Design of an Integrated Transit Monitoring System based on Radio Frequency Identification

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Abstract

Current transit data collection systems emphasize either passenger counting or vehicle location information. The prototype described in this paper represents the integration of automatic passenger counting with automatic vehicle location to allow the automatic collection of transit system performance. The system involves the incorporation of RF/ID tags into bus passes for the purpose of improving the methods of data collection regarding transit users. Passengers carrying the tags can then be uniquely identified. In addition, RF/ID tags are placed at the bus stops to track the movement of busses along the route. This paper details the system hardware and software architecture, the functionality of the system, passenger and cost considerations, and the application of the system for possible use in route control strategies.

Keywords: radio frequency identification, database design, transit applications

Biographical Notes

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1. Introduction

In order to improve service and to increase ridership in mass transit systems, transit officials are turning to Intelligent Transportation Systems (ITS). Intelligent Transportation Systems are characterized by technological solutions which integrate information processing, communications, control, and electronics with transit management systems. Example ITS solutions include Automatic Vehicle Location (AVL) systems, Automatic Passenger Counting (APC) systems, and Automated Toll Collection (ATC) systems. Intelligent Transportation Systems give transit managers the ability to collect meaningful data concerning the characteristics of the transit systems. The key to improved transit service is the transformation of the automatically collected data into useful information for decision making.

The prototype described in this paper, represents an ITS solution which integrates AVL and APC. By combining the functionality of AVL and APC, the system is able to capture data which is normally unavailable from individual implementations of these systems. Levinson[1] identified the merger of APC and AVL systems as an important goal in allowing for improved real time planning and control of transit systems. Since the prototype represents an integrated approach to AVL/APC, we call the system a Transit Integrated Monitoring System (TIMS). This paper details the system hardware and software architecture, the functionality of the system, passenger and cost considerations, and the application of the system for possible use in route control strategies.

2. Hardware Architecture

The prototype Transit Integrated Monitoring System (TIMS) consists of hardware and software components which interact with the transit system by means of radio frequency devices carried by passengers or embedded in the roadway. Figure 1 presents an overview of the hardware/software configuration. Radio frequency receivers emitting an energy field activate a transponder within the card, receive the data stored on the card, and then transmit the data via RF links to a central data collection system. Passengers carrying the cards can then be uniquely identified. The data captured could include fare information, event times (boarding and alighting times) of the transit user, and transit stop identification. In addition, the system includes a straight forward way to track the movements of vehicles by placing RF/ID tags in the roadway. With an additional antenna on the vehicle to read the embedded roadway tags, the system can automatically record the location of the vehicle at its last transmission.

As indicated in Figure 1, the hardware elements of the system consist of RF/ID tags, a RF decoder, RF antenna, communications equipment and a host computer. The basic hardware configuration calls for:

- (1) decoder mounted within the bus powered by 24V DC
- (2) RF modems, one attached to the serial port of the decoder on the bus, the other attached to serial port on the host computer system
- (4-6) tags per bus stop, 1 tag for each passenger
- (4) antennas per bus: 1 side read antenna for the front doorway, 2 side read antennae for the rear doorway, 1 antenna mounted underneath the bus
- a computer serving as a remotely located host base station

Figure 2 indicates the positioning of the antenna on the bus. Figure 3 indicates the layout of embedded tags in the roadway. Minor variation in the layout for each stop is necessary. For example, some stops on a route have an off road loading/unloading zone, but other stops simply have the bus stop alongside of the road. Tag 3 in the picture is positioned near the middle of the lane so that the tag will pass midway between the wheels of the bus. Tag 1 is intended to capture a bus that pulls up short of the stop due to traffic or other conditions. Tag 2 is intended to capture the normal stopping zone of the bus and tag 4 is intended to capture the bus departing from the stop. The following section details the TIMS's software architecture including the basic information requirements and an overview of the software application.

3. Software Architecture

The information requirements of the prototype were obtained from a study sponsored by the Transportation Research Board on bus route evaluation standards, see Benn[2] and by consulting with transit officials at our demonstration site. Benn[2] cited five categories for bus route evaluation standards. The criteria given in Table 1 under two of the five categories were identified as pertinent to the project

TABLE 1 Key Bus Evaluation Criteria

Schedule Design Standards	Economic and Productivity Standards
maximum number of standees	passengers per hour
maximum intervals	passengers per mile
peak periods vs. off-peak periods	passengers per trip
minimum intervals	passenger miles
duration of standee time	
time spent waiting at a transfer point	

Other information considered important included: number of transfer points per passenger per trip, bus stop to bus stop transit times, total transit use time, origin/destination counts, number waiting, number of passengers in transit, demand patterns, number of balking users. Benn[2] also indicates that most transit systems obtain data for these criteria manually, on a yearly basis, and at great cost. For improved decision making, data must be made available frequently and in a cost effective manner. A relational database application was then designed to support the collection of data to support these information requirements.

3.1 Relational Database Application

The relational database application consists of the database and support modules for validating, inputting, and interacting with the data. Figure 4 illustrates how the modules interact. The raw data input module captures the data transmitted during the operation of the automatic RF/ID system for storage and retrieval into the database. The Data Validation Module parses through the raw captured data and eliminates data discrepancies. It places each validated record into a valid data input file. This file is then entered into the Data Input Module for processing into the database. The Data Input Module places the data into the proper fields in the database. This module is also responsible for computing certain statistics such as dwell time, number standing, number on/off etc. It then outputs these statistics into the appropriate database files within the database. The reporting module allows standard statistical reports to be generated based on queries into the database. Example reports include: on-time performance, boarding/alighting patterns, cost and usage statistics. The Browse Database Module allows attribute data entry through input forms for data required by the database. This module allows these entities and their attributes to be browsed by the user. It also provides basic query abilities. This module also allows the user to input/update information into the database.

4. Database Design

This section describes the relational model for the software application. We refer the reader to Elmasri and Navathe[3] for more information on relational database design. A relational database is interpreted by the users as a collection of tables. A table represents a entity which is being modeled in the system. The columns of the table represent attributes associated with an entity. Links or relationships between entities occur when entities have attribute values in common. Each entity is required to have a primary key, i.e. an attribute which allows it to be uniquely identified. If a primary key for an entity appears as an attribute for another entity, then it is called a foreign key. The basic steps of database modeling are: determining the entities to be modeled, indicating the relationships between entities, defining the primary keys for each entity, determining the attributes of each entity, and then normalizing the data model. Database modeling and development is facilitated by the use of an entity relationship diagram (ERD). This involves representing the relationships pictorially. In an ERD, an entity is represented by a rectangular box. Entities are connected to other entities via lines. Each line is labeled with a single arrowhead or multiple arrowheads depending on whether the relationship is one-to-one, one-to-many, many-to-one, or many-to-many. In the following section, we will discuss our relational model.

4.1 Relational Database Model

The major entities involved in the system include passenger, bus, bus stop, and route. The passenger entity has tag transactions recorded and origin/destinations associated with a trip. The bus entity has tag transactions, bus mileage, and bus statistics recorded. In addition, the bus and a driver can be assigned to a link along a route. A route is made up of links. A link is a sequence of bus stops. Each route has a schedule associated with it which indicates the expected times that a bus should arrive to the bus stop and statistics which can be collected concerning route performance. A bus stop has transactions concerning passengers and busses which may occur and can appear in a schedule. The relational database is shown as an ERD in Figure 5. The entity relationship diagram can be translated into the following database schema.

DRIVER = (d-id, d-name)

PASSENGER = (p-id)

PASSENGER_OD = (p-id, origin, destination)

OD = (origin, destination, number)

BUS = (bus-id, bus_type, num_seats, capacity)

BUS_MILEAGE = (bus-id, month, year, miles, day-count)

BUS_SERVICE = (service-id, bus-id, service-type, amount, cost, date)

PASSENGER TRANSACTION = (p-id, bs-id, purpose, bus-id, time, date)

BUS TRANSACTION = (bus-id, date, num-on, num-off, num-on-bus, arrive_time, dwell_time, num-standing)

BUS_STOP = (bs-id, location)

LINK = (link-id, link_name, route-id, length-mi, length-time, num_of_stops)

LINK_STATS = (link-id, bs-id, h-avg, h-var, h-nobs, h-sumsq, h-cv, rt-avg, rt-var, rt-nobs, rt-sumsq, rt-cv)

ROUTE = (route-id, route_name, length-mi, length-time, num-of-links)

ROUTE_STATS = (route-id, month, year, miles, day-count)

ASSIGN = (Bus-id, d-id, link-id, date)

SCHEDULE = (bs-id, link-id, schedule_time_arrival, headway, sequence, period)

For each of the above relation schemas, the underlined attributes indicate the primary key. In Turitto[4], the above database schema was shown to be in 3rd normal form.

4.2 Database Testing

In order to examine the behavior of the database under sample processing conditions, we developed a simulation model of the demonstration route. Data was collected using software which allows a person using a laptop computer to record boarding and alighting counts for each stop along a route while riding the bus. On the demonstration route, one bus services twenty-two stops on the route with a scheduled headway of 30 minutes. Data was collected on forty, 30 minute loops of the bus on the route. Since the simulation was to be used to test the processing of the data, the fidelity requirements of the simulation are significantly less than those required when using the simulation to model the bus route performance. The passenger arrival distribution was assumed to be Poisson. The boarding data can then be used to set the mean of the Poisson process for each bus stop. The number of alighting passengers at a stop can be modeled as a binomial random variable which is dependent upon the number of passengers on the bus as it approaches a stop. The count data obtained from the software can then be used to set the probability that a passenger will alight at a stop along the route. Both of these assumptions are justified given previous literature on modeling bus route operations. From a time analysis of the collected data, the minimum, maximum, and average running times between bus stops was computed. Using this information, a triangular distribution was selected to model the running times between stops. We refer the reader to Adamski[5] for information concerning passenger service models and to Koffman[6] for information on simulating other aspects of bus operations.

The simulation model mimics the traveling of a bus along the route. At each stop, the number of boarding and alighting passengers is computed, the bus and passenger transactions are written to an ASCII file, and the bus routed to the next stop along the route. The ASCII file of bus and passenger transactions is in the same format as that expected by database validation module. The size of the output file was varied in order to predict the behavior of the database in terms of processing speed and storage requirements. Twelve datasets were created to represent system operation ranging from one-half day to 10 days. For each dataset, the number of events, validation time in seconds, input time in seconds, and storage size in bytes were recorded. For each dataset, the measurements were recorded starting with an empty version of the database. The number of events is the number of passenger and bus transaction events within the dataset. For a more complete discussion of the simulation and testing results, we refer the reader to Motter[7]. All testing was performed on a Intel based 486dx2-66 computer running Windows 3.1. A regression line was fit to each output variable as a function of the number of events. The resulting models were:

- Database Size = 20583.2 + 75.196(Number of Events) with $R^2 = 1$
- Validation Time = -3.571 + 0.027578(Number of Events) with $R^2 = 1$
- ln(Input Time) = -6.16709 + 1.50427 ln(Number of Events) with $R^2 = 0.97$

As expected, database size and validation time was a linear function of the number of events. For the field site route, the number of events for one day was approximately 1668. Thus, for each day of operation approximately 146 Kbytes of data will be added to the database with an input time of approximately 147 seconds and a validation time of approximately 42 seconds. In addition to monitoring the above performance variables, the data stored in the database for such items as the number of boarding passengers, dwell time, etc. were compared to the numbers produced by the simulation. The results matched. This verifies that the database is computing these fundamental statistical quantities correctly.

5. Passenger Responses

In order to understand the passenger acceptance of RF/ID technology, bus passengers at the University of Virginia and its surrounding community were surveyed. Five surveys were used in the study: the Hereford Route Transit Survey, Passenger Acceptance Survey (Bookstore distribution), Passenger Acceptance Survey (Bus distribution), Automated Transit Pass Pre-Survey, and Automated Transit Pass Usage Survey. We refer the reader to Weisenberg[8] for a more detailed discussion of these results.

5.1 Hereford Route Transit Survey

The purpose of the Hereford Route Transit Survey was to obtain the preliminary views of passengers concerning the radio frequency transit passes. The survey was distributed to 131 passengers along the Hereford Special route of University Transit Service(UTS) during November 1995. The preliminary survey indicated that most transit passengers would not oppose the automated transit database system. Only 26.5% responded with objections to the system. The most common problems stated were forgetting tags and privacy concerns associated with monitoring passenger trips. This survey served to provide possible questions for the remaining surveys and provided some initial support for passenger acceptance.

5.2 Passenger Acceptance Survey (Bookstore distribution)

The main objective of the Passenger Acceptance Survey was to forecast the likelihood of passengers accepting the automated system and to identify any widespread objections. Surveys were distributed to 368 customers at the University of Virginia Bookstore on January 15-17, 1996. The results suggest that most individuals do not hold strong opinions supporting or opposing the automated transit database. Figure 6, shows the predicted acceptance of a passenger rated on a 0-10 scale. This illustrates that the overall system acceptance follows a distribution skewed slightly toward the higher ratings.

The surveyed population indicated that the benefits of improved routing and scheduling and eliminating the need of physically displaying a bus pass were important, with over 40% replying that such benefits were “extremely important”. When asked their concerns with the system, over half of the sample viewed the cost of the bus passes as “extremely important”. Approximately 45% of the sample indicated that they did not believe that privacy was an important issue with the system. The main limitation in the surveys distributed at the University of Virginia Bookstore is that the majority of those surveyed were University of Virginia students, so the sample group was mostly of the same age and educational level. In order to improve the sample, surveys were distributed to bus passengers in the Charlottesville community.

5.3 Passenger Acceptance Survey (Bus distribution)

The student data collectors distributed 62 surveys to users of Charlottesville Transit Service(CTS). These surveys, distributed in February 1996, included two additional questions to identify the passenger’s age and educational level. It was also noted whether the respondent was a UTS or CTS passenger. The results of this survey are limited because of non-response. Only 34 of the 62 distributed surveys were fully completed.

The overall results of the bus/bus stop surveys supported the results of the bookstore surveys. The results indicated that passengers consider improved routing and scheduling and the cost of a bus pass as important issues. Similarly, the results of both surveys indicate that privacy issues and the size or shape of the pass are not significant issues for passengers. Approximately three quarters of the sample stated that they do not anticipate the system changing their use of transit services. One of the most significant differences between UTS and CTS passenger responses involves the importance of automated fare collection, as displayed in Figure 7.

The graph illustrates that CTS passengers have a much higher need for an automated fare collection system. Since CTS passengers currently have to pay fares, they would benefit from an automated system that would eliminate the need for carrying the exact change necessary for a given trip each day. UTS passengers, on the other hand, do not need to pay fares and so would not gain any benefits from such a system. CTS passengers also worried more about boarding with no money left on an automated bus fare card. This would suggest a need for a system that could handle a credit or debit card. Those worried about not having money on their fare card could obtain a credit fare card while those who wished to pay for bus fares in advanced could obtain a debit fare card.

Figure 8 displays various passenger groups' predicted acceptance of the system. The figure shows acceptance significantly higher for the bus survey sample as compared to the bookstore sample. For both UTS and CTS passengers, only a small percentage of the people would likely oppose the system. Unfortunately, more data would be required to draw significant conclusions regarding differences in passenger acceptance by age, educational level, and bus system use.

5.4 Automated Transit Pass Pre-Survey and Usage Survey

The main objective of the final two surveys was to determine if opinions of the system changed after carrying the radio frequency tags on a daily basis. Those University of Virginia students participating in the prototype database test completed the Pre-Survey upon receiving their tags. The participants agreed to complete and return the Usage Survey during the third week of February 1996.

The Automated Transit Pass Surveys reveal that passenger views of the automated bus passes do not change significantly after possessing and carrying the tags for several weeks. This supports the responses to the Passenger Acceptance Survey. The Usage Survey indicated that over 90% of the respondents accepted the system. This is about the same as previous responses. In addition, the Usage Survey confirmed the Passenger Acceptance Survey's conclusion that most passengers do not actively support or oppose the system, as no one responded that changes in their use of the Hereford Special bus were due to the automated passes. Over 90% of the group responding to the Usage Survey carried their automated pass all of the time. A large fraction of the sampled passengers were concerned with the inconvenience of replacing a broken pass and system failure. Thus, it would be important for a system to be capable of sending tags to people through the mail, or some other effortless method of distribution. Carrying the radio frequency devices allowed testers to notice the potential for automated fare collection. The importance of automated fare collection rose in the second survey. After having tested the bus passes, passengers seemed less willing to reveal personal attributes for an automated database. A large portion of the sample responded as preferring a key ring bus pass or credit card-shaped bus pass to the current shape of the tag. When asked to rate their preferences for contactless bus passes as fare cards compared with cash, tokens, magnetic stripe cards, and contact smart cards, passengers rated the contactless passes highest as displayed in Figure 9.

In response to open-ended questions, passengers liked the system's efficiency in that it eliminates the need to carry exact change for a bus fare. Passengers anticipated quicker boarding with the implementation of the system, and would appreciate cheaper fares since transit managers can minimize costs with optimized routes and schedules. Some listed drawbacks of the system were forgetting the pass, losing the pass, system failure, privacy, and potential for running out of money if the automated pass acts as a debit card. After testing the tags, people indicated that they liked not having to physically display the tag. People worried about the cost of the tag and whether cash could still be used to pay fares for people unfamiliar with a community's automated bus system.

6. COST CONSIDERATIONS

Transit operator acceptance is dependent primarily on the value and convenience of automatically collected data in conjunction with the cost of collecting the data. Current passenger data collection methods range from manual methods which use the bus driver to press a counter as passengers enter the bus to fully automated passenger counting (APC) systems, see for example Levinson[2]. Automated or semi-automated fare collection systems also offer possibilities for collecting ridership data. A typical system will collect fares with an electronic fare box on each bus either through fare cards or coins. The fare collection device will count the number of passengers that ride based on the amount of fares collected. The fare collection device must be removed nightly and the data downloaded by a probe. Ridership reports can then be generated. These systems simply count the number of riders per day and can not associate passengers with a particular origin or destination. Thus, these systems do not approach the functionality available in an RF/ID based system. The costs associated with enhanced APC systems were reported in Levinson[2] and are repeated in Table 6 for comparative purposes.

TABLE 6 Cost Considerations in APC and RF/ID

APC/AVL Item	Cost	RF/ID Item	Cost
Counting Sensors	$1200-1700/bus	**ASGI Tag**	$17-$25/tag
Microprocessor	$1500/bus	**Decoder**	$1500/bus
Data retrieval unit	$4000-5000/unit	**Host computer**	$3000
Display unit	$1500/unit	**High Speed modem**	$600/bus
Signposts	$300/unit	**RF antennas**	$600/bus
Signpost receiver	$1000/unit	**Installation**	$12/tag
Signpost antenna	$200/bus		
Installation	$300/sign post		

The functionality and costs as reported by Levinson [2] of these upgraded APC systems is very comparable to the functionality of the TIMS. The approximate costs on a per bus basis are $2,900 for the APC/AVL type system and $2,700 for the RF/ID system. Both systems require a method for retrieving and storing the data with similar costs if additional disk storage is considered for our system. In addition, better installation methods should be considered to cut the installation costs. The primary requirement for tags embedded in the roadway is to track bus movements. Other tracking technology could be considered such as global positioning systems (GPS).

7. EXAMPLE USE IN ROUTE MANAGEMENT

Because the system captures the location of the bus, our system has the potential to provide near real-time information on the status of the entire transit system(busses and riders). In order to illustrate how the integration APC and AVL based on RF/ID can be exploited, we examined the use of the information stored in the database to control bus headway.

7.1 Threshold Based Control Strategies

Headway is defined as the time or distance, from a fixed point, between the departure of one vehicle and the arrival of the next. The scheduled headway along a route indicates to passengers how often a bus arrives at a stop (i.e. every 10 minutes). Variations in observed headway along a route can cause buses servicing the route to "bunch" which can decrease system performance. Bunching can contribute to increases in overall passenger waiting times at a stop in addition to increasing overall passenger waiting times along the route. These increases lessen the reliability of the service in the eyes of the transit user and generally lead to ill will between the transit user and operator. This can result in decreases in ridership. Reductions in headway variation can be translated directly into decreased passenger waiting and transit times. In order to reduce headway variation along a route, methods such as threshold based control can be used. A threshold-based strategy involves identifying a certain value (x_0), known as the threshold value, at a particular bus stop along the route which acts as a control point. If the observed headway between an incoming bus and the previous bus is less than (x_0), then the incoming bus is held up to the threshold value. If the observed headway is greater than the threshold value the bus is not held. In order to implement this strategy, an optimal control stop and optimal threshold value must be identified. We refer the interested reader to references [9], [10], and [11] for more information on determining the threshold value and control point.

Research has also determined the route characteristics that warrant threshold-based holding strategies. Routes that have sufficiently short headways, less than 10 minutes, have shown performance improvements from threshold-based holding strategies, see Abkowitz and Lepofsky[11], whereas Turnquist[12] showed routes that had sufficiently large headways benefited more from other holding strategies such as schedule-based holding strategies. Passenger profiles are also relevant in determining which routes may benefit from threshold-based holding strategies. Routes that have either passengers boarding along the middle of the route and alighting at the end or boarding and alighting uniformly along the route have shown the most significant reductions in headway variation and passenger waiting times, see for example Abkowitz and Tozzi[10].

7.2 Prototype Support for Threshold Based Control

Abkowitz and Engelstein[13] gave the following methodology to determine which control strategy for headway variation control should be applied to any given route:

1. Determination of mean running time
2. Determination of running-time variation
3. Determination of headway variation
4. Determination of passenger wait time
5. Determination of optimal control strategy

The prototype is able to calculate values for the mean running times, running time variations, and headway variation from actual observed data captured along the route.

This should be contrasted with the use of empirical or simulation based regression equations to determine these parameters as discussed in reference [14]. RF/ID enables the actual collection of the necessary data in a timely manner. In order to complete step 4 of the methodology, passenger waiting times are required. Some researchers, see Barnett[15] have assumed purely random passenger arrivals, while others, Turnquist[16]. considered random and non-random passenger arrivals. Other studies, Abkowitz and Tozzi[10] have indicated that the passenger random arrival assumption is valid only for those routes with short headways, around ten minutes or less. Research assuming random passenger arrivals has yielded the following equation for the expected waiting time for a passenger until a bus arrives to a stop, see reference [16]:

$$E[W] = \frac{E[H]}{2} + \frac{Var[H]}{2E[H]}$$

where E[W] is the expected wait time, Var(H) is the headway variation, and E[H] is the expected headway.

Thus, under the assumption of random arrivals the passenger waiting time at a stop is dependent upon the expected headway and the headway variation which are easily computed from the database. In addition to passenger waiting times step 4 requires data on the number of passengers on the bus and boarding/alighting along the route, all of which can be computed from the database. The relevant piece of data that is needed to determine threshold values and control points is an accurate description of the flow of passengers through the route. The prototype is able to obtain accurate descriptions of the passenger boarding/alighting patterns along the route and can also show how they might change over different time periods. The boarding/alighting patterns can be generated from the OD relation of the relational database and from the BUS TRANSACTION relation. The OD relation tracks the number of passengers that board at a specific location and alight at another location. The BUS TRANSACTION relation shows how many passengers board or alight at a specific bus stop. It also shows how many passengers are on board the bus at each stop. With this information, a more accurate boarding/alighting pattern can be generated by the prototype which would give a transit manager more input in determining where possible locations for a control point may be for a certain route.

7.3 Prototype Support For Management Techniques

In order to analyze the effects of threshold values and control points, a simulation model of the route is extremely useful. In order to develop a simulation model the information listed below is needed:

1. run time data (averages, variation, coefficient of variation)
2. passenger boarding and alighting patterns at each stop
3. number of passengers traveling along the route
4. number of buses along the route

Since the prototype obtains average run times and run time variation from stop to stop, this information could be used to develop a more accurate distribution that drives the buses along the route. A separate distribution can be generated for the run times at each particular stop. The number of buses used along the route is also needed. Both the number of buses and the run time information can be directly obtained from the relational database. The transit manager would merely have to indicate which route to simulate and the database could process the necessary queries to obtain the number of buses and run time information. The passenger arrival process can be generated from general passenger count data that again can be obtained directly from the database. In fact, the database supports the ability to generate different arrival processes for different time periods. This passenger information can all be obtained from the PASSENGER TRANSACTION entity of the database, while all the stops located on the route chosen by the transit manager can be obtained from the SCHEDULE entity. The boarding and alighting pattern can be generated from the OD and BUS TRANSACTION entities which could be used in generating a more accurate arrival process. With extra effort the entire simulation process could be automated. In addition, for those routes where threshold based control strategies are inappropriate, the database can support other scheduling and design changes.

8 Summary

This paper described a prototype for a Transit Integrated Monitoring System (TIMS) based on RF/ID tagging of transit users in order to monitor transit user movements and the operating performance of the transit system. Existing radio frequency identification (RF/ID) hardware was modified, adapted, and tested under conditions representative of transit practice for the purpose of collecting information on the movements of transit users and vehicles within the transit system. A software prototype was developed which enables the use of RF/ID hardware within the transportation community by specifically addressing data collection needs. In addition, algorithms and databases for the translation, storage, and retrieval of data collected from transit users were developed and tested in conjunction with the hardware. By adapting and integrating RF/ID technology into transit management systems, transportation agencies can achieve significant results in the following areas:

- real-time status information for transit users
- fare collection
- transit user convenience and marketing
- data collection regarding transit users

In addition, the collected data will support many management functions such as simulation, scheduling crews, scheduling busses, and monitoring vehicle schedule adherence, see for example Martin[17].

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Figure 1 Hardware/Software interaction

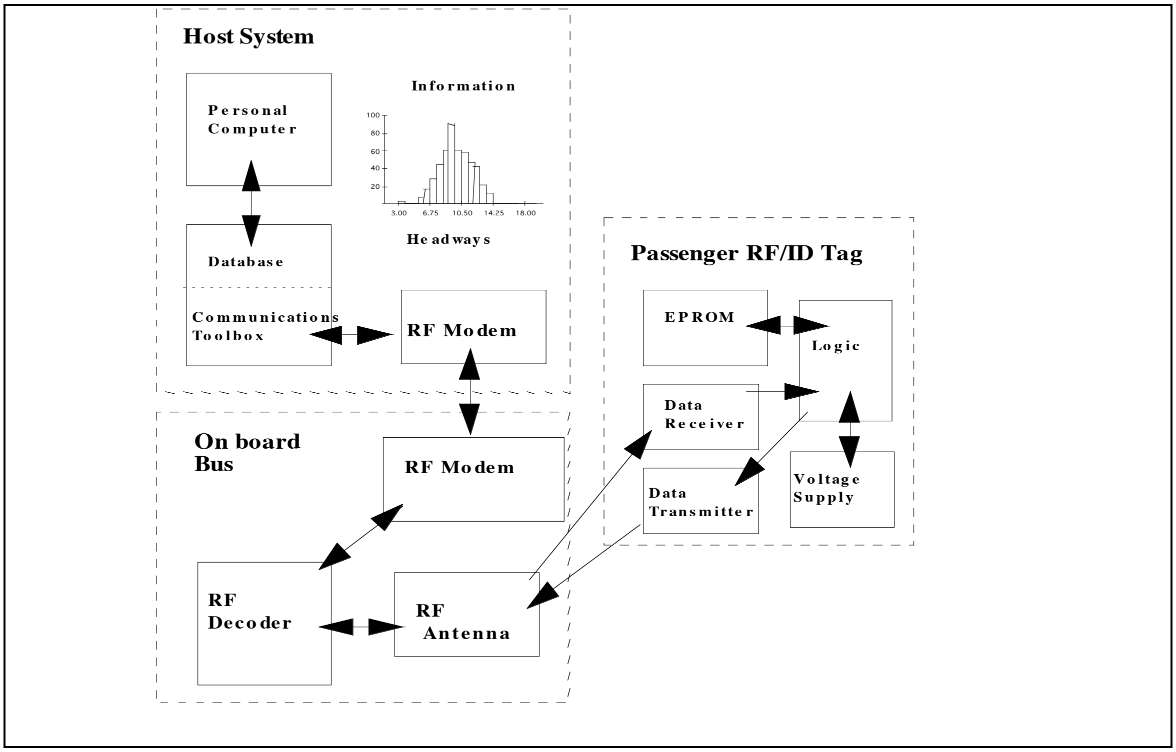

Figure 2 Layout of antennas on bus

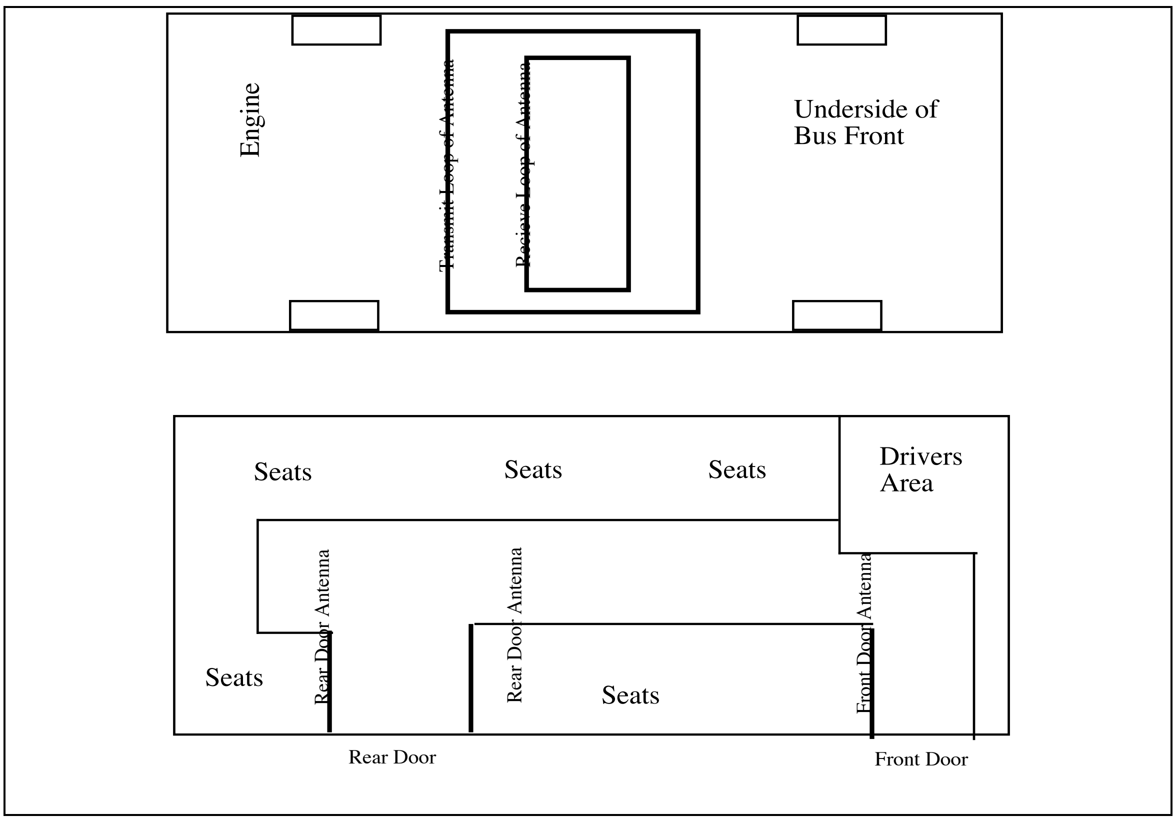

Figure 3: Basic tag layout

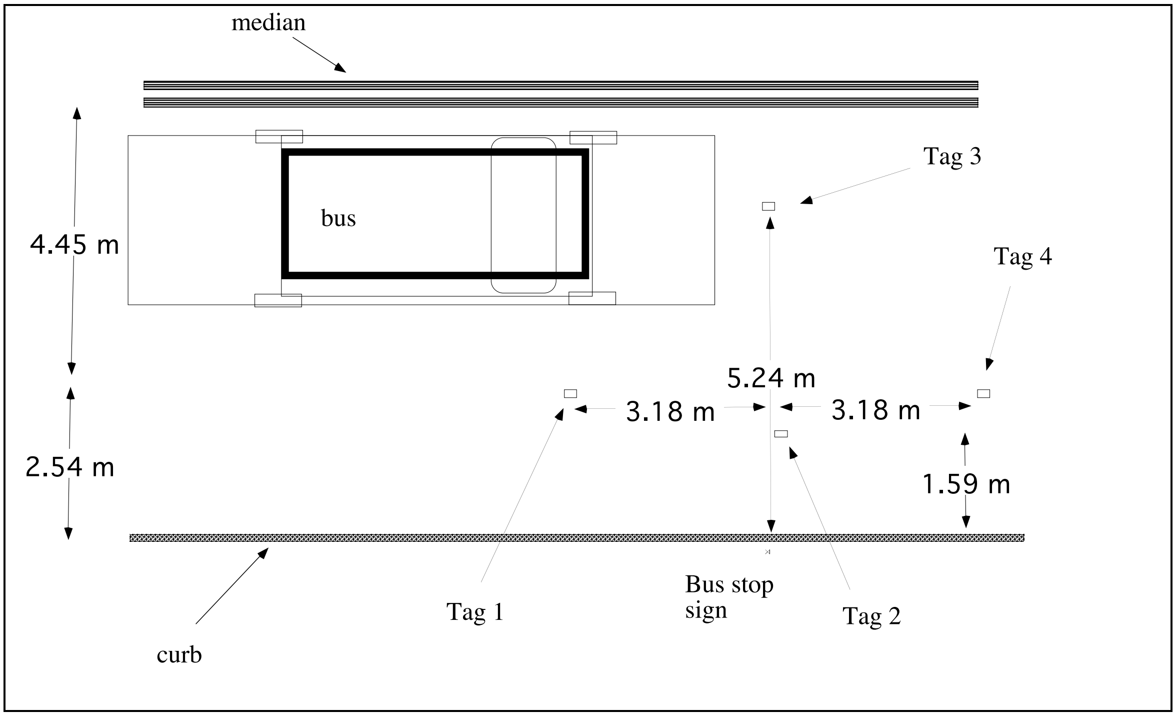

Figure 4 Software/Hardware subsystems

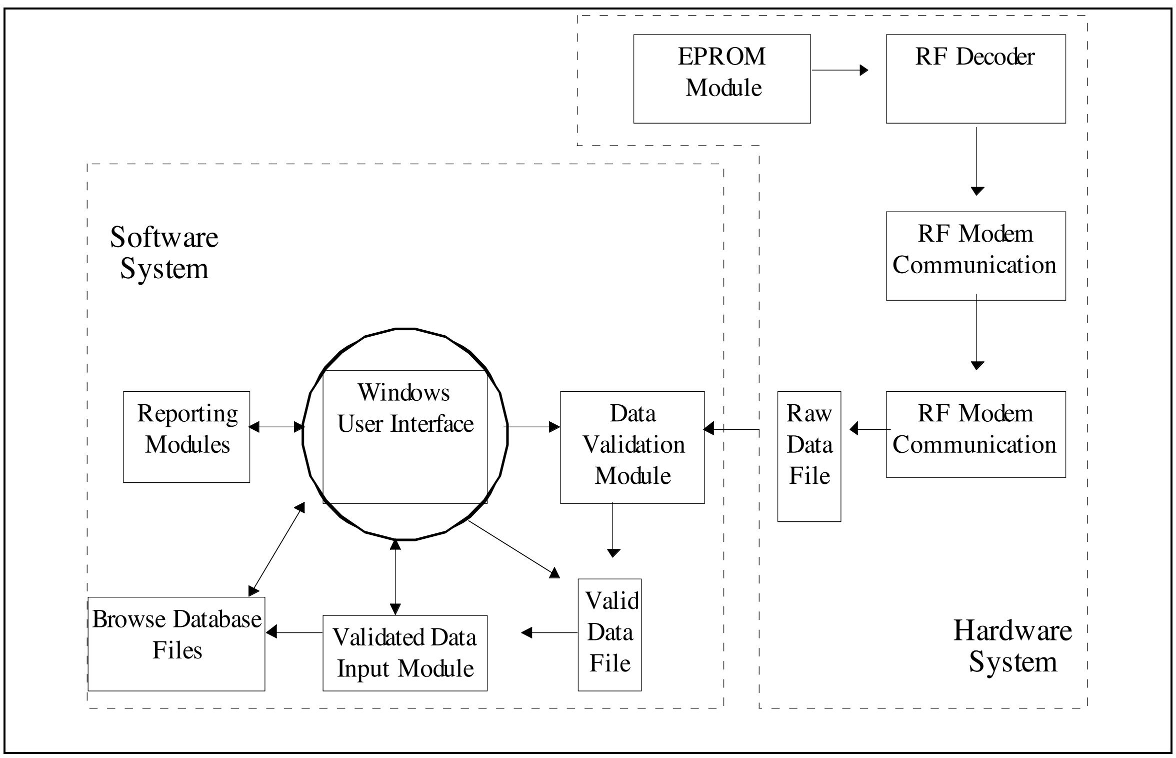

Figure 5 Entity relationship diagram

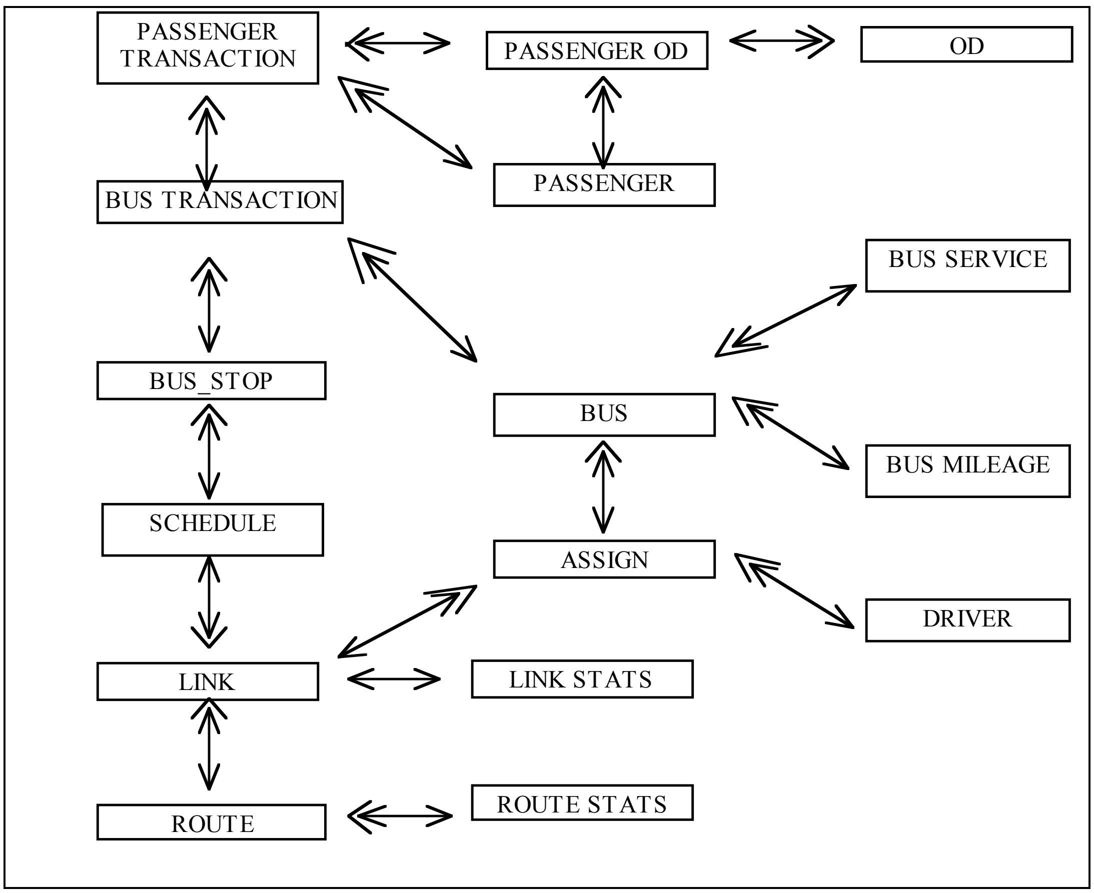

Figure 6 Passenger acceptance distribution

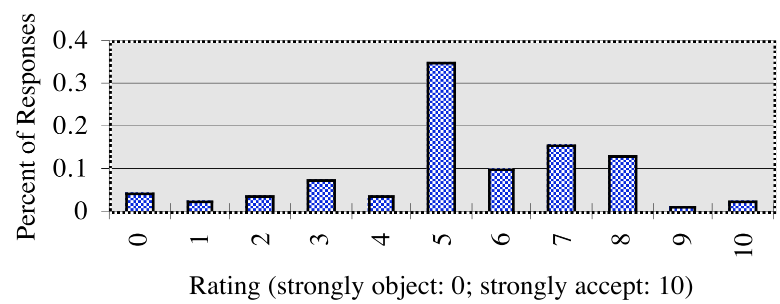

Figure 7 Importance of Automated Fare Collection

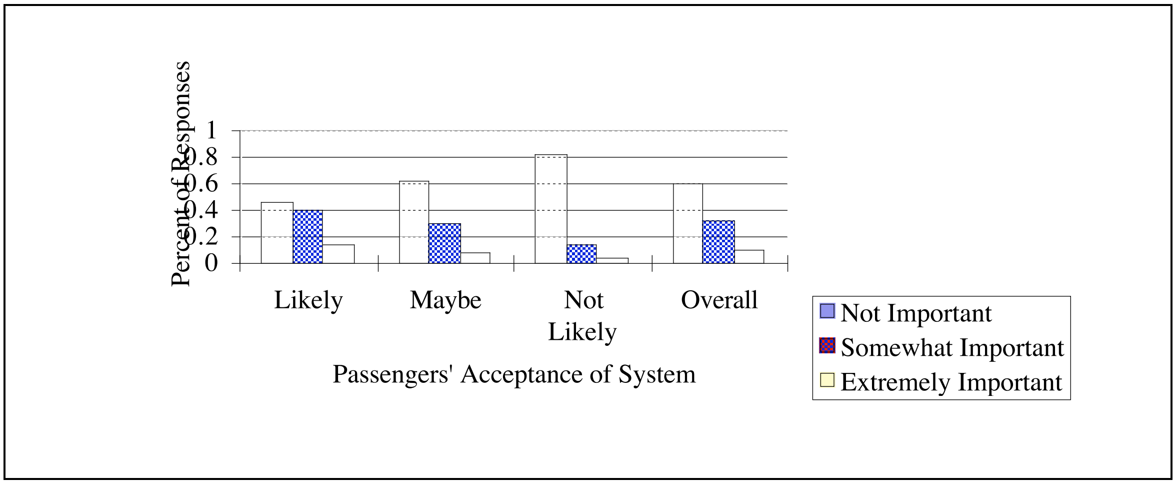

Figure 8 Predicted Passenger Acceptance UTS/CTS Surveys

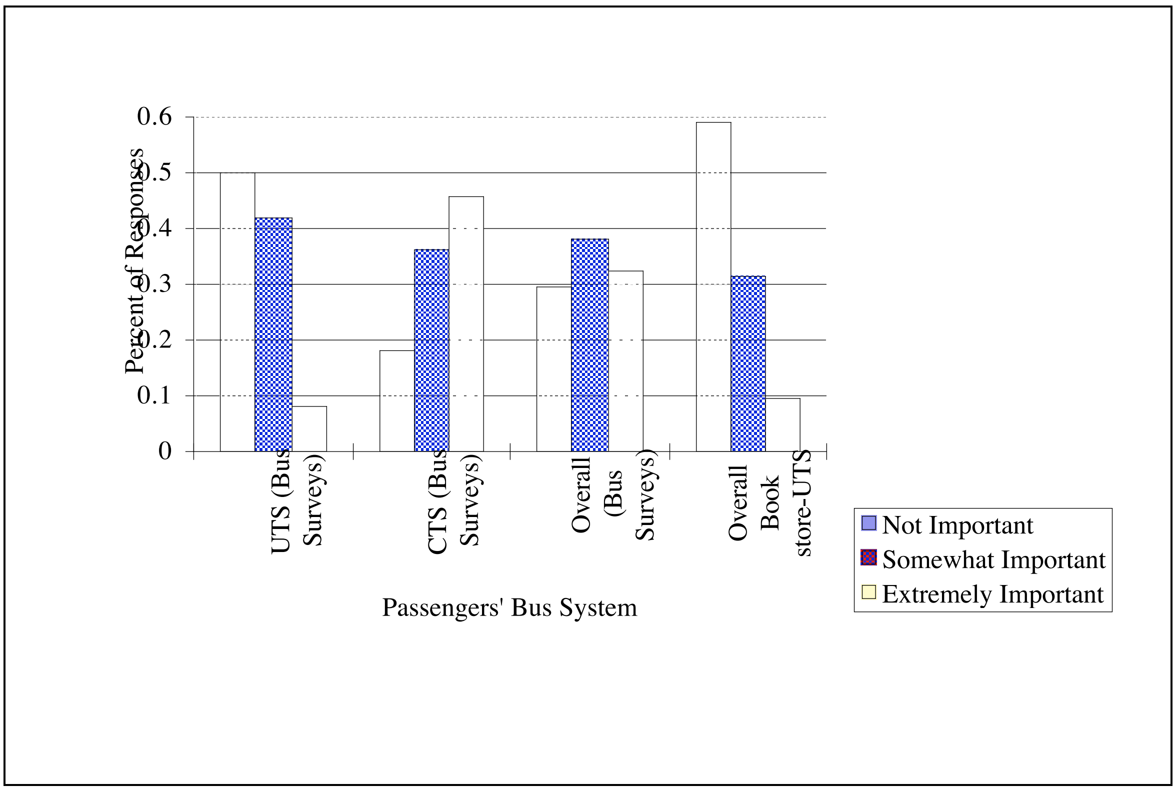

Figure 9 Preferred Method of Fare Collection