	____Frequently	____Frequently
____Often	____Often	____Often	____Often
____Sometimes	____Sometimes	____Sometimes	____Sometimes
____Rarely	____Rarely	____Rarely	____Rarely
____Never	____Never	____Never	____Never

6.9. Part 3: Feature Demonstration

Please demonstrate three (3) positive operational features of your SWIFT device:
Feature #1______________________________
Feature #2______________________________
Feature #3______________________________
Please demonstrate three (3) negative operational features of your SWIFT device:
Negative Feature #1______________________________
Negative Feature #2______________________________
Negative Feature #3______________________________

APPENDIX D: MESSAGEWATCH SOLUTION TO USABILITY TEST

SEIKO MESSAGE WATCH USABILITY FIELD TEST
OPERATIONAL STEPS

DEVICE USEABILITY

View the Third (3rd) Message (3 total key strokes)

- Press the **MESSAGE** button three times

Save the Fifth (5th)Message (6 total key strokes)

- Press the **MESSAGE** button five times
- Press and hold the **LOCK** button
- When the **KEY** Icon appears, release the **LOCK** button

View the Time that the Second (2nd) Message was Received (3 total key strokes)

- Press the **MESSAGE** button two times
- Press the **TIME** button once

Delete the fourth (4th) Message (5 total key strokes)

- Press the **MESSAGE** button four times
- Press and Hold the **LOCK** button
- Continue Holding while the word **DELETE** is flashing
- When the word **DONE** appears, release the **LOCK** button

Turn Beep Mode Off and then Turn Beep Mode back On (4 total key strokes)

- Press and Hold both the **TIME** and **MESSAGE** buttons
- Press and Hold both the **TIME** and **MESSAGE** buttons again

MESSAGE DECIPHERING ANSWER SHEET

a. I5, Level 2 both directions, Ravenna
b. I90, Closed westbound, East Mercer
c. SR520, Level 1 westbound, Bellevue Way
d. I5, Level 1 southbound, Convention Center
e. I5, Level 1 southbound, Klickitat Dr.
f. Hwy169, Closed both directions, Maplewood Pl.
g. SR520,Level 1 westbound, Montlake Blvd.
h. Hwy99, Level 1 southbound, Marginal Way
i. Hwy99, Level 2 northbound, Military Road
j. SR405, Level1 southbound, NE 8th St.
k. Super Sonics score, 93-103 (Sonics lost), 42 wins, 13 losses
l. Sun Index = 2 (very low ultra-violet rays)
m. Morning weather = 42 degrees, High 46, 80% chance of precept, Low 38
n. Ski Report = Temp. 26 degrees, freezing level 4300 Ft., 107” at base, 2” new snow
o. Evening weather = Forecast for tomorrow, High 50, rain, Low 37

APPENDIX E: NAVIGATION UNIT SOLUTION TO USABILITY TEST

DELCO NAVIGATION USABILITY FIELD TEST
OPERATIONAL STEPS

READ THE MOST CURRENT TRAFFIC MESSAGE (2 key strokes)

- Press the **TRAFFIC** button
- Press the **ENTER** button

FIND THE BELLEVUE LIBRARY (20 key strokes)

- Press the **MENU** button
- Press **ENTER** onto the MEMORY CARD
- Press **ENTER** onto the ETAK GUIDE
- Press the **DOWN ARROW** one (1) time
- Press **ENTER** onto CONVENIENCE
- Press the **DOWN ARROW** nine (9) times
- Press **ENTER** onto LIBRARIES
- Press **DOWN ARROW** four (4) times)
- Press **ENTER** onto LIBRARY

SAVE THE BELLEVUE LIBRARY AS DESTINATION #5 (Note: Each participant was asked to save the destination in a different slot {1-8} result is that the minimum number of key strokes is 4 and the maximum number of key strokes is 11. And the average number of key strokes was 7)

- Press the **SAVE** button
- Press **ENTER** onto BELLEVUE LIBRARY
- Press the **DOWN ARROW** six (6) times
- Press **ENTER** on DESTINATION NUMBER 5

RECALL THE BELLEVUE LIBRARY (Note: Each participant was asked to recall the destination that was saved previously {slots 1-8} result is that the minimum number of key strokes is 5 and the maximum number of key strokes is 9. And the average number of key strokes was 7)

- Press the **MENU** button
- Press the **DOWN ARROW** two (2) times
- Press **ENTER** onto recall destination
- Press the **UP ARROW** four (4) times
- Press **ENTER** onto DESTINATION NUMBER 5: BELLEVUE LIBRARY

RETRIEVE THE BELLEVUE LIBRARY'S ADDRESS, PHONE NUMBER, AND ESTIMATED TIME OF ARRIVAL (5 key strokes)

- Press the **DEST INFO** button two (2) times and address will show on monitor
- Press the **DEST INFO** button once more and the phone number will show on monitor
- Press the **NAV INFO** button two (2) times

CHANGE THE LOCATION AND DESTINATION RADIUS FROM 100 TO 50 OR FROM 50 TO 100 (Minimum key strokes 5 and Maximum key strokes 23)

- Press and hold the TRAFFIC button until the screen changes
- Press the DOWN ARROW ten (10) times or Press and Hold Down Arrow (1 key stroke)
- Press the TRAFFIC button again
- Press the DOWN ARROW ten (10) times or Press and Hold Down Arrow (1 key stroke)
- Press ENTER

APPENDIX F: COMPUTER SOLUTION TO USABILITY TEST

PORTABLE COMPUTER USABILITY FIELD TEST
OPERATIONAL STEPS

LOAD UP SEATTLE MAP AND ENABLE COMMUNICATIONS (4 key strokes)
- Move pointer to MAP and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to NEW and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to COMMUNICATIONS and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to CONNECT and **CLICK TOP** or **LEFT BUTTON**

DISPLAY SPEED INFORMATION FOR ALL LANES EXCEPT HOV (9 key strokes)
- Move pointer to SPEED ICON and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to MAP OPTIONS and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to SPEED Tab and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to Northbound and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to Southbound and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to Eastbound and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to Westbound and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to Reversible and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to OK and **CLICK TOP** or **LEFT BUTTON**

DISPLAY TRAFFIC INCIDENT INFORMATION (4 key strokes)
- Move pointer to the traffic “A” ICON and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to the actual traffic incident ICON on the map and **DOUBLE CLICK TOP** or **LEFT BUTTON**
- Move pointer to the OK and **CLICK TOP** or **LEFT BUTTON**

DISPLAY BUS TIME POINTS/LOCATIONS FOR ROUTE 243 FOR SATURDAY, MAY 17, 1997 (9 key strokes)
- Move pointer to MAP OPTIONS and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to BUS tab and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to the DOWN ARROW (located on the right hand side of the window) and **PRESS AND HOLD TOP** or **LEFT BUTTON** to scroll down the list of bus routes
- **RELEASE TOP** or **LEFT BUTTON** and move pointer to ROUTE 243 and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to SHOW LOCATION and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to SHOW TIME POINTS and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to DAY, then to SATURDAY and then **CLICK TOP** or **LEFT BUTTON**
- Move pointer to OK and **CLICK TOP** or **LEFT BUTTON**

FIND INTERSECTION OF 12th STREET NE AND 106th AVENUE NE (7 key strokes)
- Move pointer to MAP and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to FIND ADDRESS and **CLICK TOP** or **LEFT BUTTON**
- **TAB** to STREET and **TYPE** 106th AVE NE
- **TAB** to CROSS STREET and **TYPE** 12th STREET NE
- Move pointer to SEARCH and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to SEARCH RESULT and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to OK and **CLICK TOP** or **LEFT BUTTON**

FIND THE NEAREST TACO BELL TO THE ABOVE ADDRESS (12 key strokes)
- Move pointer to MAP and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to YELLOW PAGES and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to CATEGORY and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to the DOWN ARROW (located on the right hand side of the window) and **PRESS AND HOLD TOP** or **LEFT BUTTON** to scroll down the list
- **RELEASE TOP** or **LEFT BUTTON** and move pointer to DINING and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to SUBCATEGORY and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to the DOWN ARROW (located on the right hand side of the window) and **PRESS AND HOLD TOP** or **LEFT BUTTON** to scroll down the list

PORTABLE COMPUTER USABILITY FIELD TEST
OPERATIONAL STEPS
(Continued)

- **RELEASE TOP** or **LEFT BUTTON** and move pointer to TACO BELL and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to SEARCH and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to SHOW ALL and **CLICK TOP** or **LEFT BUTTON**
- Move pointer to the Taco Bell closest to 12th Street NE and 106th Avenue NE and **DOUBLE CLICK TOP** or **LEFT BUTTON**