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Phase IIB Operational Test Report of Commercially Available Radio Frequency Identification (RFID) Systems for Baggage Identification, Tracking and Security Applications

Continental Airlines Trial

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16. Abstract

The following is a test report describing the results of the Phase IIB Operational RFID Test conducted with Continental Airlines in San Antonio and Houston, Texas to demonstrate the feasibility of conducting baggage tracking in a complete, real-time end-to-end mode using RFID Technology.

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EXECUTIVE SUMMARY

The increasing importance of commercial airline passenger and baggage security, combined with the need to sort and track ever larger numbers of passenger baggage quickly and accurately, have led to the search for more efficient methods of performing the baggage sortation, tracking and security functions. Any tool used to facilitate these functions must be able to rapidly and reliably process, reconcile and track passenger and baggage information. Without this capability, flight delays and increased operational costs are likely to result. Passenger inconvenience could lead to decreased tolerance of airline security regulations and loss of confidence in the air transport industry.

Phase I Testing

In 1997, the FAA sponsored the initial phase of testing of commercially available RFID systems for the support of passenger/bag matching and baggage sortation functions. The term "commercially available" is used to indicate that no Government funding was provided for the research and development of these systems. The initial phase had two stages. Stage one was Qualification Testing. The RFID systems which passed Qualification Testing subsequently entered Stage Two of Phase I testing, which consisted of Operational Testing in paired domestic/international airports. The objective of this phase of testing was to examine and verify the operational validity and viability of candidate RFID systems for passenger/baggage matching, tracking and sortation application in an actual airport environment.

The test results clearly demonstrated the feasibility of using RF technology to support these bag match and sortation functions. Several systems showed high levels of baggage identification performance, even in suboptimal operational environments. In addition, there were a number of suggested approaches for improving system performance, which were identified during the first phase of testing.

Phase II Testing

The successful initial phase of feasibility testing of the candidate RFID systems led to this current (second) phase of testing – the Integrated System Test. The Operational Test for this second phase will be conducted in four stages at different combinations of airport sites. Each test stage will focus on specific portions of the end-to-end identification, tracking and security functions. The overall objective of this phase of testing is to demonstrate the technical and operational feasibility of conducting baggage tracking in a complete, real-time end-to-end mode, using RFID technology, while adding overall value to baggage operations and baggage management, to include the security function.

This report describes only the results of the second stage of Phase II testing, Phase IIB, which took place jointly at the San Antonio, Texas airport and the Houston, Texas airport in cooperation with Continental Airlines. In this stage, the tests included:

- Passenger baggage check-in (bag tag encoding and printing)

- Reading and data collection of the RFID bag tag data on the delivery belt to the baggage make-up room using a delivery belt reader
- Reading and data collection of the RFID bag tag data in the baggage make-up room (reading the encoded bag tags with a tethered handheld reader)
- Reading of the bag tag data on the loading ramp to the aircraft using a belt loader reader
- Transfer of the baggage to a connecting flight, which includes: reading the encoded bag tags on the ramp as the baggage is unloaded from the arriving flight; and reading them again with a handheld reader on the loading ramp as baggage is loaded onto the departing flight

The following vendors participated in these tests:

Confidence International (Sweden) – System Integrator
Texas Instruments (Texas) – RFID Inlays
Philips (United Kingdom) – RFID Inlays
FEIG Electronic GmbH (Germany) – Delivery belt/Belt Loader Readers
Flughafen Frankfurt am Main Aviation Ground Services (Germany) – BRS
IER (Texas, France) – Bag Tag Printers
idSystems (United Kingdom) – Printer read/write module
Microlise Engineering Limited (United Kingdom) – Handheld Readers
Moore Research Corporation (New York) – Bag Tag Labels
Sihl GmbH (Germany) – Bag Tag Labels
Microlabsystems (Sweden) - Integration, Installation Support for Confidence International
Softlab – BRS Software

Candidate RFID Systems must be fully representative of the suppliers total system configuration at the time of testing and will be evaluated solely on their performance with no considerations given to product maturity. Operational requirements demand not only that the candidate RFID systems perform specific communications functions, but that these systems also possess the capability to:

- Withstand repetitive cycles of sustained operations with little to no maintenance
- Perform in a physically demanding environment
- Not degrade the existing operational electronic environment with additional Radio Frequency Interference (RFI)/Electromagnetic Interference (EMI) or not be affected by the ambient RF environment at the operational airport locations

Ten flights a day from San Antonio to Houston were identified as test flights. Each test cycle began in San Antonio where special baggage identification tags with embedded RF inlays were printed and attached to passenger bags going to Houston. There were four different bag tag/inlay combinations that were tested:

- Moore tags/Phillips inlays
- Moore tags/TI inlays
- Sihl tags/Phillips inlays
- Sihl tags/TI inlays

The RFID bag tags were read three times in the San Antonio test site before being loaded onto the test flight:

- Automatically by a delivery belt RFID reader in the baggage make-up room
- By a handheld RFID reader operated by test personnel in the baggage make-up room
- Automatically by a ramp RFID reader mounted on a mobile belt loader at the departure aircraft ramp

After the test flight arrived at Houston, the RFID bag tags were read once during the unloading process. This was done automatically by a ramp RFID reader mounted on a mobile belt loader at the arrival aircraft ramp (similar to the ramp reader in San Antonio). Then designated portions of the bags going to connecting flights from Houston were read by handheld RFID readers operated by test personnel at several departure aircraft ramps during the baggage loading process. Thus the test covered the entire baggage handling process from passenger check-in through a tail-to-tail transfer.

The critical elements of the operational test system were:

- Bag tag printers modified to encode and print special RFID tags
- Paper bag tags with embedded RFID inlays
- Automatic RFID belt and ramp readers (panels mounted on either side and on the bottom of the delivery belt {belt reader} and the mobile belt loader {ramp reader})
- Handheld manually operated RFID readers

The evaluation of the RFID system under test was based on the following criteria:

- <u>The encoding rate of success</u>, or the percentage of successfully encoded RFID bag tags printed during the baggage check-in process
- <u>The read rate of success</u>, or the percentage of successful readings of RFID bag tags during the baggage sortation and transfer process

- Operator impact, or the measure of any additional operations to be performed or additional time to be spent in the normal baggage handling operations to accommodate the RFID system

The analysis of data for the printers shows an overall encoding success rate of 98.6%. The RF Voids, or failures, consisted of 141 tags out of a total of 10050 tested. Further analysis of the RF Voids indicates that there were four causes of the voids:

- The majority of the voids were due to failed Philips inlays. This was consistent for both Sihl and Moore paper bag tag types. This is similar to the results for the Phase IIA Frankfurt trial. Although different printers and paper bag tag types were used in Frankfurt the majority of the RF Voids were also due to failed Philips inlays

- The next largest number of RF Voids (0.13%) was due to the absence of an inlay in the tag, which only occurred in the Moore paper bag tag type and was consistent for both the Philips and TI inlays. As the results of these tests were being documented, Moore revealed that they intentionally did not insert an RFID tag into the leading and trailing label in the roll; this was not communicated to the test team prior to the tests. This explains the counting of these RF Voids which were intentional non-RF tags

- The third group of failures actually read as valid tags when they were tested with the handheld reader. This was a result of the printer encoding process succeeding, but the printer verifying process failing. This occurred for 17 tags with a Philips inlay and 1 tag with a TI inlay

- The final group of failures was due to the tag not being programmed. When tested with the handheld reader the default value of the tag was read, which indicates that the inlay was functioning. This failure type accounted for only 3 tags

The first read point for the RFID tags was by the belt reader in the baggage make-up room in San Antonio. The data for the belt reader shows an overall successful read rate of 92.39%, The overall read success rate for the individual inlay/paper types ranged from 89.00 to 98.70%. The Moore/Philips combination performed the best at 98.70%, and the Moore/TI combination performed the worst at 89.00%.

The actual bag tag paper type should have had little effect on the readability of the tag once the printer correctly encoded a tag. The belt reader and ramp reader should have allowed for equal performance of both the Philips and TI inlay since they were designed to read either inlay type. However, for the belt reader the overall read rate for the Philips inlay was 95.52% and 89.66% for the TI inlay.

Analysis of the read rate performance by day for both the Philips and TI inlay indicates inconsistent performance of the belt reader for both the Philips and TI inlays throughout the trial. There was concern that any external noise or interference present at the test site could degrade performance of the belt reader system. Attempts to identify and eliminate sources of noise did not seem to improve performance. It was also unlikely that an RFID tag that was properly encoded by a printer in the check-in area failed on its way to the make-up room. Because of the slow speed of the belt and the fact that it was often stationary, the reader should have had multiple opportunities to read an individual RFID tag. Yet the belt reader read rate was well below that measured during Qualification Testing.

The second read point for the RFID tags was with a handheld reader. During original planning for this trial, the requirement for the handheld reader was that it be capable of reading at a maximum distance of 6 inches. Shortly before the Qualification Test was to begin it was learned that the vendor supplying the handheld reader could not meet the technical and delivery date requirements. An alternate source for the readers was found, but the read distance of 6 inches could not be met for the trials. During the trials, the handheld was first held at approximately 3 inches from the RFID tag. However, this did not seem to provide a reliable reading. Finally, after some experimentation, the most reliable read rate was achieved when the handheld reader was placed directly on the tag then swept across the surface of the tag. Using this method, the overall read rate for the handheld reader in San Antonio was 98.99%.

This method provided a good read rate. However, one of the expected benefits of using an RFID tag versus a Barcode tag for a handheld read is that with the RFID tag it should be possible to read the tag without seeing a specific portion of the tag, and without having to reorient the bag or tag. This benefit is eliminated when the read range is as limited as it was in this test.

The third read point for the RFID tags was with a ramp reader in San Antonio. The data for the ramp reader shows an overall read rate of 86.40%. Comparing results by RFID inlay only, the overall read rate for the Philips inlay was 92.50%, and 76.50% for the TI inlay. As with the belt reader, the results indicate inconsistent performance for both the Philips and TI inlays throughout the trial.

Several operational issues were noted during the test of the ramp reader. The first was that the vertical antenna panels read a tag not only across the belt, but also from the outside of the antenna panels causing false reads. A second issue was that the belt loaders are often used to load or remove cargo from the aircraft. For these tests a different belt loader had to be brought in for cargo because the distance between the two vertical reader antenna panels would not allow the cargo to fit. There were also some problems with standard baggage. There were many times when the baggage jammed between the two antenna panels and the belt had to be stopped. The final design of any ramp reader would have to take these considerations into account.

The fourth read point for the RFID tags was with the ramp reader in Houston. The data for the ramp reader shows an overall read rate of 94.75%. The read rate for the Philips inlay was 92.64% and 97.44% for the TI inlay.

Although the ramp reader in Houston performed better than both the belt reader and ramp reader in San Antonio, the results still indicate inconsistent performance for both the Philips and TI inlays throughout the trial.

The operational issues discussed for the ramp reader in San Antonio are also true for the ramp reader in Houston.

The fifth read point for the RFID tags was with a handheld reader at the arrival ramp in Houston. The aircraft used during this test had either two or three compartments. For the arriving aircraft in Houston the ramp reader was placed at the compartment with the most baggage and a handheld reader was used at one of the other compartments. The overall read rate for the handheld reader used at arrival in Houston was 99.03%.

The same read method of direct contact with the tag was used again, defeating one of the benefits of using an RFID tag versus a barcode tag.

The final opportunity to read the RFID tags was during the Tail-to-Tail transfer operation in Houston. Connecting flights scheduled for the highest number of bags with RFID tags were selected. These bags were then read at the departing aircraft's loading ramp. As with the other handheld readers, it was found that the approach that provided the most reliable read rate was when the handheld reader was placed directly on the tag then swept across the surface of the tag, negating the advantage of using an RFID tag versus a barcode tag. The overall read rate for the handheld reader, used in Houston during the tail-to-tail transfer operation, was 95.34%.

ACRONYMS AND ABBREVIATIONS

AM .... Amplitude Modulation
ASCII .... American National Code for Information Exchange
Bd .... Baud
BRS .... Baggage Reconciliation System
BSM .... Baggage Source Message
CI .... Control/Interface
CRC .... Cyclic Redundancy Check
DCS .... Departure Control System
DOT .... Department of Transportation
Dpi .... Dots per Inch
Dpmm .... Dots per Millimeter
EEPROM .... Electronically Erasable Programmable Read Only Memory
EMC .... Electromagnetic Compatibility
EMI .... Electromagnetic Interference
FAA .... Federal Aviation Administration
FAG .... Flughafen Frankfurt/Main AG
FAATC .... Federal Aviation Administration Technical Center
g .... gram
Hz .... Hertz
IAH .... George Bush Intercontinental Airport/Houston
IATA .... International Air Transport Association
ICODE .... Philips Semiconductor RFID inlay
I/O .... Input/Output
Ips .... Inches per Second
KBd .... Kilobaud
LAN .... Local Area Network
lb .... pound
LCD .... Liquid Crystal Display
LED .... Light Emitting Diode
m .... meter
mA .... milliamps
MHz .... Megahertz
Mm .... millimeters
Mmps .... Millimeters per Second
OEM .... Original Equipment Manufacturer
OTP .... Operational Test Plan/Procedure
PC .... Personal Computer
PCB .... Printed Circuit Board
PET .... Polyethylentherephtalate
PPBM .... Positive Passenger Bag Match
PROM .... Programmable Read Only Memory
QTP .... Qualification Test Plan/Procedure
RAM .... Random Access Memory
RF .... Radio Frequency

RFI................. Radio Frequency Interference
RFID.............. Radio Frequency Identification
RISC.............. Reduced Instruction Set Computer
ROM.............. Read Only Memory
RX................. Receive
SAT............... San Antonio International Airport
SITA.............. Société Internationale de Télécommunications Aéronautiques
SRAM........... Static Random Access Memory
Tag-it............. Texas Instrument RFID inlay
TI................... Texas Instrument
TTL................ Transistor Transistor Logic
TX.................. Transmit
ULD............... Unit Loading Device
um.................. micrometer
VA................. Volt Amps
VAC.............. Volts alternating current
VDC.............. Vendor Data Collection

1 INTRODUCTION

1.1 Background

The increasing importance of commercial airline passenger and baggage security, combined with the need to sort and track ever larger numbers of passenger baggage quickly and accurately, have led to the search for more efficient methods of performing the baggage sortation, tracking and security functions. Any tool used to facilitate these functions must be able to rapidly and reliably process, reconcile and track passenger and baggage information. Without this capability, flight delays and increased operational costs are likely to result. Passenger inconvenience could lead to decreased tolerance of airline security regulations and loss of confidence in the air transport industry.

Phase I Testing

In 1997, the FAA sponsored the initial phase of testing of commercially available RFID systems for the support of passenger/bag matching and baggage sortation functions. The term "commercially available" throughout this document is used to indicate that no Government funding was provided for the research and development of these systems. The initial phase had two stages. Stage one was Qualification Testing. Its objective was to qualify vendor RFID products and systems, in a controlled laboratory environment, to:

- Operate within the physical and operational constraints associated with airline and airport environments
- Perform the functional requirements associated with baggage sortation and passenger/baggage match security objectives in the airline and airport environment, without degradation of existing electronic systems

The RFID systems which passed Qualification Testing subsequently entered Stage Two of initial testing, which consisted of Operational Testing in paired domestic/international airports. Of particular concern in initial Operational Testing were the following characteristics of the candidate systems:

- Performance
- Reliability
- Electromagnetic compatibility (EMC) with airline, airport and aircraft operations and systems
- Compatibility with airport communications restrictions (power, frequency)
- Technical and operational approach to supporting passenger/baggage matching and sortation functions

Operational Testing was conducted in conjunction with sponsor airlines and airports, as well as with the cooperation of a Baggage Reconciliation System (BRS) provider. The test results clearly demonstrated the feasibility of using RF technology to support passenger/baggage matching and sortation functions. Several systems showed high levels of baggage identification performance, even in suboptimal operational environments. In addition, there were a number of suggested approaches for improving system performance, which were identified during the first phase of testing.

Phase II Testing

The successful initial phase of feasibility testing of the candidate RFID systems led to this current (second) phase of testing – the Integrated System Test. The Operational Test for this second phase will be conducted in four stages at different combinations of airport sites. Each test stage will focus on specific portions of the end-to-end identification, tracking and security functions.

The first stage, Phase IIA, was conducted at the Frankfurt Airport (Germany) in cooperation with United Airlines, and with the participation of RF vendors Texas Instruments and Omron Electronics, Inc. The tests there encompassed the passenger baggage check-in process (bag tag encoding) and the reconciliation of the baggage in the baggage make-up rooms (reading the encoded tags).

This second stage of tests, Phase IIB, took place jointly at the San Antonio International Airport, Texas and the George Bush Intercontinental Airport/Houston, Texas in cooperation with Continental Airlines. In this stage, the tests expanded to include:

- Passenger baggage check-in (bag tag encoding and printing)
- Reading and data collection of the RFID bag tag data on the delivery belt to the baggage make-up room using a delivery belt reader
- Reading and data collection of the RFID bag tag data in the baggage make-up room (reading the encoded bag tags with a tethered handheld reader)
- Reading of the bag tag data on the loading ramp to the aircraft using a ramp reader
- Transfer of the baggage to a connecting flight, which includes: reading the encoded bag tags with a ramp reader as the baggage is unloaded from the arriving flight; and reading them again with a handheld reader on the loading ramp as baggage is loaded onto the departing flight

The test included participation by the following vendors:

Confidence International (Sweden) – System Integrator

Texas Instruments (Texas) – RFID Inlays

Philips (United Kingdom) – RFID Inlays

FEIG Electronic GmbH (Germany) – Belt and Ramp Readers

Flughafen Frankfurt am Main Aviation Ground Services (Germany) – BRS

IER (Texas, France) – Bag Tag Printers

idSystems (United Kingdom) – Printer read/write module

Microlise Engineering Limited (United Kingdom) – Handheld Readers

Moore Research Corporation (New York) – Bag Tag Labels

Sihl GmbH (Germany) – Bag Tag Labels

Microlabsystems (Sweden) - Integration, Installation Support for Confidence International

Softlab – BRS Software

The third stage of testing, Phase IIC, will take place at two domestic airports: the Miami, Florida Airport and JFK Airport in New York. This stage will expand to include the test of a reusable container tracking system with RF "seals", and testing of varying RFID system frequencies. These tests will be done in conjunction with Tower Airlines.

The fourth stage of testing, Phase IID, will include the test of both disposable and reusable RF bag tags, and international interline transfer of baggage. It will be conducted in conjunction with Alaska Airlines and Singapore Airlines at both domestic and foreign airports. Tentative sites include San Francisco, Seattle, and Vancouver for Alaska Airlines and Singapore, Penang and Narita for Singapore Airlines.

This document addresses only the results of the Phase IIB Operational Test in San Antonio and Houston. Results of other phases of testing have been and will be addressed individually in separate documents.

1.2 Purpose

The purpose of this report is to present the results of the Phase IIB Operational Test conducted at the San Antonio International Airport, San Antonio, Texas (SAT) and the George Bush Intercontinental Airport/Houston, Texas (IAH) in cooperation with Continental Airlines. The overall objective of this phase of testing is to demonstrate the technical and operational feasibility of conducting baggage tracking in a complete, real-time end-to-end mode, using RFID technology, while adding overall value to baggage operations and baggage management, to include the security function.

1.3 Scope

The Operational Test of vendor-provided, commercially available RFID systems is in the process of being conducted at selected domestic and international airports in cooperation with sponsor airlines. Candidate RFID systems will be installed and tested at these sites under normal operational conditions. Candidate RFID Systems must be fully representative of the suppliers total system configuration at the time of testing and will be evaluated solely on their performance with no considerations given to product maturity. Operational requirements demand not only that the candidate RFID systems perform specific communications functions, but that these systems also possess the capability to:

- Withstand repetitive cycles of sustained operations with little to no maintenance
- Perform in a physically demanding environment
- Not degrade the existing operational electronic environment with additional Radio Frequency Interference (RFI)/Electromagnetic Interference (EMI) or not be affected by the ambient RF environment at the operational airport locations

As candidate RFID systems are installed at the test sites, all control and interface functions are being exercised to assure proper operation with the test equipment, and with the interfacing airport systems.

2 REFERENCE DOCUMENTS

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DOT/FAA/AR-97/44	Qualification Test Procedures (QTP) of Commercially Available Radio Frequency Identification (RFID) Systems for Positive Passenger Baggage Match (PPBM) Applications, June 1997
DOT/FAA/AR-97/40	Operational Test Plan (OTP) of Commercially Available Radio Frequency Identification (RFID) Systems for Positive Passenger Baggage Match (PPBM) Applications, June 1997
DOT/FAA/AR-97/45	Operational Test Procedures (OTP) of Commercially Available Radio Frequency Identification (RFID) Systems for Positive Passenger Baggage Match (PPBM) Applications, June 1997
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DOT/FAA/AR-98/XX	Phase II Qualification Test Plan and Procedures (QTP) of Commercially Available Radio Frequency Identification (RFID) Systems for Baggage Identification, Tracking and Security Applications, October 1998
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	Security Applications, United Airlines Trial, March 1999
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DOT/FAA/AR-99/XX	Phase IIB Operational Test Plan and Procedures of Commercially Available Radio Frequency Identification (RFID) Systems for Baggage Identification, Tracking and Security Applications; Continental Airlines Trial; San Antonio and Houston, Texas; September 1999
DOT/FAA/AR-99/XX	Qualification Test Report; Phase IIB Qualification Test of Commercially Available Radio Frequency Identification (RFID) Systems for Baggage Identification, Tracking and Security Applications; Continental Airlines Trial, October 1999
DOT/FAA/AR-99/XX	Quick Look Test Report; Phase IIB Operational Test of Commercially Available Radio Frequency Identification (RFID) System for Baggage Identification, Tracking and Security Applications; Continental Airlines Trial; October 1999

3 OPERATIONAL TEST SYSTEM DESCRIPTION

3.1 Test System Overview

The overview of the entire system is shown in Figure 3.1, Operational Test System Components and Interfaces, San Antonio and Houston Test Sites. The test was conducted in two locations: the San Antonio International Airport (SAT) and the George Bush Intercontinental Airport/Houston (IAH). The test began in San Antonio where special baggage identification tags with embedded RF inlays were printed and attached to passenger bags going to Houston. For each test bag tag issued, the Continental Departure Control System (DCS) sent a Baggage Source Message (BSM) to the Baggage Reconciliation System (BRS) at the Houston site. This BSM data served as control data against which to check the test system read results.

The test bags were passed through an RFID reader mounted on the conveyor belt delivering the bags from the check-in stations to the baggage make-up room. This belt reader automatically read the 10-digit barcode number encoded on the test bag tags. That information was sent to a Vendor Data Collection (VDC) PC. In addition, the test bag tags were read independently in the baggage make-up room using an RFID handheld reader tethered to another VDC. As the bag tag data was read with the handheld reader, it was sent to the VDC for storage.

The test bags were then transported to the appropriate aircraft ramp for loading. The mobile belt loader used on the ramp was also fitted with an RFID ramp reader, so that as the bags moved along the belt into the aircraft cargo bin, they were automatically read again.

The flight then took the bags to the Houston airport. When the flight arrived in Houston, the bags were unloaded using a mobile belt loader fitted with another RFID ramp reader (similar to the belt loader used for departure in San Antonio). As the bags came off the flight, the test bag tags were automatically read when they passed through this reader. Since there was only one ramp reader, if any bags were simultaneously unloaded from a second bin in the arrival aircraft, test personnel in Houston used a handheld RFID reader to read those test bag tags.

Additionally, the Houston test team dispersed to the departure gates of the three connecting flights (i.e., connecting with the flight from San Antonio) having the heaviest baggage load. There the test bag tags of the bags being loaded onto the connecting flights were read using a handheld RFID reader, and the data stored. This data was later downloaded to a Vendor Data Collection unit.

Using this procedure, the test bag tags destined for Houston were read independently three times at the San Antonio airport before departure. At the Houston end, the bags were read once at arrival, and a portion of those bags were read a second time as they were loaded onto their connecting departure flight.

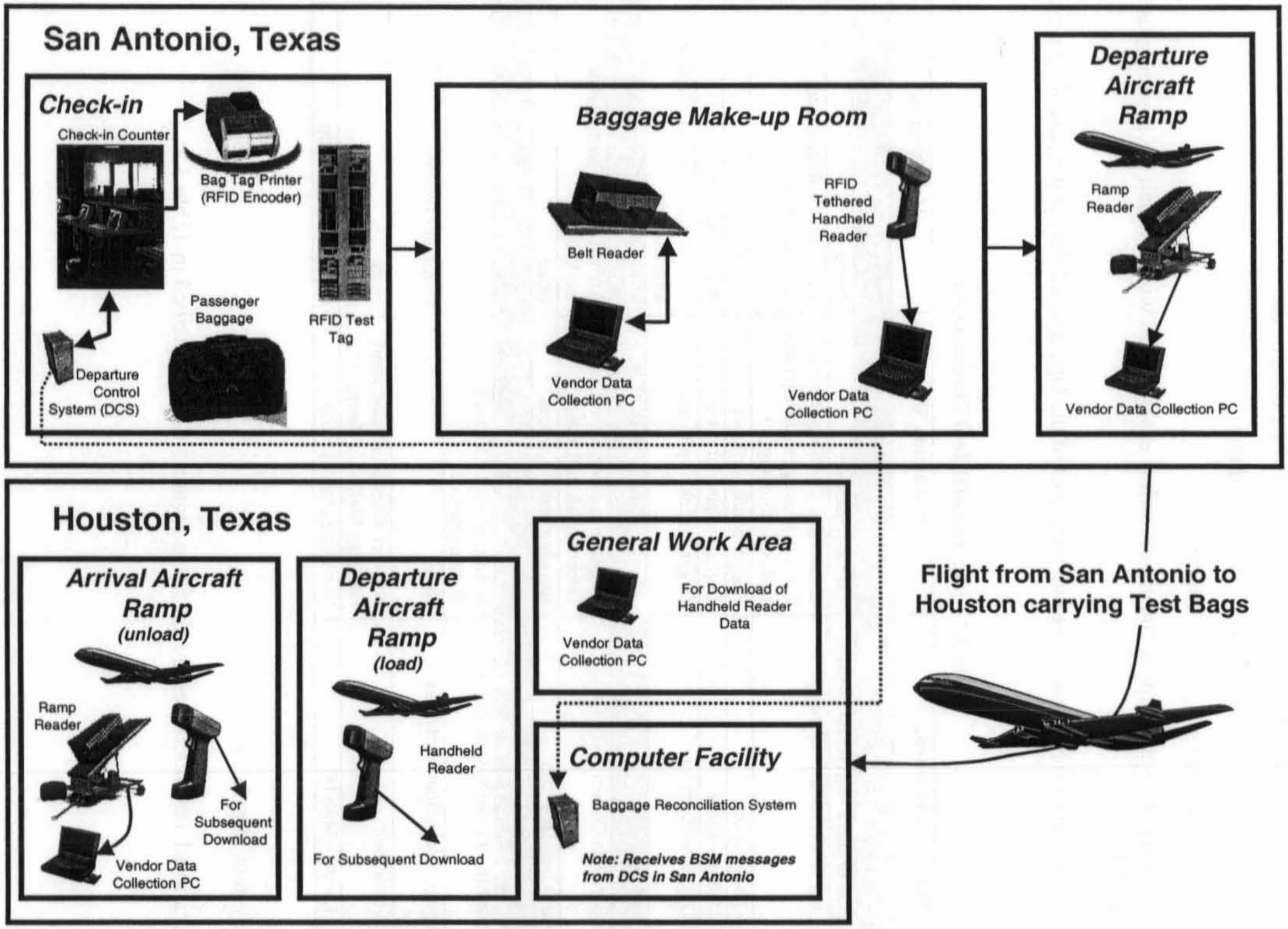

Figure 3.1 Operational Test System Components and Interfaces, San Antonio and Houston Test Sites

3.1.1 Test Components

The Operational Test components fall into the following categories:

- Components that make up the system under test
- Components that support the test effort
- Components that comprise the airport/airline environment within which the system must operate

Table 3.1 below lists the components that were part of the Operational Test and where they were used.

Table 3.1 Operational Test Components

System Component	San Antonio Site	Houston Site
• System Under Test		
a) Bag tag printers with RFID module	Check-In Station	None
b) Bag tag labels with RFID Inlay	Encoded at Check-In Station. Read in baggage make-up room and departure ramp	Read at arrival ramp and departure ramps
c) RFID belt reader	Baggage make-up room	None
d) RFID ramp reader	Departure aircraft ramp	Arrival aircraft ramp
e) RFID handheld readers	Baggage make-up room	Arrival aircraft ramp; Departure aircraft ramp
• Test Support Systems		
a) Vendor Data Collection (VDC) PC	Baggage make-up room; Departure aircraft ramp	Arrival aircraft ramp; General work area
b) Control Interface (CI)	Baggage make-up room	None
• Airline/Airport Systems		
a) Departure Control System (DCS)	Interfaced with Check-In Station printers	None
b) Baggage Reconciliation System (BRS)	None	Computer facility
c) Conveyor Belt	Between Check-In Station and Baggage Make-Up Room	None
d) Belt Loader (Mobile)	Departure aircraft ramp	Arrival aircraft ramp

3.1.2 System Interfaces

The Operational Test interfaces are shown in Figure 3.1 and described in Table 3.2.

Table 3.2 Phase IIB Operational Test System Interfaces

Interface	Description
DCS ⇒ Modified Bag Tag Printer	The Modified Bag Tag Printer connects directly to the DCS. This printer is a standard bag tag printer with an RFID encoder mounted inside.
RFID Handheld/Belt/Ramp Readers ⇒ VDC	The VDC PC received and recorded bag tag and time stamp data from the RFID Handheld, Belt and Ramp Readers.
DCS ⇒ BRS (Houston)	The BRS received the BSM data from the DCS.

3.1.3 System Under Test

3.1.4 Bag Tag Printers/RFID Board

The printers used to encode the RFID bag tags were modified versions of an IER 512B bag tag printer manufactured by IER Incorporated and shown in Figure 3.2. The printer is a direct thermal printer used by the air transportation industry to print self-adhesive barcode bag tags. The characteristics of the printer are listed in Table 3.3.

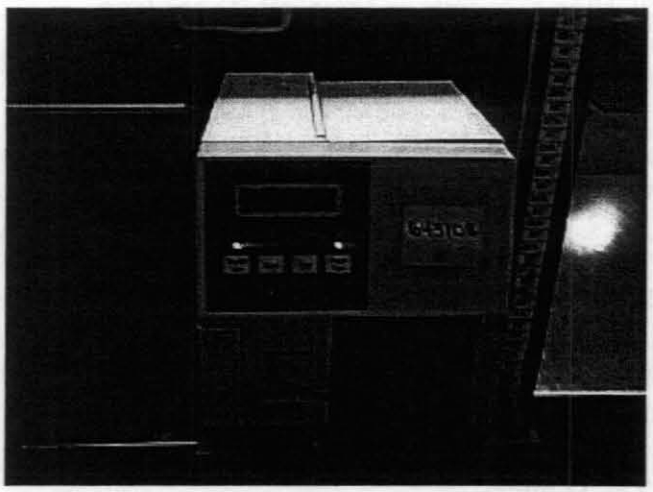

Figure 3.2 IER 512B Bag Tag Printer

Table 3.3 IER Bag Tag Printer Characteristics

Characteristic	Specification
Printing Technology	Thermal
Print Resolution	8 X 8 dots per mm
Print Speed	Up to 7 in/sec
Interface	Serial, RS232
Voltage	85 to 264 VAC (Auto switching), 50/60 Hz

The printer was modified with the addition of an RFID read/write module, provided by idSystems, to allow encoding and reading of bag tags with either TI or Philips RFID inlays laminated in them. This module is intended for embedding within portable computers and handheld data terminals, but may also be used with a number of motherboards to provide a wide range of additional interfaces, including user memory, real time clock, RS232 interface, keypad and digital I/O. The module characteristics are listed in Table 3.4.

Table 3.4 idSystems Read/Write Module Characteristics

Characteristic	Specification
Read/Write Support	Philips and TI RFID Inlays
Operating Frequency	13.56 MHz
Interface	Serial, RS232

Thirteen of these modified RFID Bag Tag printers were used at the check-in sites in the San Antonio Airport during testing to encode and print RFID bag tags.

3.1.5 Paper Bag Tags

Two types of Paper Bag Tags, manufactured by Moore Research Corporation of New York and Sihl GmbH of Germany, were used for this test. The Paper Bag Tags supplied by Moore and Sihl were standard bag tags, used by the air transportation industry, with RFID Inlays laminated in them to produce RFID Bag Tags. Moore produced a minimum of 2500 RFID bag tags with Philips inlays, and a minimum of 2500 RFID bag tags with TI inlays. Similarly, Sihl produced a minimum of 2500 RFID bag tags with Philips inlays and 2500 RFID bags tags with TI inlays. This provided a total of more than 10,000 RFID bag tags for this test with four different possible combinations of paper stock and inlays:

- Moore paper stock/ TI inlay
- Moore paper stock/ Philips inlay
- Sihl paper stock/ TI inlay
- Sihl paper stock/ Philips inlay

3.1.6 RFID Inlays

3.1.6.1 Philips RFID Inlay

3.1.6.2 The Philips RFID Inlay is a thin read/write RF transponder shown in Figure 3.3. Data is stored in and read from a 512-bit EE-PROM contained on the inlay. The RFID inlay has an anti-collision option that allows simultaneous operation of several tags. The technical specifications for this inlay are shown in Table 3.5.

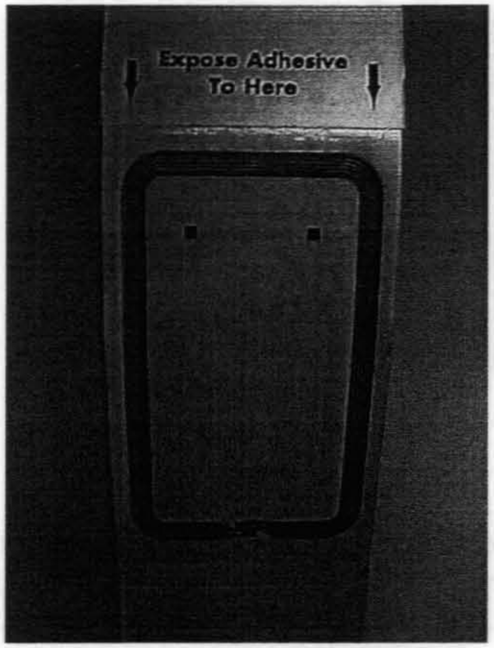

Figure 3.3 Philips RFID inlay

Table 3.5 Technical Specifications for Philips RFID Inlay

RFID Inlay	**Technical specification**
RF Communication frequency	13.56 MHz
Memory	512-bit EE-PROM
Size	96 ± 0.5mm L x 48 + 0.6mm/- 0.0mm W
Thickness of electronic part	259 μm
Overall thickness of copper antenna	47 μm

3.1.6.3 TI RFID Inlay

The TI RFID inlay is a very thin, read/write memory, Radio Frequency (RF) transponder fabricated on a polymer tape substrate as shown in Figure 3.4. Data is stored in and read from a 256-bit, non-volatile user memory contained on the inlay. The RFID inlay can be factory programmed with a simultaneous identification algorithm that allows multiple transponders to be read simultaneously. The technical specifications for the RFID inlay are shown in Table 3.6.

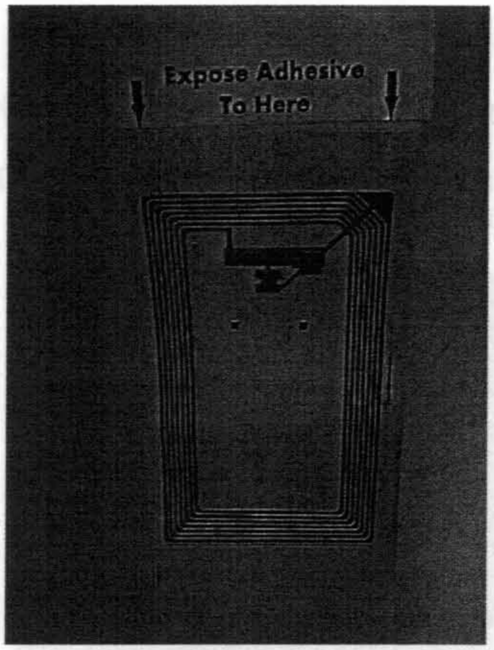

Figure 3.4 TI RFID inlay

Table 3.6 Technical Specifications for TI RFID Inlay

RFID Inlay	Technical Specification
RF Communication Frequency	13.56 MHz
Memory	256-bit programmable user memory (8x32 bit blocks)
Antenna size	45 x 45 mm or 45 x 76 mm
Operating Temperature	-25^{0}C to +70^{0}C
Uplink/Downlink data rates	26.7 kBd/6.2 to 9 kBd secured with CRC
RX modulation	Pulse Width coded AM 100%
TX frequencies	Manchester encoded, A=f_c +/- 423.75 kHz, B= f_c +/-484.29 kHz Low bit: transition A to B, High bit: transition B to A
Thickness	Chip and contact: 0.375 mm All other areas: 0.085 mm
Base Material	Substrate: Polyethylentherephtalate (PET) Conductive area: Aluminum

3.1.7 Belt Reader/ Ramp Reader

The baggage delivery belt and aircraft belt loaders were fitted with automatic RFID bag tag readers supplied by FEIG Electronic GmbH. The readers for both the delivery belt and belt loader were the same. They consisted of antennas and electronics for reading the RFID bag tags. Two of the antennas were located on each side of the moving belt, while the third antenna was located under the belt. The system is configured as shown in Figure 3.5. This antenna configuration allows the automatic reading of the RFID bag tags regardless of orientation.

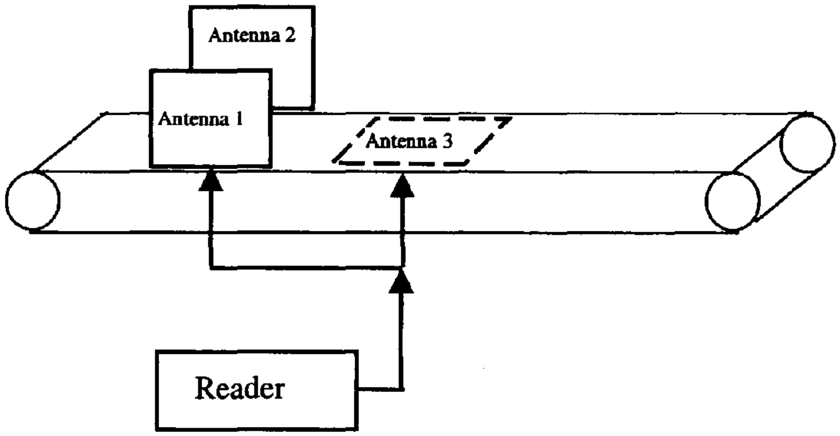

Figure 3.5 Belt Reader/ Ramp Reader Configuration

The characteristics of the belt and ramp readers are shown in table 3.7.

Table 3.7 Belt Reader/ Ramp Reader Characteristics

Characteristic	Specification
Electronics Housing	
Dimensions	300 x 300 x 120 mm
Power	60 VA
Interface	RS232
Side Antennas	0.9 m x 0.7 m x 0.1 m
Distance between side antennas	0.87 m
Bottom Antenna	0.9 m x 0.6m
Distance between side and bottom antenna	1.0 m
Operating Frequency	13.56 MHz
Max read/write distance	1.20 m

3.1.8 Handheld Readers

Handheld Readers manufactured by Microlise Engineering were used for the testing. These Handheld Readers are barcode readers modified to read from and write to 13.56 MHz RFID Inlays produced by both TI and Philips. Three Handheld Reader models were used for the testing: 1) Dexter 4, 2) Tracer 4, and 3) Rugged Scanner 4. The Rugged Scanner 4 was used in the baggage make-up area in San Antonio, while the Dexter 4, and the Tracer 4 were used on the aircraft ramp at Houston.

3.1.8.1 Dexter 4

The Dexter 4, shown in Figure 3.6, is the smallest and lightest of the Handheld Readers used. It features an ergonomic design resembling a handheld remote control unit with a Liquid Crystal Display (LCD) and Reduced Instruction Set Computer (RISC) processor. The characteristics of the Dexter 4 are shown in Table 3.8.

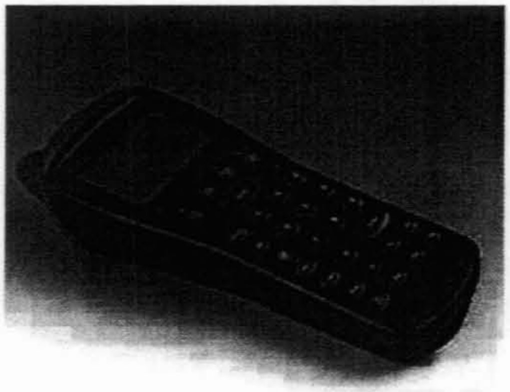

Figure 3.6 Dexter 4 Handheld Reader

Table 3.8 Characteristics of Dexter 4 Handheld Reader

Characteristic	Specification
Operating Frequency	13.56 MHz
Dimensions	225 mm (height) 87 mm (width) 55 mm (depth)
Weight	470 g
Power	Lithium-ion battery
Interface	RS232

3.1.8.2 Tracer 4

The Tracer 4 Handheld Reader is shown in Figure 3.7. It features an ergonomic design with a pistol grip type handhold. It also has a LCD and a RISC processor. The characteristics of the Tracer 4 are shown in Table 3.9.

Figure 3.7 Tracer 4 Handheld Reader

Table 3.9 Characteristics of Tracer 4 Handheld Reader

Characteristic	Specification
Operating Frequency	13.56 MHz
Dimensions	225 mm (height) 97 mm (width) 205 mm (long)
Weight	706 g
Power	Lithium-ion battery
Interface	RS232

3.1.8.3 Rugged Scanner 4

The Rugged Scanner 4 Handheld Reader is shown in Figure 3.8. It is similar to the Dexter 4 and Tracer 4 in function, but it is specifically designed to provide durability and reliability while operating in environments that expose it to harsh temperature and shock. The characteristics of the Rugged Scanner 4 are shown in Table 3.10.

Figure 3.8 Rugged Scanner 4 Handheld Reader

Table 3.10 Characteristics of Rugged Scanner 4 Handheld Reader

Characteristic	Specification
Operating Frequency	13.56 MHz
Dimensions	225 mm (height) 71 mm (width) 158 mm (depth)
Weight	550 g
Power	Battery
Interface	RS232

3.2 Test Support Systems

3.2.1 Vendor Data Collection (VDC) PC

The VDC is a PC with specialized software to collect and manage data from the belt, ramp, and handheld readers. It received and stored RFID bag tag data automatically from the belt reader and the handheld reader in the baggage make-up room, and from the ramp reader at the departing and arriving aircraft ramps. Data was downloaded to it from the handheld readers used at the arriving aircraft ramp and at the tail-to-tail baggage transfer. All of this data was downloaded from the VDC for analysis following the tests.

3.2.2 Control Interface (CI)

The CI consists of customized software, which resides on a Micron TransPort Xpe laptop PC. Originally it was to be used in the baggage make-up area in San Antonio to provide the interface between the VDC PC, that was receiving data from the belt reader, and the BRS. The CI was not used for this purpose since there was no BRS in San Antonio. However, after some reprogramming of the CI software, it was used to replace a VDC that failed during testing. The failed VDC was being used for recording data from the handheld reader in the baggage make-up room in San Antonio prior to its failure.

3.3 Airport/Airline Systems

3.3.1 Departure Control System (DCS)

As passengers are being checked in, their flight and baggage information is entered into the airline's host computer, or DCS. When this data is entered, the DCS generates a standardized 10-digit barcode (known as the license plate number) for each item that is checked in. This code is used for baggage sortation, tracking, and security purposes. The barcode is printed on the bag tag, which is attached to the checked bag. The DCS then sends a Baggage Source Message (BSM) to the airline's BRS, if available. This message contains the passenger departure, connection and arrival information, along with the license plate identification numbers of any checked bags.

3.3.2 Baggage Reconciliation System (BRS)

The BRS, developed by Flughafen Frankfurt/Main AG (FAG), is a computerized baggage reconciliation system with multiple airline-host connectivity. It consists of a host computer residing at the Houston airport, connected via a local area network (LAN) to numerous terminals throughout the airport. Continental Airlines does not currently use a BRS in San Antonio. A modification was made by Continental to allow the BRS system in Houston to accept BSM data from San Antonio for the duration of the test.

The BRS was not used as an integral part of these tests. The stored BSM database was used as a check against the RFID read results from the various readers that were part of the test system.

3.3.3 Conveyor Belt (from Check-In Stations to Baggage Make-Up Room)

The standard conveyor belt system at the San Antonio International Airport was used in the normal manner to transport the test bags from the check-in stations to the baggage make-up room. The belt reader, as described in paragraph 3.2.4, was mounted onto the conveyor belt in the baggage make-up room. It automatically read the RFID bag tags on the baggage as it was delivered to the baggage make-up room.

3.3.4 Belt Loader (Mobile)

The belt loader is a 660 series manufactured by S&S TUG. It is a vehicle-mounted conveyor belt system that can be driven to the aircraft ramp and inclined so that baggage can be loaded onto the aircraft from the ground or vice versa. Characteristics of the belt loader are shown in Table 3.11.

Table 3.11 TUG Series 660 Belt Loader Characteristics

Characteristic	Specification
Conveyor Length	294 in.
Conveyor Width	34 in.
Conveyor Capacity	2000 lb.
Conveyor Speeds 1) Gas & Diesel 2) Electric	 45 to 90 feet per minute 10 to 90 feet per minute

4 TEST AND EVALUATION DESCRIPTION

4.1 Test Schedule and Locations

The Phase IIB Operational Tests were conducted at two domestic airports simultaneously: the San Antonio International Airport, and Houston's George Bush Intercontinental Airport, both in Texas. The following areas of the airports were used for the tests:

San Antonio	Passenger Check-In Area Baggage Make-Up Room Aircraft Departure Ramp
Houston	Aircraft Arrival Ramp Aircraft Departure Ramp

The testing schedule for both sites was as follows:

• Installation, checkout and final adjustment of test equipment	9/18/99 through 9/21/99
• Operational testing	9/22/99 through 9/30/99
• Disassembly and packaging (for shipping) of test equipment	10/1/99

4.2 Test Participants

Test Personnel

The FAA conducted the tests, and was supported by the following contractors:

BCI, Inc. (*Basic Commerce and Industries, Inc.*)

Responsible for:

- Managing test activities (Houston)
- Operation of test equipment (Houston)
- Data collection (Houston)

CIE, Inc.

Responsible for:

- Assistance in test planning

SEXTANTechnologies

Responsible for:

- Liaison with airport/airline personnel (San Antonio and Houston)
- Data collection (San Antonio)

Veridian Engineering, Inc.

Responsible for:

- Planning and coordination of all test activities (San Antonio and Houston)
- Liaison with vendors
- Definition of all test plans, procedures (San Antonio and Houston)

- Monitoring of vendor test equipment installation/checkout (San Antonio and Houston)
- Managing test activities at the San Antonio site
- Operation of test equipment (San Antonio and Houston)
- Data collection (San Antonio and Houston)
- Development of test analysis software
- Analysis and documentation of test results

Vendors

The table below lists the vendors who participated in the Phase IIB Operational Test and their area of responsibility. Components from the consortium members were provided under the direction of Confidence International. They are identified in the table.

Table 4.1 List of Vendors

VENDOR	RESPONSIBILITY
Consortium Members	
Confidence International (Sweden)	System Integrator
FEIG Electronic GmbH (Germany)	Belt and Ramp Readers
Microlabsystems (Sweden)	Integration, Installation Support for Confidence International.
Microlise Engineering Limited (UK)	Handheld Readers
Philips (UK)	RFID Inlays
Sihl GmbH (Germany)	Bag Tag Labels
Non-Consortium Vendors	
Flughafen Frankfurt am Main Aviation Ground Services (Germany)	BRS Equipment
IER (Texas, France)	Bag Tag Printers
IdSystems (UK)	Printer Read/Write Module
Moore Research Corporation (New York)	Bag Tag Labels
Softlab	BRS Software
Texas Instruments (Texas)	RFID Inlays

4.3 Test Objective and Evaluation Criteria

The purpose of this phase of testing was to verify that RFID technology can be successfully introduced into an actual airport operational environment to perform the baggage identification, tracking and security functions. This phase of testing focused on the passenger check-in process, and the identification and tracking of baggage from check-in through tail-to-tail transfers.

The evaluation of the RFID system was based on the following criteria:

- Encoding Rate of Success. The encoding rate of success is a measure of the RFID system's capability to correctly encode and print the RFID bag tags. The encoding rate of success was based on the percentage of successfully encoded tags printed during the baggage check-in process

- Read Rate of Success. The read rate of success is a measure of the RFID system's capability to correctly read the RFID bag tags. The read rate of success was based on the percentage of successful tag reads during the baggage sortation and transfer process

- Operator Impact. The operator impact is a measure of any additional functions or operations that must be performed, or any additional time that must be spent performing the normal operations in order to accomplish RF baggage identification and tracking. The operator impact will be based on observations made by test personnel during the baggage check-in process and the baggage handling process

4.4 Test Descriptions

4.4.1 Test Procedures: San Antonio

Each test cycle began in San Antonio. The test involved tagging all passenger baggage for selected test flights. Initially only 10 flights going directly from San Antonio to Houston were to be used. However, after the test began this was expanded to include all Continental flights leaving San Antonio. The check-in counters are shared by America West in addition to Continental . Since these flights were intermingled with the Continental flights the America West baggage was also tagged.

1) Passenger Check-In Stations

The thirteen modified bag tag printers (that enable the printing and encoding of RFID bag tags) were installed and checked at the Continental San Antonio check-in counters as well as in the curbside check-in kiosks prior to the start of testing. The designated FAA test personnel loaded each printer with RFID bag tag stock. The test tags were color-coded to indicate the bag tag paper/RFID inlay combination that was being used; thus there were four different colors used over the entire test period. At the time of loading, the test personnel recorded the printer location, the bag tag type (color), the date and time that it was loaded, and the first barcode number printed on the loaded roll. Airline personnel checked in passengers in the normal manner, and tagged their baggage with the RFID bag tags.

If the printer failed to encode the RFID bag tag for any reason, it printed "RF VOID" in large block letters on the tag. The printer automatically reissued the tag. The failed tags were collected by test personnel. On the back of each failed tag, the test personnel recorded the following information:

- Printer Station
- Time and date
- Brief description of failure (circumstances, etc.)

Test personnel observed the baggage check-in process, and recorded the following information:

- Total number of RFID bag tags issued and affixed to bags not placed on the conveyor belt because of oversize baggage, animal cages, re-booked flights, etc.
- Description of errors encountered in printing RFID bag tags
- Description of difficulties encountered in operating the modified printers
- Description of difficulties encountered by airline personnel in performing the normal baggage check-in process
- Description of any other conditions, anomalies, or mishaps related to the use of the test system that affected the check-in process

2) Baggage Make-Up Room

Prior to the start of the test period, the belt reader and its Vendor Data Collection PC were installed and checked out on the conveyor belt leading into the baggage make-up room as shown in Figure 4.1. In addition, a handheld reader and its Vendor Data Collection PC were set up and checked out.

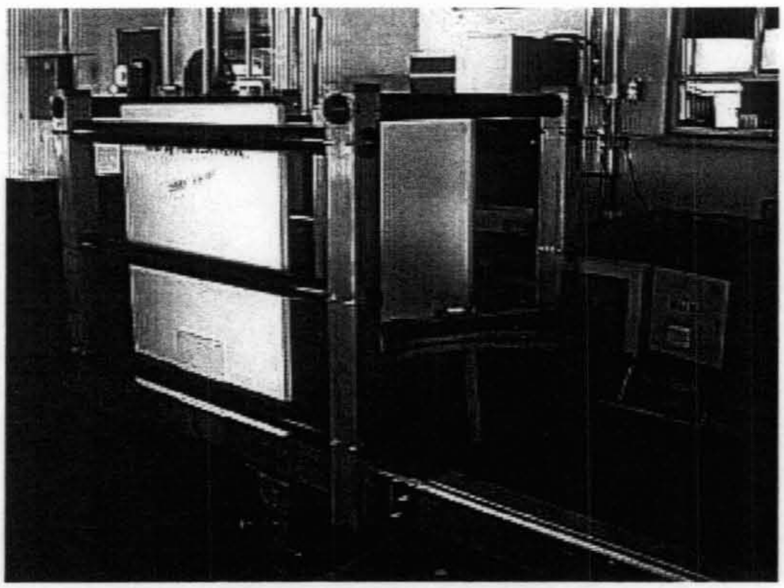

Figure 4.1 Delivery Belt with Belt Reader

As passenger baggage arrived in the baggage make-up room on the conveyor belt, it passed through the antenna panels of the belt reader. The reader automatically read the 10-digit license plate number from the RFID bag tags on the bags. The VDC connected to the belt reader recorded the license plate number and a time stamp for each RFID bag tag that was read. Test personnel recorded a manual count of the total number of RFID bag tags that passed through the belt reader.

After the test bags had passed through the belt reader, their RFID bag tags were read again by test personnel using a handheld reader. If the first read attempt was unsuccessful (i.e., the handheld reader did not register a read), a second attempt was made to read the RFID bag tag. If the second attempt was also unsuccessful, the bag was allowed to continue through its normal processing by airline personnel, and the bar code number of the tag was recorded manually as an

unsuccessful read. The VDC, connected to the handheld reader, recorded the 10-digit license plate number and a time stamp for each RFID bag tag read. After each RFID bag tag was read with the handheld reader, airline personnel processed it as usual.

As the test was being conducted, test personnel recorded the circumstances of any read errors or of any failed attempt to read a tag. They also recorded any incidences or impact to the baggage make-up process from use of the RFID system. After the baggage make-up process had been completed for the given test flight, the RFID bag tag data from both VDCs was downloaded and stored for later analysis.

3) Departure Aircraft Ramp

Before the test began, a mobile belt loader was fitted with a ramp reader and a connected VDC as shown in Figure 4.2. This system was checked out prior to the beginning of the tests to ensure that it operated correctly.

Figure 4.2 Belt Loader with Ramp Reader at Departure Aircraft Ramp, San Antonio

The passenger baggage with RFID bag tags was transported to the departure ramp, and loaded as normal onto the moving belt. As the bags moved past the antenna panels of the ramp reader, the ramp reader automatically read the RFID bag tags. The VDC recorded the 10-digit license plate number for each tag that was successfully read, along with a time stamp.

Test personnel monitored the baggage loading process, and recorded a manual count of the total number of RFID bag tags that passed through the ramp reader. They also recorded any impact to the baggage loading process that occurred due to the use of the RFID system, as well as any problem encountered with ramp reader or VDC operation. After the baggage loading was completed, the RFID bag tag data from the VDC was downloaded and stored for post-test analysis.

4.4.2 Test Procedures: Houston

After each test flight completed its loading process in San Antonio, it flew to Houston where the second test team awaited its arrival. The San Antonio test team communicated by phone with the Houston test team whenever any test procedures had to be changed from the normal pattern, so that the Houston test team could adjust their plans accordingly.

Prior to the arrival of each test flight from San Antonio, the Houston test team coordinated with Continental baggage handling personnel to determine: a) the number of the arrival gate, b) the three connecting flights departing from Houston which had the largest loads of test bags, and c) the departure gates of the three top connecting flights. This allowed the positioning of the test team members to read arrival and departure RFID bag tags.

1) Arrival Aircraft Ramp

Before the start of testing, a ramp reader and connected VDC, similar to the system used at the departure ramp in San Antonio, was mounted on a mobile belt loader in Houston. This configuration is depicted in Figure 4.3. A picture of the system in operation at the arrival ramp in Houston is shown in Figure 4.4. This system was checked out prior to the start of testing to ensure that it was working correctly. Continental personnel were assigned to drive the loader to the appropriate arrival ramp in preparation for each arriving flight.

When the test flight from San Antonio arrived in Houston, the loader was used to unload baggage from the aircraft. Baggage handling personnel processed the baggage in the normal manner. As the test bags moved out of the aircraft and down the belt, the ramp reader automatically read the RFID bag tags. The connected VDC recorded the 10-digit license plate number and a time stamp for each tag that was read.

Test personnel monitoring the unloading process recorded a manual count of the total number of test bags that passed through the reader. They also recorded the details of any problems encountered with the operation of the ramp reader or the VDC, as well as any impact on the usual baggage handling process that occurred due to the use of the RFID system.

After all baggage had been unloaded from the arrival aircraft, test personnel downloaded the RFID bag tag data from the VDC for later analysis.

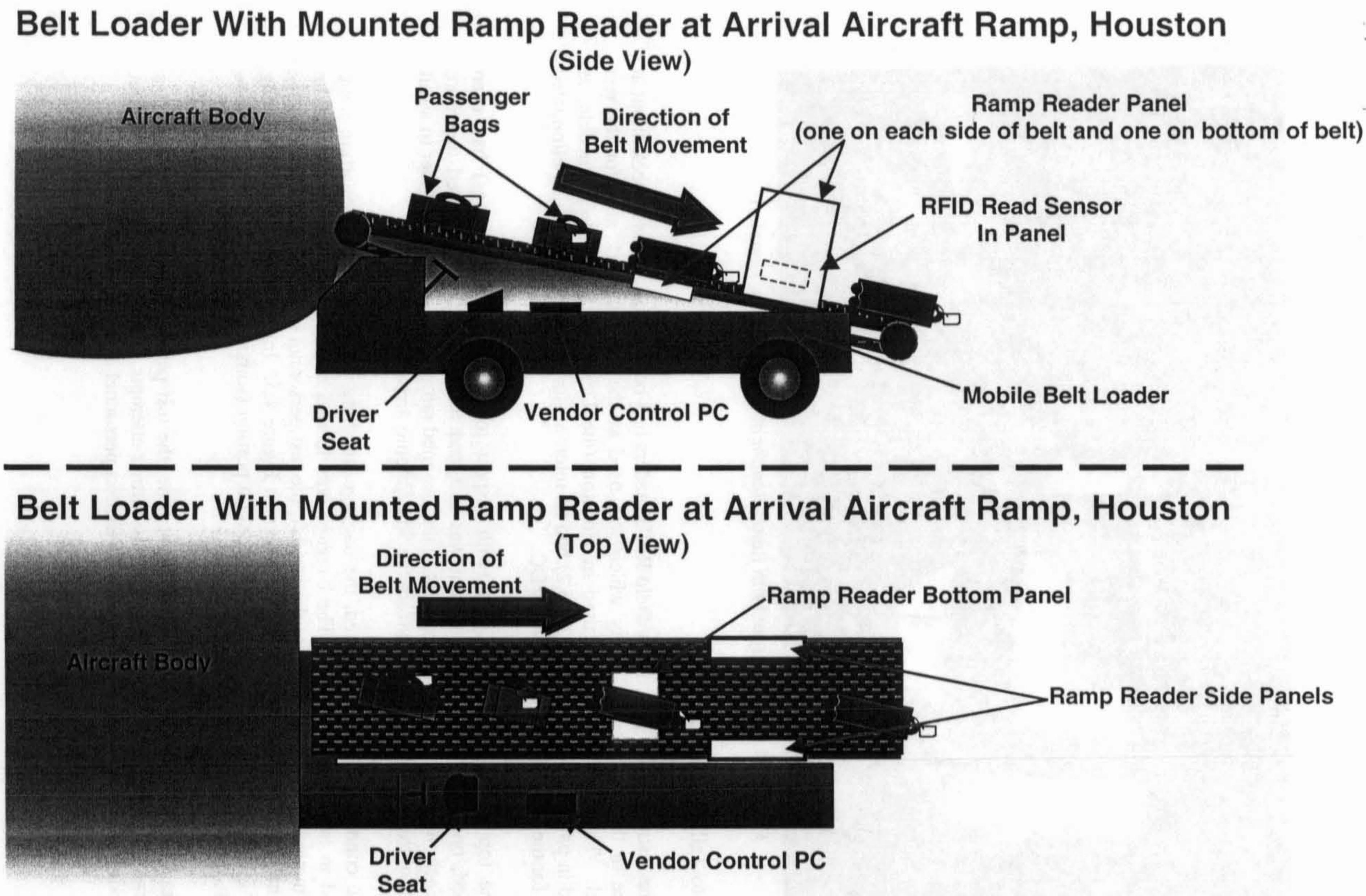

Figure 4.3 Belt Loader Configured with Ramp Reader at Arrival Ramp, Houston

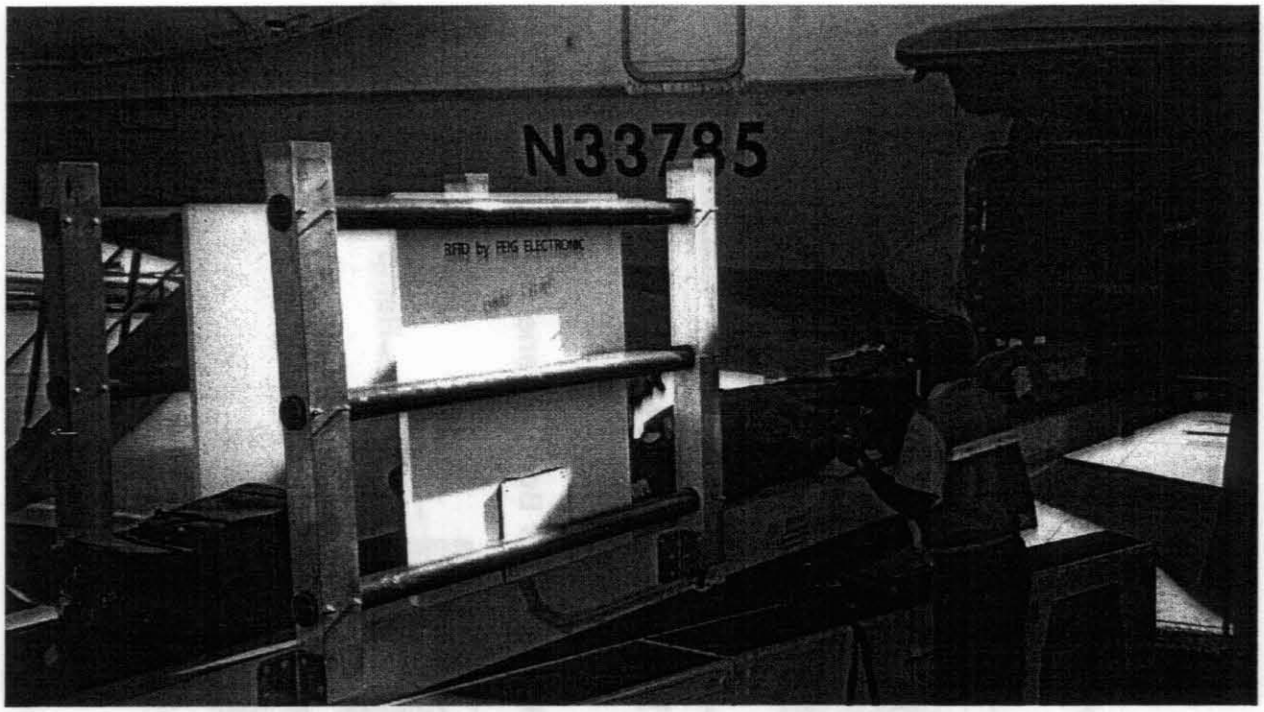

Figure 4.4 Belt Loader With Ramp Reader at Arrival Ramp, Houston

2) Tail-to-Tail Transfer Ramps

Before the testing period started, handheld RFID readers had been initialized and checked out at the office in the Continental facility which was used as the general work area for the test personnel. The handheld readers used in Houston (the Dexter and the Tracer models, as described in paragraphs 3.2.5.1 and 3.2.5.2) had an internal storage capability, which eliminated the need for the direct connection to the VDC.

When the top three connecting flights (with respect to the loads of test bags) had been determined, one member of the test team was assigned to each of the designated departure ramps. Each member of the test team went to the assigned ramp with a handheld reader to await the arrival of the connecting baggage from the San Antonio arrival flight.

When the connecting baggage arrived, the baggage handling process at each departure ramp proceeded in the normal manner. The baggage was loaded onto the belt loader, and as the baggage moved up the ramp and into the aircraft, the test personnel scanned the RFID bag tags with the handheld reader. This process is shown in Figure 4.5. In the cases of the connecting flights, the bags bearing RFID bag tags were only a portion (sometimes a small portion) of the baggage loaded onto the flight.

If a test tag failed to read successfully the first time, the test personnel attempted to read it a second time. In the event of a second failure, no further attempts were made to read the tag, but the bar code number was recorded manually by the test personnel as a read failure.

The handheld readers stored the 10-digit license plate number and a time stamp for each RFID bag tag read. The test personnel recorded the total number of RFID bag tags that were loaded onto the connecting flight, and the number of the bags for which no read could be made. Test personnel also recorded any impact to the baggage handling process resulting from the use of the handheld readers, and any problems encountered with the operation of the readers.

Once the baggage loading process had been completed, the test personnel downloaded the flight data from the handheld reader to the VDC (which remained in the general work area at Houston). At the end of the final day of testing, all data from the VDC was downloaded and stored by the test team for later analysis.

4.5 Data Collection and Analysis Methods

Data collection was done at a number of different points in the testing, using several different methods. This was done to obtain as much backup data as possible, since it was acknowledged that there were some points at which the data collection could have encountered problems. The following methods were used to collect data:

Figure 4.5 Reading Baggage with Handheld Reader at Tail-to-Tail Transfer – Departure Ramp, Houston

At check-in stations (San Antonio).

- Manual logs — At each loading of the printer with tag stock, test personnel recorded: 1) time and date of loading, 2) printer identification number, 3) color of tag stock, and 4) barcode number of the first tag from the loaded roll.

- Printer configuration tag — Each printer can generate this piece of information that indicates the total number of RFID tags issued by that printer.

In baggage make-up room (San Antonio).

- Belt reader — For each tag read, the following information was recorded: 1) the 10-digit license plate number, 2) the time and date that the tag was read, and 3) an internal tag ID which indicates whether the tag contained a Philips or a TI inlay.

- Handheld reader — For each tag read, the following information was recorded: 1) the 10-digit license plate number, and 2) the time and date that the tag was read.

- Manual tag counts — Test personnel manually counted the number of RFID bag tags being processed by the belt reader.

At the aircraft departure ramp (San Antonio) and the aircraft arrival ramp (Houston).

- Ramp reader — For each tag read, the following information was recorded: 1) the 10-digit license plate number, 2) the time and date that the tag was read, and 3) an internal tag ID which indicates whether the tag contained a Philips or a TI inlay.

- Handheld reader (Houston only) — Test personnel in Houston used a handheld reader to read RFID bag tags unloaded from any aircraft bin other than the one being covered by the mobile ramp reader. The data recorded was: 1) the 10-digit license plate number, and 2) the time and date that the tag was read.

- Manual tag counts — Test personnel manually counted the number of RFID bag tags being processed by the ramp reader.

At the tail-to-tail transfer departure ramp (Houston).

- Handheld reader — For each tag read, the following information was recorded: 1) the 10-digit license plate number, and 2) the time and date that the tag was read.

Continental's internal baggage management system.

- Baggage Reconciliation System — For each tag issued, a BSM was sent to the BRS, which included the following information: 1) the 10-digit license plate number, 2) the time and date of issue, and 3) the ID number of the printer which issued the tag.

Analysis of the data was performed based on each point in the trials at which RFID tags could be encoded or read. For these trials, the encode or read points in San Antonio include the RFID bag tag printers, the belt reader, the baggage room handheld reader, and the departure ramp reader. In Houston they include the arrival ramp reader, the arrival ramp handheld reader, and the departure ramp handheld reader. For each encode or read point the corresponding combined encode or read rates of success for all RFID bag tags were calculated based on the number of RFID bag tags successfully encoded or read versus the total number of RFID bag tag read or encode attempts at that point. Encode or read rates of success for each encode or read point were also calculated according to bag tag paper/RFID inlay combination.

Finally, an RFID failure analysis was performed to determine the types of RFID bag tag failures by bag tag paper/RFID inlay combination. In addition to the encode/read rates of success and the RFID failure analysis, the daily read rates for each of the three belt readers was plotted. This includes; 1) the belt reader and 2) the ramp reader in San Antonio, and 3) the ramp reader in Houston.

Paragraph 5 discusses test problems and anomalies, including the failure of any equipment during the trial. In all cases where equipment failed during the test, physical counts were recorded of the RFID tags missed by the failed equipment. These numbers were then eliminated from the final analysis and not counted as no-read data.

5 TEST PROBLEMS AND ANOMALIES

Baggage Reconciliation System

Originally the test plan called for use of a Baggage Reconciliation System (BRS) in San Antonio. San Antonio currently does not have a BRS system. A PC running BRS software provided by Flughafen Frankfurt am Main Aviation Ground Services (FAG) and Softlab was to be connected to the belt reader in the make-up room and to an existing BRS in Houston via a LAN line installed by Continental. However the LAN line and associated equipment could not be installed in time for this trial. Therefore the BRS testing was eliminated. However, it was still important to the test to obtain BRS data to provide a complete record of all RFID bag tags issued. This required a change in the Houston BRS system to accept Baggage Source Message (BSM) data for all Continental Flights leaving San Antonio. Continental personnel made this change prior to the start of the trial. The BSM contains bag tag data including the 10-digit barcode number, date, time, flight information, and the ID of the printer that issued the tag. This data was to be used in the final data analysis to set up a master database. Although several attempts were made to obtain the BSM data on a daily basis, the BSM data could not be obtained from Continental until after the conclusion of the trial. It was then found that much of the data was corrupt or incomplete. Apparently during the nine-day testing period, Continental experienced some system problems with the BRS, and BRS data was lost. Again, it was necessary to have a complete record of all RFID bag tags issued. The preferable method was to have been through the BRS data. Prior to the start of the trial, a contingency plan had been developed in case there was a problem with the BRS system. This plan involved using the data collected by the handheld readers to generate the master database. Therefore, although it was intended that the BRS data was to play a key roll in this trial, the failure of the BRS to provide accurate data was fully accounted for in the final analysis and the read rates reflect the actual reader performance.

Printers

The modified bag tag printers were installed prior to the start of the trial. Upon initial testing it was found that the printers did not function properly. A bag tag can have several segments depending on how many connecting flights a passenger has before reaching the final destination. The modified firmware in the printers was tested using a canned data stream from a 4-segment trip. When the printers were tested by IER prior to shipment to San Antonio they functioned properly using this canned data stream. The data stream actually contained the barcode information in two locations for each bag tag. One location was always the same. The second location changed depending on the number of segments in the total trip that the bag would traverse. For example, the second location for the barcode information would be in a different spot for a two-segment trip than it would be for a three-segment trip, while the first location was the same for both. The existence of the first (unchanging) location was not recognized during the initial printer testing, and the second (changing) location of the barcode data was actually being read. Because the testing was always done on a four-segment tag, the position of this data appeared to be unchanging. The firmware was setup to read the barcode from the second location (which was only valid for a four-segment tag). Once the testing started and problems arose, a closer examination of the data stream revealed the presence of the unchanging barcode data location. A change was made in the printer firmware correcting the problem prior to the start of the trial.

Printer Stock

The original test procedure was to test one paper/inlay type at a time. It was determined after the start of the trial that this procedure would increase the length of the trial beyond what was originally planned. It was decided by the FAA test team that once a printer ran out of one type of stock it would immediately be replaced with the next type, instead of waiting for all the printers to run out of a particular type of stock. The number of individual tags per type would then be determined by physically counting the tags at each reader location. A miscommunication resulted in the change to this procedure before the entire test team could be informed. This resulted in a group of 241 tags being processed through the reader points without a physical count. Although these tags were included in the overall results, they could not be included in the results presented by stock/inlay type. Therefore, the total number of tags shown in the results presented by stock/inlay type differs from the overall total.

Belt Reader (San Antonio)

The belt reader in the make-up room stopped functioning after the initial set-up and test on the fourth day of the test (9/25/99). The software application controlling the reader was stopped and the computer was rebooted after which it functioned normally. This caused the reader to miss the first 173 RFID tags.

Handheld Reader (San Antonio)

One of the Vendor Data Collection PCs failed on the seventh test day (9/28/99) in San Antonio. This was the VDC that was recording the data from the handheld reader in the baggage make-up room. The VDC was quickly replaced by the FAA Control Interface (CI), which required some reprogramming of the CI software. During the one-hour transition period, some RFID bag tags went unread by the handheld reader.

The handheld reader in the make-up room in San Antonio stopped functioning on the fifth test day (9/26/99). It was immediately replaced with a backup handheld and no bags were missed.

Ramp Reader (Houston)

On the fourth test day (9/25/99), one of the Vendor Data Collection PCs in Houston failed. This was the VDC that interfaced to the ramp reader being used for the arrival flights. It failed during the first arrival flight of the day, resulting in no record of the tags read for that arrival. It was discovered that the VDC battery was not recharging properly. The battery was supposed to be recharging via its connection to the belt loader. Once the problem was identified, the test personnel responsible for arrivals removed the battery from the VDC and recharged it in the Houston site general work area prior to each arrival flight. The VDC was turned on only shortly before each arrival flight pulled into the designated gate, and the arrival personnel ran a quick test using sample test tags to ensure that the VDC was indeed operating correctly. As soon as the last arrival RFID bag tag had been read, the VDC was turned off to conserve the battery charge. When this procedure was followed, no further problems with this VDC were encountered. The problem resulted in the loss of data for two arrival flights on this day.

Hand Held Readers (Houston)

Some minor problems with the handheld readers were experienced at the Houston test site. The readers that were used in Houston were the Dexter and the Tracer models. As these readers successfully read RFID bag tags, a small diode changed color to provide a visual indication of success. The display showed a cumulative count of how many tags (records) had been read.

With some regularity, when the data from these handhelds was downloaded to the VDC after a flight, the handheld would fail to download one of the records. For example, if 38 tags had been read (as indicated by the display, and confirmed by the manual count taken by the test personnel), the reader might only be able to download 37 to the VDC. On rarer occasions, a reader would fail to download two or three of the records it had accumulated. This was an intermittent problem. No solution was found for it during the testing period.

6 RESULTS AND CONCLUSIONS

The test results are presented in Tables 6.1, 6.2, and 6.3. Table 6.1 shows the overall results for each encode and read point. Table 6.2 shows the results for each encode and read point broken down by inlay/paper type. An attempt was made to read each "RF Void" tag after the test to determine if the RFID inlay failed or if the inlay was still good but not programmed. Table 6.3 presents a detailed analysis of these results. No pass/fail criteria were set for the Operational Test. This section presents the results and it is left to the reader to decide whether these results are acceptable for a particular application.

The printers issued a total of 10,050 RFID tags. This number was derived from the master database created from the handheld reader in San Antonio. As stated in paragraph 5, originally the plan was to use the data from the BRS to create the master database. Due to the failure of the BRS to provide accurate data, a contingency plan was used. Every RFID tag that was sent to the make-up room in San Antonio was accounted for at the handheld reader station. The tag was read by the handheld reader and accounted for in the handheld reader database. If the tag could not be read, this was documented in a manual log. The combination of the handheld reader database and the manual log was used to create the master database. The total number of tags accounted for at the handheld reader station was 9,707. The printers generated a total of 141 RF Voids and the check-in agents voided 202 RFID tags. The sum of these numbers (9,707 + 141 + 202) yields a total of 10,050 RFID tags issued.

Printers

The data for the printers presented in Table 6.1 shows an overall success rate of 98.6%. The RF Voids consisted of 141 tags out of a total of 10,050 tested. Table 6.2 indicates that a majority of the RF Voids contained the Philips inlay. The detailed analysis of the RF Voids shown in Table 6.3 indicates that the majority of the RF Voids (97 out of 141) were due to failed Philips inlays. This was consistent for both Sihl and Moore paper types. This is similar to the results for the Phase IIA Frankfurt trial. Although different printers and paper types were used in Frankfurt the majority of the RF Voids were also due to failed Philips inlays. The next largest number of RF Voids (0.13%) was due to the absence of an inlay in the tag, which only occurred in the Moore paper bag tag type and was consistent for both the Philips and TI inlays. As the results of these tests were being documented, Moore revealed that they intentionally did not insert an RFID tag into the leading and trailing label in the roll; this was not communicated to the test team prior to the tests. This explains the counting of these RF Voids which were intentional non-RF tags. The third group of failures (18 out of 141) actually read as valid tags when they were tested with the handheld reader. They were programmed with valid barcode numbers. The printer encoding process is a two-step process of encoding, then verifying. It seems that the encoding process succeeded; however, the verifying process failed. This occurred for 17 tags with a Philips inlay and 1 tag with a TI inlay. The final group of failures (3 out of 141) was due to the tag not being programmed. When tested with the handheld reader the default value of the tag was read, which indicates that the inlay was functioning. This failure type accounted for only 3 tags.

Belt Reader (SAT)

The first read point for the RFID tags was by a belt reader in the baggage make-up room in San Antonio. After the installation and prior to the start of the test, the FEIG engineer tuned the belt reader to achieve optimum performance. Attempts were also made during the first few days of the trial to re-tune (tweak) the belt reader to optimize performance. In a final system, any manual tuning would have to be replaced with some type of self-tuning feature. The data for the belt reader in Table 6.1 shows an overall read rate of 92.39%. The overall rate for the individual inlay/paper types shown in Table 6.2 ranged from 89.00 to 98.70%. The Moore/Philips combination performed the best at 98.70% and the Moore/TI combination performed the worst at 89.00%.

The actual paper type should have had little effect on the readability of the tag once the printer correctly encoded a tag. The read rates should therefore be examined by inlay type. The belt reader and ramp reader should have allowed for equal performance of both the Philips and TI inlays since they were designed to read either inlay type. However, for the belt reader the overall read rate for the Philips inlay was 95.52% and 89.66% for the TI inlay.

Figure 6.1 shows the read rate performance by day for both the Philips and TI inlays. Figure 6.1 also shows the total number of tags tested each day. This must be taken into account when comparing daily results. The results indicate inconsistent performance of the belt reader for both the Philips and TI inlays throughout the trial.

During the first few days of testing the FEIG engineer was monitoring the reader equipment for possible sources of outside interference. There was concern that any interference could degrade performance of the system. The performance of the reader was suspect during the third day of the trial (9/24/99). The engineer from FEIG initially suspected that it might be interference from the RF Test Set that was used to measure background interference. The RF Test Set was shut down and the reader problems continued. Therefore the RF Test Set was eliminated as the source of the interference. It was then suspected that noise on the power line to the reader might have been causing interference. That evening after the testing was completed, a power line filter was installed. After the installation of the line filter the performance of the belt reader did improve for the Philips inlays. However, the performance for the TI inlays actually degraded.

The reader was designed to read a bag in almost any orientation that passed through the antenna panels, assuming the reader was tuned for optimum performance and the RFID tag was working properly. There was only about a 30-foot section of belt between the check-in area and the make-up room. It is very unlikely that an RFID tag that was properly encoded by a printer in the check-in area failed on its way to the make-up room. The section of belt where the reader was placed was the final section of belt in the make-up room. This belt moved intermittently when a new bag coming from the check-in area tripped a visual sensor or when the baggage handler stepped on a switch. The speed of the belt, when it was moving, was 0.42 m/s. The reader system was designed to continue reading an RFID tag as long as it is within the antenna field. The reader would have had multiple opportunities to read an individual RFID tag because of the slow speed of the belt and the fact that it was often stationary.

Handheld Reader (SAT)

The second read point for the RFID tags was with a handheld reader. During the original planning for this trial, the requirement for the handheld reader was that it be capable of reading at a maximum distance of 6 inches. The initial response from Confidence International (System Integrator) was that they would be able to provide a handheld reader that met this requirement. Therefore, the read distance requirement of 6 inches was documented and put into the Qualification Test requirements. Shortly before the Qualification Test was to begin it was learned that Symbol Technologies, the vendor agreeing to supply the handheld reader, could not meet the technical and delivery date requirements. Confidence International quickly found an alternate source (Microlise). Although the time schedule could be met, the technical requirement for a read distance of 6 inches could not be met in that timeframe. During Qualification Testing it was shown that the handhelds could read reliably at a read distance of 3 inches. Therefore, the requirement for 6 inches was waived and the handhelds were allowed to be used in Operational Testing.

Designated personnel from the FAA test team operated the handheld readers. During the Operational Test there was a learning curve required to use the handheld reader. At first, the handheld was held at approximately 3 inches from the RFID tag. However, this did not seem to provide a reliable read. The positioning of the bags and RFID tags made it difficult to determine the position of the inlay in the tag. Often the bags continued to move along the belt and required a quick read. After the 3-inch range did not produce reliable results, the tags were read by placing the handheld reader directly on the tag (contact). The positioning of the bags and RFID tags again made it difficult to determine the position of the inlay in the tag. It was found that the approach that provided the most reliable read rate was when the handheld reader was placed directly on the tag then swept across the surface of the tag. On occasion attempts were made to read tags with the handheld reader while the tag was flat on the belt. In all cases the tag could be read, therefore, none of the no-read handheld data was a result of the tag being flat on the belt. The overall read rate for the handheld reader in San Antonio was 98.99%.

This method provided a good read rate. However, one of the expected benefits of using an RFID versus a barcode reader system is that the RFID reader should be able to read the tag without seeing a specific portion of the tag, and without having to reorient the bag or tag. This would, of course, only be the case if the RFID reader had the appropriate read range. This benefit is eliminated when the read range is as limited as it was in this test.

Ramp Reader (SAT)

The third read point for the RFID tags was with a ramp reader in San Antonio. After the installation and prior to the start of the test, the ramp reader was tuned to achieve optimum performance. Attempts were also made during the first few days of the trial to re-tune (tweak) the reader to optimize performance. The data for the ramp reader in Table 6.1 shows an overall read rate of 86.40%. The overall rate for the individual inlay/paper types shown in Table 6.2 ranged from 71.49% to 94.15%. The Sihl/Philips combination performed the best at 94.15% and the Moore/TI combination performed the worst at 71.49%. Since paper type has no effect on read rate, when the results are compared by inlay only, it can be seen that the overall read rate for the Philips inlay was 92.50% and 76.50% for the TI inlay.

Figure 6.2 shows the ramp reader read rate performance by day for both the Philips and TI inlays. Figure 6.2 also shows the total number of tags tested each day. This must be taken into account when comparing daily results. As with the belt reader, the results indicate inconsistent performance for both the Philips and TI inlays throughout the trial.

Outside interference was also a concern for the ramp reader. The performance of the ramp reader was suspect during the fifth day of the trial (9/26/99). It was noted that the reader had stopped reading reliably. It was again suspected that noise on the power line to the reader might have been causing interference. Prior to the start of testing on the sixth day (9/27/99), a power line filter was installed. After the installation of the line filter, the performance of the ramp reader did improve for the Philips inlays. However, for the TI inlays, the performance actually degraded. Looking at Figure 6.2, it can be seen that the installation of the line filter had little effect.

The speed of the belt on the belt loader was 0.31 m/s. The way the reader system is designed, it continues to read an RFID tag as long as it is within the antenna field. Because of the slow speed of the belt, the ramp reader would have had multiple opportunities to read an individual RFID tag.

Several operational issues were noted during the test of the ramp reader. The first was that the vertical antenna panels read a tag not only across the belt, but also from the outside of the antenna panels. Sometimes a baggage handler would walk by one of the vertical antenna panels with a bag or actually temporarily store a bag near the outside of one of the panels. The system often read these bags. Sometimes these bags would never be placed on the aircraft. This caused a false read. A second issue was that the belt loaders are often used to load or remove cargo from the aircraft. For these tests, a different belt loader had to be brought in for cargo because the distance between the two vertical antenna panels would not allow the cargo to fit. There were also some problems with standard baggage. There were many times when the baggage jammed between the two antenna panels and the belt had to be stopped. The final design of any ramp reader would have to take these considerations into account.

Ramp Reader (IAH)

The fourth read point for the RFID tags was with the ramp reader in Houston. After the installation and prior to the start of the test, the ramp reader was tuned to achieve optimum performance. Attempts were also made during the first few days of the trial to re-tune (tweak) the reader to optimize performance. The data for the ramp reader in Table 6.1 shows an overall read rate of 94.75%. The overall rate for the individual inlay/paper types shown in Table 6.2 ranged from 88.64% to 98.51%. The Moore/Philips combination performed the best at 98.51%

and the Sihl/Philips combination performed the worst at 88.64%. Since paper type has no effect on read rate, when the results are compared by inlay only, it can be seen that the overall read rate for the Philips inlay was 92.64% and 97.44% for the TI inlay.

Figure 6.3 shows the read rate performance by day for both the Philips and TI inlays. Figure 6.3 also shows the total number of tags tested each day. This must be taken into account when comparing daily results. Although the ramp reader in Houston exhibited better performance than both the belt reader and ramp reader in San Antonio, the results still indicate inconsistent performance for both the Philips and TI inlays throughout the trial.

The speed of the belt was 0.31 m/s. As discussed in the SAT ramp reader results, the design of the reader system allows it to read an RFID tag as long as the tag is within the antenna field. Because of the slow speed of the belt, the reader would have had multiple opportunities to read an individual RFID tag.

The operational issues discussed for the ramp reader in San Antonio are also true for the ramp reader in Houston.

Handheld Reader (IAH Arrival)

The fifth read point for the RFID tags was with a handheld reader at the arrival ramp in Houston. The aircraft used during this test had either two or three compartments. For the arriving aircraft in Houston the ramp reader was placed at the compartment with the most baggage and a handheld reader was used at one of the other compartments.

Designated personnel from the FAA test team operated the handheld reader. As with the handheld reader in San Antonio, it was found that the approach that provided the most reliable read rate was that in which the handheld reader was placed directly on the tag, then swept across the surface of the tag. The overall read rate for the handheld reader used at arrival in Houston was 99.03%.

This method provided a good read rate. However, as with the handheld reader test in San Antonio, the limited read range of the handheld reader eliminated the potential benefit of using an RFID tag versus a Barcode tag; that benefit is the ability to read the tag without seeing a specific portion of the tag and without having to reorient the bag or tag.

Handheld Reader (IAH Departures)

The final point at which to read the RFID tags was during the Tail-to-Tail transfer operation in Houston. Connecting flights scheduled for the highest number of bags with RFID tags were selected. These bags were then read at the departing aircraft's loading ramp.

Designated personnel from the FAA test team operated the handheld readers. The same read procedure used with the other handheld readers was used here (placing the reader in contact with the tag, then sweeping the reader along the surface of the tag). The overall read rate for the handheld readers used in Houston during the tail-to-tail transfer operation was 95.34%.

This method provided a good read rate. However, as with the other handheld reader tests, the limited read range of the handheld readers eliminated the potential benefit associated with an RFID tag versus a Barcode tag — the ability to read the tag without seeing a specific portion of the tag and without having to reorient the bag or tag.

Table 6.1 Combined Results for each Encode and Read Point

PRINTER RESULTS (SAT)	
Total Valid RFID Tags Issued	10050
RF Voids *(Printer could not encode RFID Tag)*	141
Agent Voids *(Tags issued in error and never used)*	202
Encode Rate (%) *(1 - (RF Voids / Total RFID Tags Issued))*	98.60
HANDHELD READER RESULTS (SAT)	
Total RFID Tags Processed	9707
Total RFID Tags Read	9609
Read Rate (%) *(Read / Processed)*	98.99
BELT READER RESULTS (SAT)	
Total RFID Tags Processed	***(See Note 1)*** 9534
Total RFID Tags Read	8808
Read Rate (%) *(Read / Processed)*	92.39
RAMP READER RESULTS (SAT)	
Total RFID Tags Processed	5801
Total RFID Tags Read	5000
Read Rate (%) *(Read / Processed)*	86.19
RAMP READER RESULTS (IAH)	
Total RFID Tags Processed	3826
Total RFID Tags Read	3625
Read Rate (%) *(Read / Processed)*	94.75
HANDHELD READER RESULTS (IAH ARRIVAL)	
Total RFID Tags Processed	719
Total RFID Tags Read	712
Read Rate (%) *(Read / Processed)*	99.03
HANDHELD READER RESULTS (IAH DEPARTURE)	
Total RFID Tags Processed	1266
Total RFID Tags Read	1207
Read Rate (%) *(Read / Processed)*	95.34

Notes:
1. Belt Reader stopped functioning, computer was rebooted. Missed reading 173 RFID tags.

Table 6.2 Results for each Encode and Read Point by Inlay/Paper Type

Results by Inlay/Paper Type		SIHL		Moore	
		Philips	TI	Philips	TI
Printers (SAT)	Sent to Make-up Room	2127	2238	2765	2336
	RF Void	54	2	73	12
	Agent Void	32	41	61	68
	Encode Rate (%)	97.50	99.91	97.42	98.58
Belt Reader (SAT)	RFID Processed	2127	2238	2765	2336
	RFID Read	1944	2022	2729	2079
	Read Rate (%)	91.40	90.35	98.70	89.00
Handheld (SAT)	RFID Processed	2127	2238	2765	2336
	RFID Read	2111	2221	2746	2293
	Read Rate	99.25	99.24	99.31	98.16
Ramp Reader (SAT)	RFID Processed	1658	1089	1837	1217
	RFID Read	1561	894	1675	870
	Read Rate (%)	94.15	82.09	91.18	71.49
Ramp Reader (IAH)	RFID Processed	1276	451	870	1229
	RFID Read	1131	442	857	1195
	Read Rate (%)	88.64	98.00	98.51	97.23
Handheld Reader (IAH Arrivals)	RFID Processed	248	182	102	187
	RFID Read	245	180	101	186
	Read Rate (%)	98.79	98.90	99.02	99.47
Handheld Reader (IAH Departures)	RFID Processed	321	191	138	616
	RFID Read	309	181	138	579
	Read Rate (%)	96.26	94.76	100.00	93.99

Note: Due to a change in the test procedure that was not immediately communicated to all test personnel, 241 tags could not be identified as to the individual tag type. This accounts for the difference in the total number of tags processed by the readers in San Antonio shown in Tables 6.1 and 6.2.

Table 6.3 RF Void Analysis

FAILURE TYPE	Failures (Failure Rate)				
	SIHL/Philips	SIHL/TI	Moore/Philips	Moore/TI	Totals
Not Readable (Failed Inlay)	43 (1.94%)	0 (0%)	54 (1.86%)	0 (0%)	97
No Inlay	0 (0%)	0 (0%)	12 (0.41%)	11 (0.46%)	23
Readable (Reads a valid bar code number)	11 (0.5%)	1 (0.04%)	6 (0.21%)	0 (0%)	18
Not Programmed (Tag readable, reads default)	0 (0%)	1 (0.04%)	1 (0.03%)	1 (0.04%)	3
Total RF Void	54 (2.44%)	2 (0.09%)	73 (2.52%)	12 (0.5%)	141
Total RFID Tags Issued	2213	2281	2899	2416	

Note: Failure Rate based on total RFID tags issued for each paper inlay type:
Failure Rate = Total RF Void / Total RFID Tags Issued
Total RFID Tags Issued = Sent to Make-up + RF Void + Agent Void (See Table 6.2)

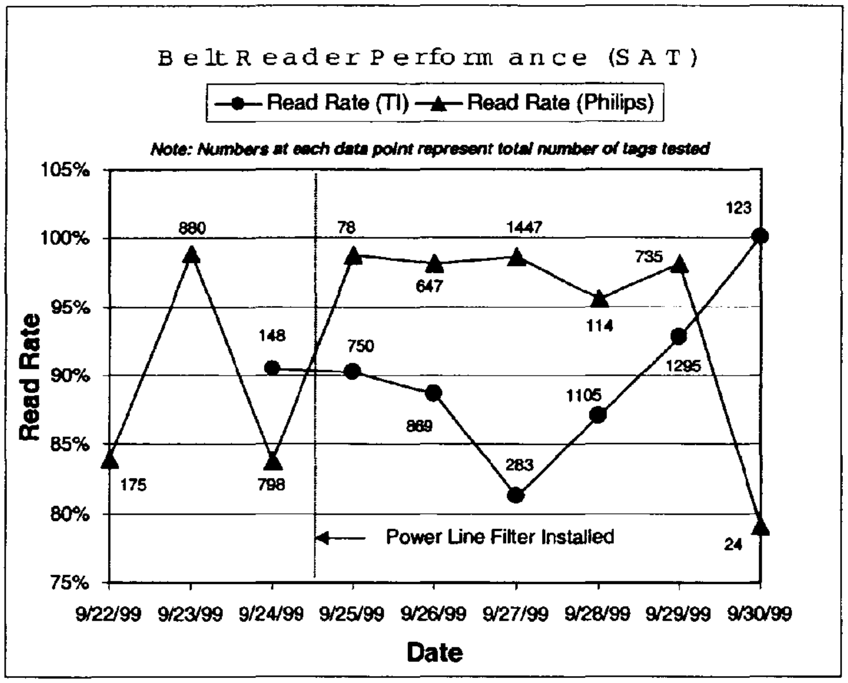

Figure 6.1 Daily Belt Reader Performance (SAT)

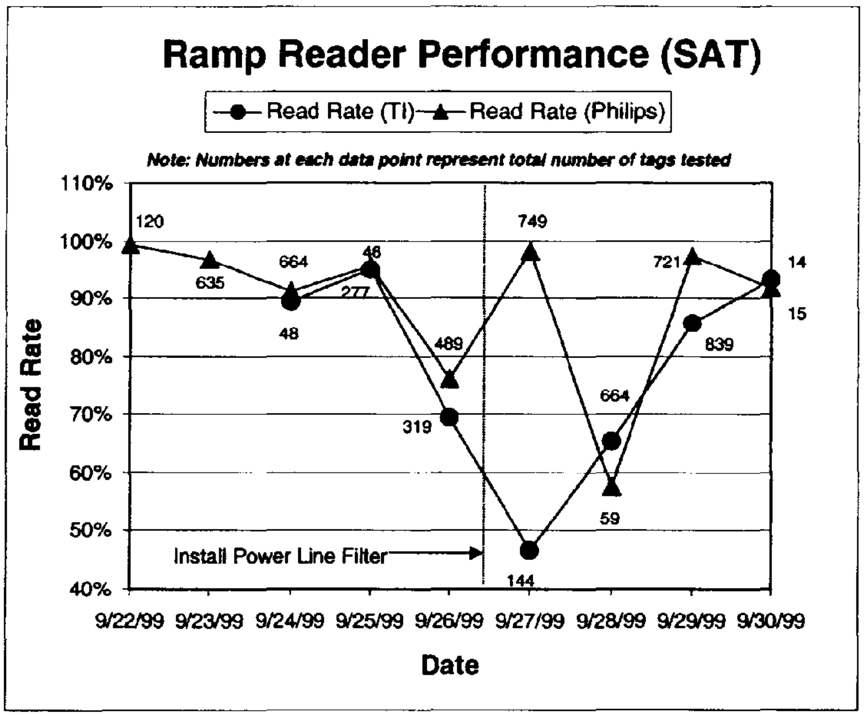

Figure 6.2 Daily Ramp Reader Performance (SAT)

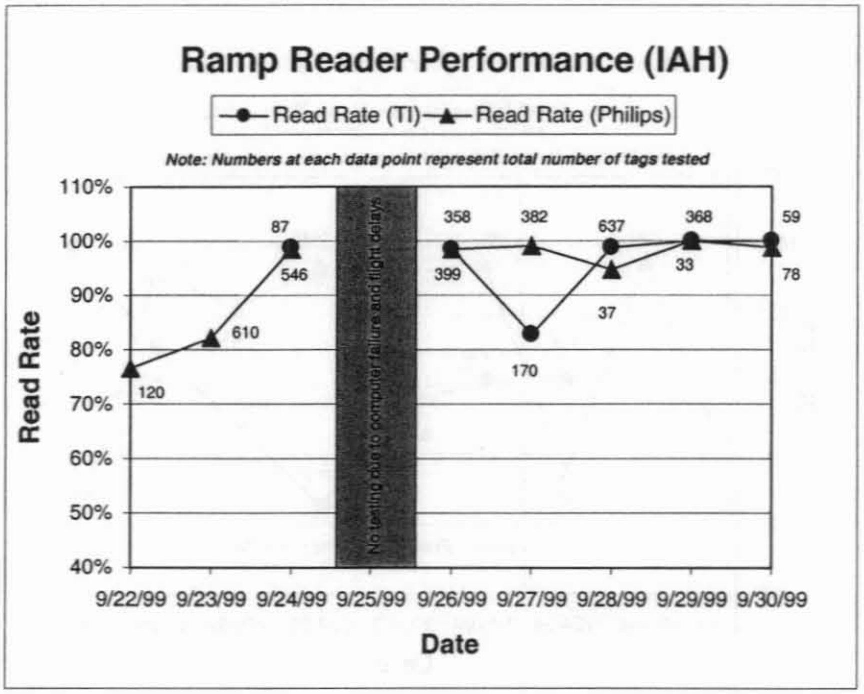

Figure 6.3 Daily Ramp Reader Performance (IAH)