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Federal Transit Administration

REGIONAL RAIL ONBOARD ELECTRONIC PAYMENT PROJECT

September 2009

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September 2009

Prepared by:
Gerald J Kane and Li Bai

FINAL REPORT
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13. ABSTRACT (Maximum 200 words) - The purpose of this project was to develop a non-proprietary, plug-and-play multi-modal transport payment application, (i.e. cash, credit card, passes, and contactless smartcard) portable solution. This project focused on the development of an open architecture and prototype design with a commercial-off-the-shelf (COTS) product for a handheld, contactless, smartcard-based unit for the mass transit and regional rail systems. The system was extended from Temple University's senior design project research efforts and SEPTA's in house backend database. The system has been demonstrated with effective applicability, usability and durability for today's transit systems.

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FOREWORD

This document presents methodology and process for developing a non-proprietary, contactless smartcard fare payment system for commuter rail service. This report's intended audiences are transit operators and planners responsible for fare payment and collection. The research project was a collaboration effort between Temple University and the Southeastern Pennsylvania Transportation Authority (SEPTA) to develop a portable solution. The project was funded by FTA through the I-95 Corridor Coalition and SEPTA during 2007-2008.

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PREFACE/ACKNOWLEDGEMENT

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EXECUTIVE SUMMARY

This report presents the findings of The Regional Rail On-board Electronic Payment Project, an investigation by SEPTA and Temple University that tested the feasibility of conducting electronic fare payment on commuter rail service using a system of hand held devices that communicate with contactless smart cards. The research project extended Temple University's senior design project research efforts and SEPTA's in house backend database improvement. Research included development of an application in which a Personal Digital Assistant (PDA) device was programmed to record cash fare transactions on board vehicles, store the transaction data, and wirelessly upload the data to a server. Despite various contactless smartcard payment systems being successfully deployed in many large US metropolitan areas, there are virtually no non-proprietary contactless smartcard systems. Thus, this project focused on developing an open architecture design with commercial-off-the-shelf (COTS) products and a Java software application to increase flexibility and decrease the cost of implementation. The project serves as a strategy to modernize the SEPTA fare collection system. The project identified several COTS products for consideration in fare collection applications using

smartcard technology, focusing mainly on interfacing with the MiFare card standard from NXP. The system has been demonstrated with effective applicability, usability and durability for today's transit system.

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1. INTRODUCTION

This report presents the findings of The Regional Rail On-board Electronic Payment Project, an investigation that tested the feasibility of conducting electronic fare payment on commuter rail service using a system of hand held devices that communicate with contactless smart cards. The project relied upon open source software and commercial off-the-shelf equipment to capture fare payment transactions, store the information, and download the information to a central database.

Since the early 1990's, many transit agencies in North America and throughout the world have invested significantly in electronic fare payment systems based on contactless technology. Investment benefits have included increased customer service, faster payment transaction speed, improved data collection, and higher fare revenues. Today, most of the large transit operators in the United States have deployed modern fare payment systems based on radio frequency identification (RFID) technology, in which an integrated circuit chip (ICC) embedded in plastic cards, communicates payment transactions with electronic readers located on vehicles and in stations. This RFID technology allows "contactless" payment, that is, riders simply wave or tap a valid card against a farebox or turnstile equipped with a reader for fare payment. Contactless payment is well suited to large systems due to transit requirements for high through-put, security, and lower equipment maintenance costs.

Applications of the contactless technology to commuter rail service, however, have lagged bus and rapid transit modes, due primarily to significant challenges of fare payment requirements associated with railroad operations. Currently, there are no examples of commuter rail contactless fare payment systems in the United States; it is within this context that the current study was undertaken.

This final report presents the findings of the project and describes processes used to automate commuter rail fare payment procedures. The project built upon earlier research and testing conducted in 2005, in which Temple University and the Southeastern Pennsylvania Transportation Authority (SEPTA) collaborated on a payment system to automate an on-board cash fare transactions project. The project developed an application in which a Personal Digital Assistant (PDA) device was programmed to record cash fare transactions on board vehicles, store the transaction data, and wirelessly upload the data to a server. The success of this earlier project led to the investigation at hand - to build upon the cash transaction procedure and determine the feasibility of designing and incorporating contactless smartcard interfaces in a commuter rail environment.

Virtually all commuter rail operators, including SEPTA, follow similar procedures and practices for payment and collection of passenger fare revenue. While electronic payment and automation are commonplace for rapid transit modes, commuter rail relies primarily on paper tickets, hand punched by conductors, in combination with visual inspection of multi-ride passes - weekly and monthly unlimited ride fare media. Consequently, this causes the inherent weakness in revenue accountability, ridership counting, and management oversight of revenue and ridership data. Briefly, commuter rail passengers board vehicles first and then are requested to present a pass, ticket, or pay with cash. Conductors carry only a hand punch and do not have electronic equipment to validate magnetic or other electronic fare media. Whereas, bus and rapid rail transit capture revenue and ridership data upon passenger entry at the farebox or turnstile, commuter rail operates an "open" system, which allows passenger boarding prior to fare payment. Cash fares paid on-board are collected by conductors who issue change and provide a duplicate Cash Fare Receipt to the passenger; the conductor remits all cash and paper receipts at the end of the day and manually completes a cash fare report. All data from the reports are manually entered into computer terminals. In view of continuing advancements in information technology and telecommunications, regional rail fare payment is overdue for innovation and process improvement.

1.1 Project Goals

At the outset, the project team formulated four goals to accomplish by the project's completion, as follows:

- **I Identify and Define Hardware Requirements for a Portable Contactless Payment System**
- **II Define the System Interface between the Contactless Smart Cards and Hardware**
- **III Develop the Concept of Operations**
- **IV Conduct Pilot Test**

Each of the above goals served as the basis for project work tasks and the report is organized around each task.

Despite various contactless smartcard payment systems being successfully deployed in many large US metropolitan areas such as Boston's Charlie card, Atlanta's Breeze card and PATCO's Freedom card, there are virtually no non-propriety contactless smartcard systems. These proprietary systems commonly require millions of dollars to be deployed and additional money if the transit agencies require modifications from the vendors. The costly proprietary solutions also cause transit agency executives to hesitate committing to a solution with fear that they might be buying today's solution with "yesterday's" technology, or exposing the agency to the consequences of faulty functionalities built into the system. To address this problem, we proposed an open architecture developed in Java and integrated with COTS components with plug-and-play capability. The research would allow many vendors to provide products with open access to the architecture allowing transit agencies to seek suitable, lower cost solutions with plug-and-play functionality

This system took the foundation of the previous on board portable unit developed at Temple University [8] and expanded it to include contactless smartcard media. A self-contained contactless smartcard reader/writer unit has been interfaced with the PDA via an SD-interface. A streamlined PDA GUI will also be developed to reduce the learning curve for the conductors and increase transaction efficiency.

2. CONTACTLESS SMARTCARD OVERVIEW

Smartcard systems have been around for many years. They were used mainly to secure physical access to corporate facilities. The advantages of the contacted smart cards are their durability and reliability. With the advancement in radio frequency technologies, the contactless smartcard systems reduce the maintenance requirements for the smartcard readers. Their use is also very time efficient because the card need not be taken out and placed in the card readers. Immediately, transit systems saw the benefits of its time efficiency, because the riders can go through the turnstile much quicker. It is essential for large metropolitan areas where the passenger flow is large. Also, logging passenger information provides an opportunity for a detailed statistical analysis of "passenger flow". This could prove extremely useful to those facing the task of managing logistics for a system whose behavior is a cumulative function of many smaller systems (stations). An advanced stochastic analysis could potentially reveal more efficient methods of operation such as scheduling of transportation vehicles that match riders' preferences. To meet the demand of the mass transit requirements, Philips developed the MiFare standard which has several types of cards with different storage capabilities. Figure 1 shows some samples contactless smartcards are used in transit systems.

Figure 1: Sample Contactless Smartcards

A proprietary standard of NXP (a Philips-founded company, www.philips.com), the MiFare standard has earned the distinction of being the most widely used contactless smartcard across the globe. From Australia and Malaysia to London and South Korea, the MiFare standard clearly enjoys a large market share. Primarily employed in mass transit systems, implementation of MiFare allows for the quick secure transfer of identification and financial information in an effort to fight system bottlenecks. By design, the cards are passive, meaning they are not self-powered and function only when in the presence of an active counterpart (reader/writer). MiFare cards operate using three embedded hardware resources: i) *RF Interface*, ii) *Digital Control Unit* and iii) Electrically Erasable Programmable Read-Only Memory (*EEPROM*).

The *RF Interface* serves as the communications and power system aboard the card by acquiring both energy and information in a fashion similar to the crystal radio. The energy is used to power devices within the *Digital Control Unit* and *EEPROM* to effectively manipulate digitized information.

The amount of information the card is capable of storing is a function of the *EEPROM* which exists in MiFare cards in several different sizes:

1. MiFare "UltraLight" with 64 bytes
2. Mifare "1k" with 1kB, and
3. the Mifare "4k" with 4kB of storage space.

The space is generally divided up into multiple *sectors*, which are divided up into *blocks* capable of storing 16 bytes of information each (Total Size = 16B * [#blocks/sector] * [#sectors/card]). Not all of this space is user programmable. There are *blocks* preprogrammed (and cannot be reprogrammed) with information about the card, such as manufacturer's information and the particular card type. In the interest of security, a *block* within each *sector* is dedicated to the storage of six-byte security keys required for accessing to the *sector* in which they exist. NXP reports a ten-year data retention span with a write-endurance of 100,000 cycles [9]. The MiFare standard also supports *Anti-Collision*, allowing for a single MiFare card to be identified and selected amongst others that also lie within the read/writer's RF field. This capability simplifies the use of the card even further, allowing multiple MiFare cards from different ticket/ID systems to be independently selected for read/write operations without leaving the wallet or holder they reside in. The MiFare standard also implements several concepts in the interest of maintaining the integrity of the stored information. Each transfer of block information is paired with a 16-bit cyclic redundancy check (CRC) to affirm the validity of the transferred data as well as parity, count checks, and coded symbols to effectively alert the system of internal errors.

3. PROJECT SCOPE AND CONCEPT

In 2006, SEPTA initiated a fare payment modernization study to evaluate payment technology options and estimate costs to replace its aging revenue collection system on all modes, including bus, trolley, rapid rail, commuter rail and paratransit. During this same period Temple University approached SEPTA to discuss the concept of improving the process of fare payment and collection for the Regional Rail System. SEPTA agreed to support and collaborate with the University on a Senior Design Project that focused specifically on using a PDA device to capture on-board cash fare transactions. The successful outcome of this project led SEPTA and Temple to seek funding for the next phase – an investigation into the feasibility of building an application with a PDA to read contactless smart cards. The timing of this effort coincided with SEPTA's larger fare collection study effort.

Continuing advancements in telecommunication technologies are providing new opportunities for transportation operators to modernize and improve fare payment and collection systems. The purpose of the Regional Rail On-board Payment Project was to integrate several non-proprietary, plug-and-play, commercial-off-the-shelf products and record on-board cash fare transaction and process electronic payments using contactless smartcards on commuter rail. These products include personal digital assistants and wireless 802.11 access points that can ensure easy, accurate, secure and efficient data and fare collections. The work tasks required data manipulation and extraction from legacy mainframe database to the eXtensive Markup Language (XML) data format. The software application has been implemented in Java so that the application could be interoperable among various other PDAs.

Phase 1 of this project [8] was originated in the College of Engineering at Temple University as a senior design project in 2004, and it was to test the PDA to record on-board cash transactions, record passenger data, and upload sales information to a backend database. Phase 2 of the project was followed by Phase 1's successful completion in 2005 and SEPTA hired several senior design students to further develop the backend database system and a portable refined Graphic User Interface (GUI) unit with SEPTA's specific fare instruments.

During Phase 2 (2005-2007), the PDA configuration included test acceptance of electronic payment applications, beginning with the SEPTA's magnetic media and moving toward read/write magnetic and contacted smart card technology. With successful implementation of these two phases, this project intends to develop specifications consistent with the Regional Interface Specification (RIS) developed by the Port Authority of New York and New Jersey. Briefly, this includes the use of the International Organization for Standardization (ISO) ISO-14443A contactless smartcard interface communications protocol, message sets, data dictionary and security protocols between the card and the card interface device (the PDA).

Conceptually, the SEPTA/Temple project team believed the idea held considerable promise. As stated earlier, electronic fare payment/collection on commuter rail has defied innovation and modernization, with most properties reliant upon hand punched paper receipts and manual reporting/remittance procedures. Under controlled test environments, conductors were equipped with the PDA devices for on-board use to transact on-board fare payment automatically. The units had functionality to store payment and ridership information until conductors completed their scheduled runs, at which time the stored information was uploaded to a sever using wireless communication.

Finally, the project served as a key component within a broader strategy to modernize the SEPTA fare collection system. Bus fare boxes, rail transit turnstiles, and paratransit services, all require fare collection upgrade. The purpose was to design a common platform to integrate all modes into one coordinated system. Within this context, the SEPTA/Temple project team designed a prototype unit for the railroad with the intention of migrating the fare collection system to the other operating modes.

4. PROJECT WORK TASKS

As previously mentioned the project's purpose is to introduce a COTS technology for electronic fare payment/fare collection operations to commuter rail fare payment and collection, utilizing handheld technology for recording fare transactions with electronic fare media, including read/write magnetic cards and contactless smart cards. This project was divided into four tasks.

4.1 Task 1: Identify and Define Hardware Requirements for a Smart Card Payment System

The research group (SEPTA and Temple University) identified several COTS products for consideration in fare collection applications using smartcard technology. Currently in Asia and Europe, portable contactless smart card reader/writer applications have been widely used for different financial transactions both in mass transit and non-transit services.

Also, the research group defined the smart card interface and determined the primary contactless technology standards for use in fare collection applications. After the research group studied other transit systems which were using the contactless smartcard system, the research group decided to use MiFare 1K cards. Then, the research group investigated several vendors who are capable of supplying the components with the open system standard necessary to build a contactless system with interoperable equipment.

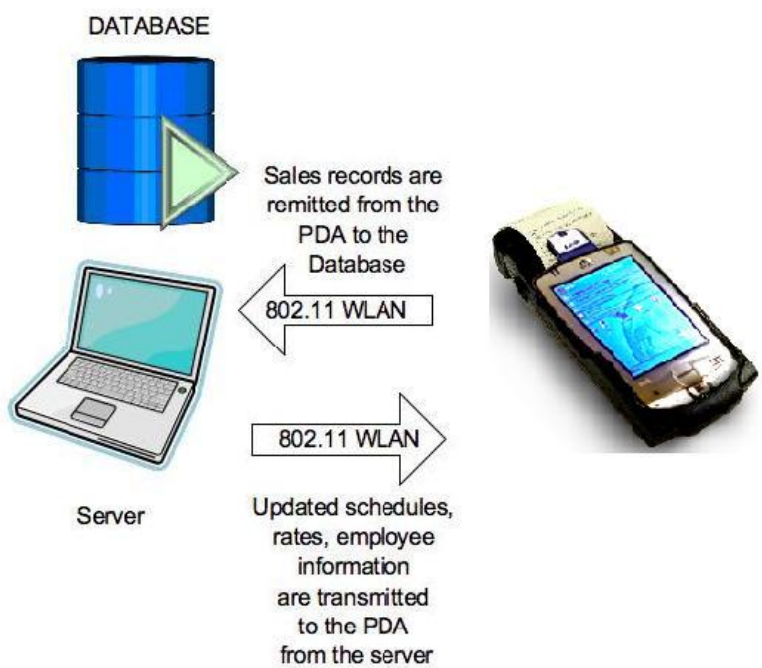

Figure 2. The Process of the Proposed System

Figure 2 outlines the system which is comprised of several COTS components. Also, it presents the process flow of the proposed system. The system consists of:

1) An HP iPAQ hx2795 PDA with integrated 802.11b WLAN,
2) An DATECS PP-55MS mobile printer,
3) A SDiD1010 Secured Card interfaced smartcard reader/writer, and
4) A Dell Laptop that will function as the server/end-user workstation.

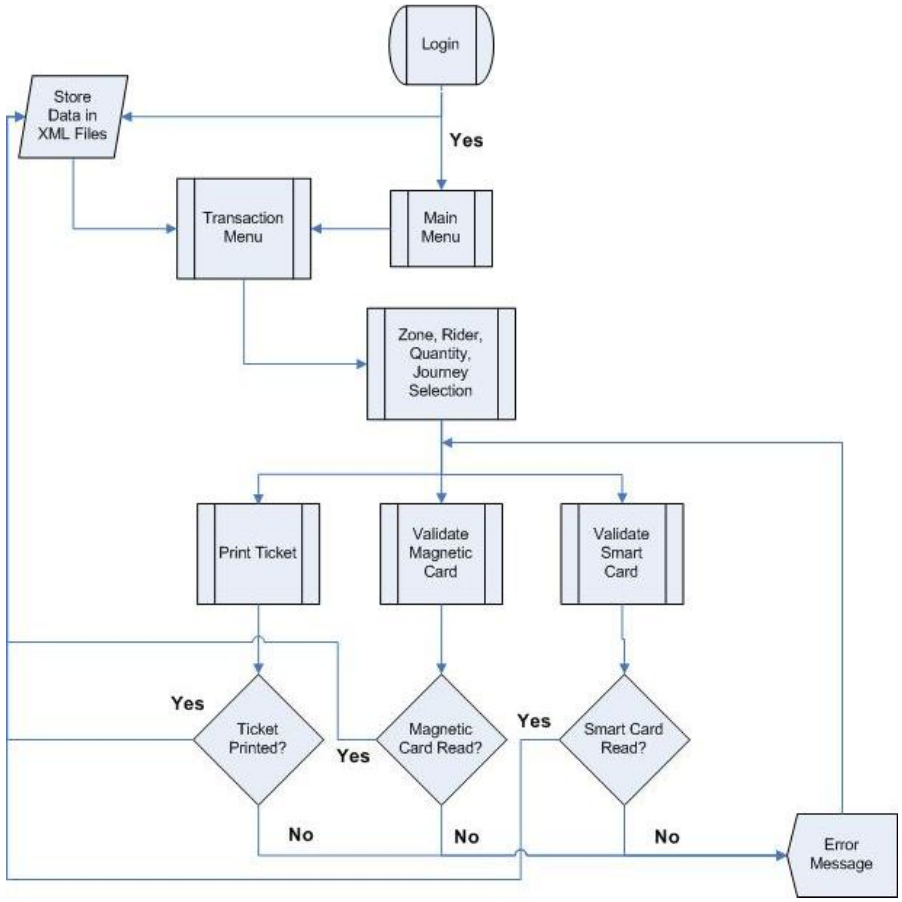

Figure 3: Transaction Control Flow

Figure 3 presents the logic flow of the front end interface using a PDA. The research group developed the Graphical User Interface (GUI) for the PDA and the server-end applications using Java programs so that it could be easily ported into any computing platform. To provide a seamless transaction, we used the extensive Markup Language (XML) [7] to provide different GUI interfaces and schedules for different conductors without modifying the software.

The PDA and a portable thermal printer provided the conductor with the capability for a variety of fare payment transactions, including cash acceptance, contactless smartcard, and transit pass payments. The magnetic card reader also validated the current transit passes so that fraudulent passes are not honored. The GUI provided fare information, stop locations and fare zones to payment methods, will be made available to allow fare transaction processing. The PDA remits transaction data to the server for statistical and accounting purposes, and the server uploads updated schedule, fare and run number information to the unit, which provides conductors with updated transit operational data.

This proposed ticketing method includes the following improvements:

- Ensures accurate monetary transactions.
- Creates sales data readily available for logistical and accounting uses in near real time.

- Reduces the amount of paperwork and margin for error.

The cornerstone of this portable wireless and smartcard-based ticketing system is software integration. The hardware is comprised of commercial components so the software was designed to provide compatibility with other hardware. All software applications for the wireless communication interface, GUI and server were created within the Java environment. The system utilized a wireless connected interface between the PDA and DATECS PP-55MS mobile printer, which was developed in Phase 2 of the project.

4.2 Task 2: Java Implementation of Smart Card Read/Write Device and Host Computer

In this task we defined a software interface to the read/write device and determined how to power the system effectively for an 8-hour working shift. Also, we created a test program to verify the smart card reader/writer device with an interface to a PDA system. In this task, Java programming provided the ability to write cards, so that they can be loaded and executed on the read/write device. Here, the host computers can have different operating systems.

In addition, we tried fabricating an adapter to couple a microSD enabled handheld device with the sDiD1010 contactless smartcard reader, because many handheld devices have only micro-SD interfaces. Further, we attempted to develop a SD to microSD adapter to incorporate sDiD1010 smartcard reader/writer modules. However, there were some concerns for power drawing which is insignificant to energize the reader. The research group has one student who prototyped a microSD pin layout board after referencing online sources of dimensions and wiring diagrams to a SD female socket.

To develop this adaptor, the research group has used processor fabrication technology by utilizing an etching process. After several unsuccessful attempts due to small dimension requirements, the research group produced a SD to micro-SD adaptor. However, this process was not successful because the research group found that the adaptor could not deliver enough power to run the RF sDiD1010 module. As a result, the research group focused on the handheld devices with SD-interfaces.

4.2.1 Java Environment

The software was developed using the Java programming environment; specifically, Java Micro Edition (JME). JME is divided into configurations, profiles, and optional APIs [10]. JME works just like the standard edition (JSE), except that JME configurations are designed for devices with memory constraints and limited processor power. The optional APIs offer additional functionalities that can be utilized by many different mobile devices. The same JME code for the HP iPAQ PDA used in this project can also be implemented into a different handheld device.

However, JME provides simple and basic GUI. To write sophisticated GUIs, we used CRÈME Java Virtual Machine due to its high speed and low memory footprint. CRÈME is highly integrated with the windows environment and is easily configurable to an application's particular requirements. The code developed for this project does not need to be modified when the program is transferred to a different handheld device, as it is fully functional on any Java Virtual Machine. This allows the developed code to be utilized on many commercialized PDA products.

4.2.2 Graphical User Interface

The Graphical User Interface (GUI) is the interface between the user and the program. The GUI utilizes the Java libraries, JSwing and Abstract Windowing Toolkit (AWT). The goal of a GUI was to make the system user friendly. The GUI allows the conductor to navigate through the program with easy access to the train information and ticketing sales. It provides a login screen prompting the employee to sign into the system. Once logged in, the main page is displayed. The employee's schedule and train information are displayed on the main page. The GUI makes it quick and easy for the employee to produce the desired ticket sale. After printing the ticket the employee is directed back to the main page to continue until the employee is finished. The system also prompts the employee to remit the daily transaction data to the server. When the onboard ticking process is complete, the employee can log out.

A large amount of the GUI from senior project [8] was transferable to this project. Based on the user survey results of SEPTA employees in the phase 2 of the project, however, there was desire to improve GUI's design to optimize efficiency and provide a better user-friendly operating environment.

4.2.3 Server - Client Communication

SEPTA's back-end database serves as the repository for all fare payment information. Due to restrictions placed on the access to the SEPTA network, a replica of the network was produced utilizing a laptop and a native XML database. The replica server contains all the essential data the real server contains, and stores all of the data onto XML documents. The XML documents act as a database, since they contain both data and metadata. The database metadata is the data in the database describing the information that is stored in that database [7]. The metadata allows for easy retrieval of information like the employee's name, password, and schedules. With the fully developed system the conductors have the ability to download a temporary XML document from the server that contains login information, updated train schedules, and fare information. The temporary XML document can be updated from SEPTA's server and stored in the PDA's memory daily.

The benefits of using XML are that an XML document is already in a database structure and is portable, easy to use, and universally understood[7]. The use of XML documents allowed for quick, efficient transfer of data information to and from SEPTA's network. Other databases, such as MySQL and Microsoft Access may require a Java driver to easily store and retrieve information from the database. In addition, due to the memory constraints of the PDA, MySQL and Microsoft Access files consume considerable memory, which slows the processor speed. The use of XML documents as databases provided an excellent replication of SEPTA's server, as they required minimal storage space on the PDA. However, a program has been developed to access the XML database and import data into a Microsoft Access database.

4.2.4 System Integration

Once all Java codes were written for the project, the application was built and compiled using the J-Creator software (Java Integrated Development Environment (IDE)). The initial simulations consisted of running software on a desktop computer with no connection to the laptop server. After debugging and testing the software, it was loaded onto the PDA for hardware testing and functional verification. The system was then fully tested to confirm wireless communication with the printer and server. Test transactions were performed to produce authenticated printed tickets, magnetic and contactless smartcard validation and transaction data remittance from the PDA to the server. The test also verified that operational information was uploaded from the laptop server to the PDA. The PDA's remittance process is shown in Figure 4.

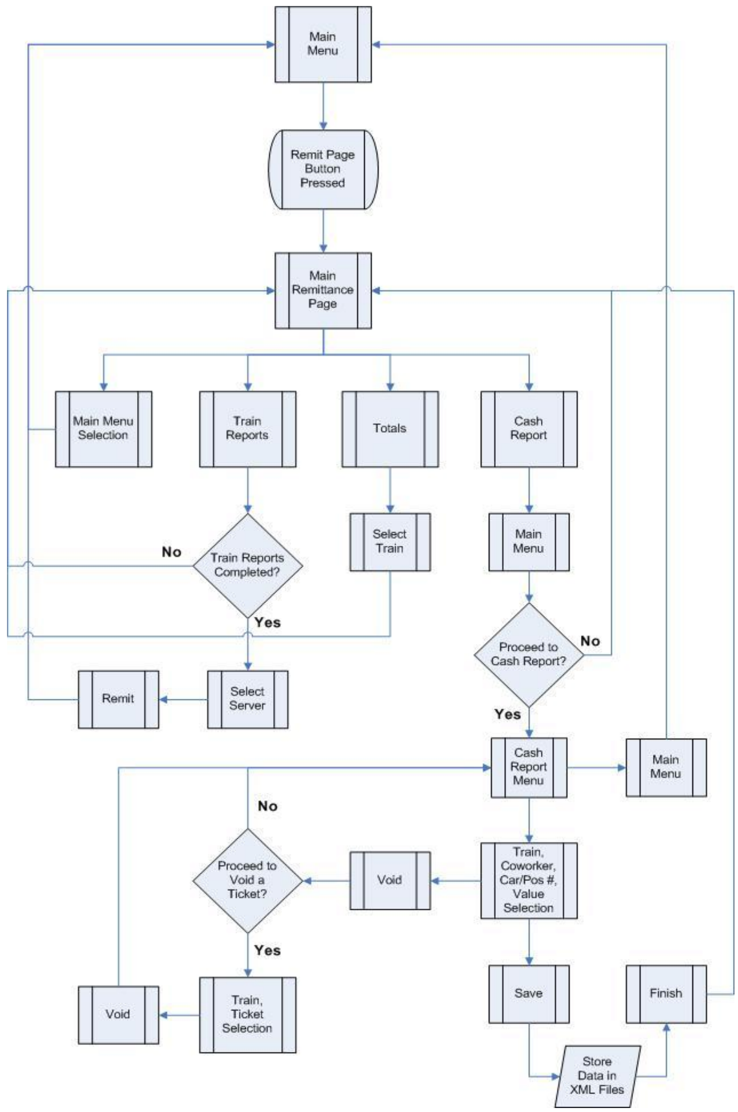

Figure 4: Remittance Control Flow

After we performed an adequate number of tests of the software and hardware to verify functionality, a system demonstration was given for SEPTA on June 12, 2008. It was demonstrated that the whole system can be easily incorporated with the backend process developed at SEPTA.

4.3 Task 3: Concept of Operations (05/2008 – 10/2008)

This task was refined to improve system integration within the onboard environment. We identified the application to be programmed for the read/write device and contactless smartcards, and reviewed SEPTA's tariff and Crew Remittance application. Also, we investigated transferability to the read/write device. Some applications were modified for the PDA project, along with the following:

1. Determine whether the smart card will carry stored value, stored trips, or stored time,
2. Determine how the handheld device will store smart card information and remit this information onto a server,
3. Define printing storage needs and capacity.
4. Define central cardholder database that supports the capture, storage, retrieval, retention, integrity and management of data necessary for the card management system, and
5. Identify the computer, peripherals and software which are needed to capture the information used to enroll a cardholder.

The process flow will ensure a smooth transaction for purchasing contactless smartcards and use of the contactless smartcards on board. Also, included were cash transactions and pass validation for the SEPTA issued magnetic cards. This developed a closed loop system with the front end unit and back end database system fully integrated.

4.4 Task 4: Live Test and Evaluation

The original work scope for the project included activities for testing the handheld system with conductors on SEPTA's Regional Rail system. During 2007 and 2008, SEPTA staff developed a Crew Remittance Database System as part of its ongoing support for railroad operations. The Crew Remittance System intended to interface with electronic handheld units carried by conductors to allow data transfer and revenue downloading from employees. In late 2007, however, SEPTA announced a decision to advance its electronic fare payment and collection system - an agency wide initiative to replace and modernize its obsolete fare collection system. While the planning phase for the new system anticipated handheld devices for regional rail operations consistent with the project at hand, and evaluated concepts based on closed end systems, SEPTA began to explore an "open loop" approach, where data exchanges occur between the card and the reader at a backend clearing house to validate fare payment. SEPTA confirmed this direction change with its announcement to implement a new fare system since the technology choice now included an "open loop payment system," in which fare validation and approval occurred in a backend database for clearing and settlement of payment transactions. Accordingly, the time and effort to test a card to reader concept developed by the Regional Rail On-board Payment Project in live operations was not warranted.

However, due to the change of the direction in SEPTA's overall smartcard project, the research group eliminated the task 4 because the concept of operation has changed from front-end read/write process. Nonetheless, the research group worked to improve the GUI interface by conducting some surveys from conductors. At this point, the research group hopes to test our GUI interface program at the real implementation of the SEPTA's overall smartcard project.

5. SYSTEM INTERFACES AND RESULTS

To effectively utilize the COTS products, the research group investigated different commercial devices for their durability and their documentations for open system architectures. For the contactless smartcard reader/writer module, the research group chose sDiD1010 unit, the module can be directly inserted in the secure digital (SD) slot in the PDA.

The programming (including the GUI and general structure) is developed in Java. The system is set up to accept the users' information, verify this information and in response perform an action. The data parsed by the code is programmed in the XML language, which can be structurally stored on the PDA as a localized database, such as schedule or train information. When it is activated, the GUI will appear on the screen and will request an ID and password. Once this stage has been verified, the next page contains button options prompting the user on which tasks to perform. Once the user has completed a task, a confirmation button is located on the bottom of the screen to proceed. The PDA then responds with its generated output and will perform a task of printing and recording every action.

More specifically, the research group can take a simple example of validating a monthly smartcard pass; the first screen to appear is the login screen as depicted in Figure 5. This screen contains four fields for access: the employee's number, run number (working schedule), password, and current date.

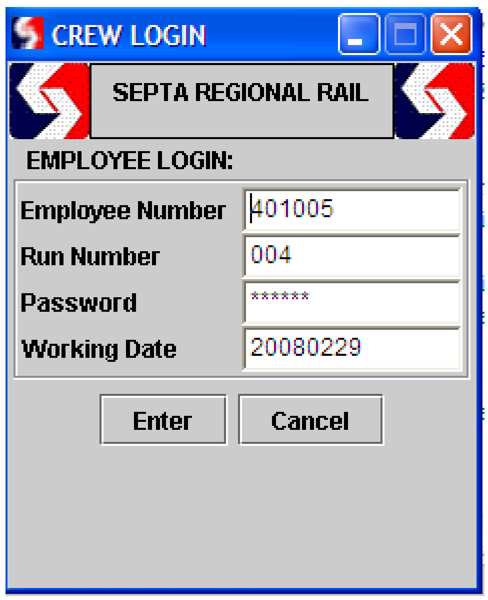

Figure 5: Login Screen GUI

Since there are numerous trains (characterized by Train Numbers) that run at any time, the selection of the type of day serves to narrow down the number of train number selection anticipated of the next page. That is, there are only certain trains that run during the Weekdays. Saturday and Sunday schedules differ from one another. Once the employee is verified, and the type of day is selected, access is granted onto the second screen as shown in Figure 6.

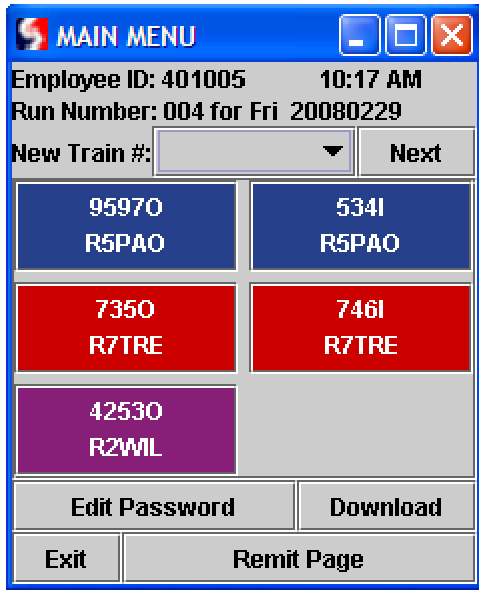

Figure 6: Rail Selection/Download/Remit GUI.

With the employee selected the train 746I, a ticket processing screen pops up, as shown in Figure 7.

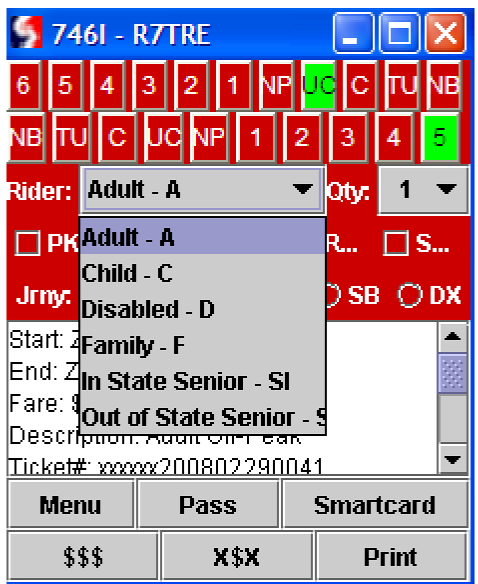

Figure 7: Ticket Processing GUI.

The conductor can also print a ticket by clicking on the "Print" button. A ticket will be printed as shown in Figure 8.

Figure 8: Ticket Printing

Also in this screen, the conductor can verify a pass or charge a ticket by using cash. Also, passengers can use a contactless smartcard to pay for the fare. A verify screen is depicted in Figure 9.

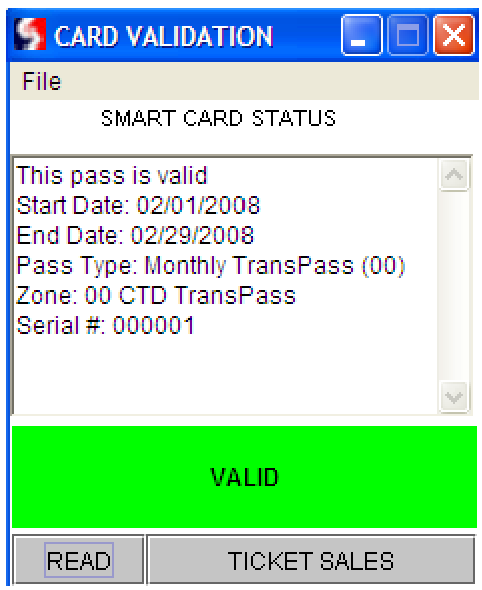

Figure 9: Verified Monthly Smartcard

As the screen indicates, the user has a validated monthly smartcard. In order to access the GUI interfaces, the server program (presently located on a laptop) must be up and running in order to listen and respond to the client's requests. Once the client program is launched, conductors can remit ticket sales information onto the database servers, or download schedule or new fare information from a database server or a peer's PDA device if the device has a more updated schedule or fare information.

6. CONCLUSION AND FUTURE IMPROVEMENTS

The goal of this project was to provide SEPTA with an open and new portable wireless ticketing system that improves transactions and sales documentation. The proposed system provides conductors with up-to-the-minute schedules and rates and will also allow for the transfer of transaction data to the

SEPTA server. As mentioned earlier, the design goal was to develop a system that will enable SEPTA Regional Rail conductors to document ticket sales information efficiently. The proposed system, if fully utilized, should be able to replicate the current ticketing process, with the exception that this system will be more efficient and provide valuable logistical data like passenger and station boarding information. Also, the research group has written one conference paper and received several student awards based on the project the research group developed.

The new system also should enable SEPTA train conductors to: (1) take ticket sales information, calculate and store ticket sales , (2) log on-board ticket sales on a *Personal Digital Assistant* (PDA), (3) securely transmit ticket sale logs to a central database via an 802.11 wireless *Local Area Network* (LAN), and (4) print out authenticated SEPTA ticket sale receipts, (5) validate a magnetic passes, and (6) extract fare information and deduct fare from a contactless smartcard.

This system will improve on the current system's deficiencies by: (1) ensuring accurate monetary transactions (2) making sales data readily available for logistical and accounting uses in real time and (3) reducing the amount of paperwork and margin for error.

Extending beyond research requirements, this system design was intended to aid SEPTA in its development of an efficient cost-effective portable wireless ticketing system. The proposed design could be used as a springboard to more advanced ticketing systems using contactless smartcard media, RFID capabilities and beyond.

7. REFERENCES

[1] L.S.K. Sim, E.A.C. Seow and S. Prakesam, "Implementation of an Enhanced Integrated Fare System for Singapore," RTS Conference, Singapore, 2003.

[2] International Mobility Observatory, Supplement No. 5, *Intelligent Transportation Systems*, No. 4.7.9. http://esd.mit.edu/ctpid/cmp/Observatory/Supplement5.pdf

[3] J. Blau, "RFID hooks ride on German mass transit," *The Industry Standard*," April 2005. http://www.thestandard.com/internetnews/002997.php

[4] B. Hopkins, "Getting Started with Java and Bluetooth," *java.net*, July 2004. http://today.java.net/pub/a/today/2004/07/27/bluetooth.html

[5] P. Tremblett, "Java" in *Dr. Dobb's Journal*, v 30, n 7CMP Media LLC, USA, July 2005, 41-44.

[6] EXTECH s2500ths Thermal Printer Specifications, *2500THS Developers Manual*, Version 1.04, February, http://www.posguys.com/mobile-computer-accessories_55/Datecs-PP-55_666/

[7] Gavin Powell, *Beginning XML Database*. Wiley Publishing, Inc., Indianapolis, IN, 2007, ch. 9.

[8] A. Adeniyi, A Birch, L. Kabiru, R. Scholl, "Wireless Onboard Ticket Dispenser," Temple University College of Engineering, 2004-2005.

[9] "MF1ICS50 Functional Specification, Product Data Sheet" *NXP Inc.*, January 2008. http://www.nxp.com/acrobat_download/other/identification/M001053_MF1ICS50_rev5_3.pdf

[10] Sing Li and Jonathan Knudsen, *Beginning J2ME: From Novice to Professional, 3rd Ed.,* New York: Springer-Verlag, 2005, ch. 1.

[11] Gavin Powell, *Beginning XML Database*. Wiley Publishing, Inc., Indianapolis, IN, 2007, ch. 9.

8. APPENDICES A

8.1 A1.1 Time Schedule

Below is the team's time schedule for the entire project's duration:

	(2007)Aug.	Sep.	Oct.	Nov.	Dec.	(2008) Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.
Research															
Software															
Development															
Networking															
Testing															
Final Presentation															
Final Report															

Table 1 - Time Schedule

8.2 A1.2 Software development

Software development was divided into three major tasks:

• Task 1 - Design involved developing a GUI that the conductors will use to log ticket sales.

• Task 2 - GUI implementation in Java entailed coding the algorithms derived from the software design phase.

• Task 3 - Debugging the ticket GUI.

8.3 A1.3 Networking

Networking was divided in three major tasks:

• Task 1 - Network design, involved mapping out the network setup.

• Task 2 - Designed a test program to demonstrate communication.

• Task 3 - Network implementation, involved establishing client server communication between the PDA and server/end-user workstation.

In addition, the entire networking phase involved testing the network to ensure proper communication and data exchange.

8.4 A1.4 Testing

Once network communication was established, trial runs were be made to assess the entire system's performance. In addition, all links were refined during this phase.

9. APPENDICES B

9.1 B1.1 Lexar Media 1GB 32X High Speed Secure Digital (SD) Memory Card

Type: Secure Digital (SD) Memory Card

Capacity: 1GB

Interface: *SD/SPI*

Special Features: High Performance, Low Power Consumption, Good Compatibility, have an erasure-prevention switch to keep your data safe.

9.2 B1.2 DATECS PP-55MS Mobile Printer

- Printing method: Line thermal dot printing

- Print speed : 50 mm per second

- Memory size: RAM 1Mbit

- Communications: Serial RS232, Optional 2 x USB Master/Slave

- AC adapter: 9 V @ 1000 rnA

- Magnetic Card Reader: 3 track head, IS07811

- Barcode Reader: CCD or Laser from Symbol or HHP

- Smart Card Reader: VME, 1 SAM, IS07816-1 /2/3

9.3 B1.3 HP iPAQ 5500 PDA Component Specifications

Processor	Intel XScale 400 MHz, 32KB data and 32KB instruction caches
Random Access Memory (RAM)	128MB SDRAM (h5500) 64 MB SDRAM (h5100)
Read Only Memory (ROM)	48 MB ROM (h5500) 32MB ROM (h1500)
SDIO slot	SD memory and SDIO card support
Audio	Microphone, speaker, 3.5mm stereo headphone jack, MP3 stereo through audio jack
Infrared	IrDA, data transfer up to 115.2 Kb per second
Bluetooth	Class II device; up to 4 dBm transmit, typical 10 meters (30 feet) range
Fingerprint Reader	Thermal swipe technology (h5500 only)

Table 2: HP iPAQ 5500 PDA Component Specifications

(a) Appendices, Glossary, References, Bibliography

(b) Metric Conversion Chart, etc.

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