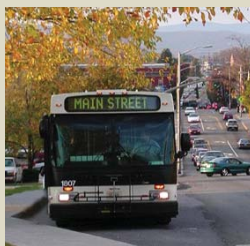


Transit Bus Routing On-Demand: **Developing an Energy-Saving System**

Developed by Blacksburg Transit and the Virginia Tech Transportation Institute

June 2015



 **VirginiaTech**
Transportation Institute

 **Blacksburg
TRANSIT**

Kimley»Horn



Transit Bus Routing On-Demand: Developing an Energy-Saving System

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Transit Bus Routing On-Demand: Developing an Energy-Saving System

TABLE OF CONTENTS

LIST OF FIGURES	vii	<i>Survey purpose and design</i>	12
LIST OF TABLES	ix	<i>Survey results</i>	12
ACKNOWLEDGEMENTS	x	Demographics and ridership	12
ABSTRACT	xi	Rider response to technology and energy-saving measures	12
1. EXECUTIVE SUMMARY	1	<i>Focus group purpose and design</i>	13
2. BACKGROUND	3	<i>Focus group results</i>	13
INTRODUCTION	3	BT4U	14
GOALS AND OBJECTIVES	3	BT4U mobile application	14
CHALLENGES AND CONSIDERATIONS	3	Cameras	14
PROJECT AND REPORT OVERVIEW	4	Hokie Passport swipe	14
AN IDEAL TESTING ENVIRONMENT	5	Kiosks	14
<i>The Town of Blacksburg</i>	5	RFID	15
<i>Blacksburg Transit</i>	5	Thumb scan	15
<i>Virginia Tech and the Virginia Tech</i> <i>Transportation Institute (VTTI)</i>	5	Wi-Fi or Bluetooth detection	15
STAKEHOLDERS	6	<i>Bus stop observation</i>	15
<i>Town of Blacksburg</i>	6	Data collection	15
<i>Virginia Tech</i>	6	Data reduction and analysis	15
<i>Virginia Tech Corporate Research Center</i>	6	Conclusions	18
<i>Hethwood</i>	6	Considerations for transit agencies	18
<i>Organization of project team</i>	7	Background	18
COLLABORATORS	7	Implementation and testing	19
<i>Blacksburg Transit</i>	7	Conclusions and considerations for transit agencies	19
<i>The Virginia Tech Transportation Institute</i>	7	<i>BT4U mobile application</i>	19
SUBCONTRACTORS	8	Background	19
<i>Kimley-Horn</i>	8	Implementation and Testing	20
<i>Automation Creations, Inc. and Nomad Mobile Guides</i>	8	Conclusions	20
<i>Dynamic Data Systems, LLC</i>	8	Considerations for transit agencies	21
<i>Virginia Tech Center for Survey Research</i>	8	<i>BT4U mobile application with iBeacons</i>	21
3. ASSESSING DEMAND FOR TRANSIT BUSES	9	Background	21
OVERVIEW	9	Implementation and testing	22
SELECTING CANDIDATE DEMAND-ASSESSMENT TECHNOLOGIES	10	Conclusions and recommendations for transit agencies	22
SELECTING TEST ROUTES	11	<i>Camera Analytics</i>	23
CHARACTERIZING RIDERSHIP	12	Background	23



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Testing	23	Implementation and validation	35
Conclusions and considerations for transit agencies	23	Forecasting conclusions	37
<i>Hokie Passport swipe</i>	23	CONCLUSIONS AND CONSIDERATIONS TO OTHER TRANSIT AGENCIES	38
Background	23	4. MODELING FUEL CONSUMPTION	39
Implementation and testing	24	OVERVIEW.	39
Conclusions and considerations for transit agencies	24	BACKGROUND	39
<i>Kiosks</i>	24	<i>Overview of the VT-CPFM</i>	40
Background	24	ON-BOARD DATA COLLECTION.	43
Implementation and Testing	25	<i>MiniDAS</i>	43
Conclusions	25	Suggestion for transit agencies	43
Considerations for transit agencies	26	<i>HEM</i>	43
<i>RFID</i>	26	Considerations for transit agencies	44
Implementation and testing	26	<i>DashDAQ</i>	44
Conclusions and considerations for transit agencies	26	Recommendation for transit agencies	44
<i>Thumb scan</i>	27	FUEL CONSUMPTION MODEL FRAMEWORK	45
Background	27	<i>Data processing</i>	45
Testing	27	<i>Separating data into calibration and validation sets</i>	45
Conclusions and considerations for transit agencies	27	<i>Model calibration</i>	45
<i>Wi-Fi and Bluetooth detection</i>	27	<i>Model implementation, testing, and validation</i>	49
Background	27	RESULTS	51
Implementation and testing	28	<i>Optimum cruise speed</i>	51
Conclusions and considerations for transit agencies	28	<i>Hybrid vs. conventional buses</i>	52
<i>Demand Assessment Technology Summary</i>	28	Fuel consumption, CO ₂ emissions rate, and passenger load	52
Evaluation	28	Comparative fuel consumption and CO ₂ emission	52
Testing	30	Comparative fuel consumption and bus maneuvers	54
HISTORICAL DEMAND	30	Comparison between two small hybrid buses and one large hybrid bus	55
<i>Passenger count data</i>	30	CONCLUSIONS AND CONSIDERATIONS FOR OTHER TRANSIT AGENCIES	55
FORECASTING RIDER DEMAND WITH THE DEMAND-ASSESSMENT ALGORITHM	31	5. THE DYNAMIC DISPATCHING DECISION SUPPORT SYSTEM (3DSS)	56
<i>Background</i>	31	OVERVIEW.	56
<i>Factors contributing to ridership</i>	31	3DSS OUTPUTS CONSIDERED.	56
Forecasting levels	31	<i>Dynamic routing</i>	56
<i>Demand assessment algorithm</i>	32	<i>Bus stop locations</i>	56
Inputs	32		
Framework	33		
Outputs	34		



Transit Bus Routing On-Demand: Developing an Energy-Saving System

<i>Route optimization</i>	57	DATA STORAGE.	68
<i>Adjusting bus stop arrival times</i>	57	DATA IMPORT	69
<i>Bus frequency changes</i>	57	DATA ORGANIZATION	70
<i>Bus size selection</i>	57	3DSS INTEGRATION.	70
3DSS ALGORITHM DEVELOPMENT.	58	FUTURE DATA APPLICATIONS	70
<i>Input variables</i>	58	<i>Bus board</i>	70
Bus database.	58	<i>Support vehicle check in / check out</i>	70
Demand assessment.	58	CONCLUSIONS AND CONSIDERATIONS TO OTHER TRANSIT AGENCIES	70
Bus passenger data	58	7. ENGAGING STAKEHOLDERS	71
Links	58	COMMUNITY OUTREACH	71
Stops	58	MARKETING THE SYSTEM	71
Travel time from tripper location	58	ENGAGING THE RESEARCH COMMUNITY	72
Fuel consumption from tripper location.	59	8. TIGGER PROJECT RESULTS AND CONCLUSIONS	73
Drive profile	59	9. APPENDICES	75
<i>3DSS framework</i>	59	APPENDIX A: PROJECT COLLABORATORS, STAKEHOLDERS, AND CONSULTANTS.	75
<i>3DSS outputs</i>	61	<i>Blacksburg Transit [31]</i>	75
Scenario 1: Add bus	61	History and Background	75
Scenario 2: Replace a smaller bus with larger tripper	61	General Information	75
Scenario 3: Remove bus	61	<i>Virginia Tech Transportation Institute [32]</i>	75
Scenario 4: Replace a larger bus with smaller tripper	61	Green Highway Initiative	76
3DSS TESTING	61	Center for Sustainable Mobility.	77
<i>Sunny days</i>	61	<i>Kimley-Horn</i>	77
<i>Rainy days</i>	61	<i>Automation Creations, Inc. and Nomad Mobile Guides, Inc.</i>	77
<i>All days</i>	61	Automation Creations, Inc.	77
<i>Assumptions and parameters</i>	62	Nomad Mobile Guides, Inc.	79
<i>Test Results</i>	62	<i>Dynamic Data Systems</i>	79
Sunny Days	62	<i>Project management structure</i>	80
Rainy days	63	<i>Project management plan</i>	81
All days.	64	Scope Management	81
FUTURE TESTING.	66	Requirements Management	82
<i>Field operational testing</i>	66	Schedule Management	82
<i>Operational testing</i>	66	Financial Management	83
CONCLUSIONS AND CONSIDERATIONS FOR OTHER TRANSIT AGENCIES	66	Quality Management.	83
6. SUPPORTING SYSTEMS FOR DEMAND ASSESSMENT, FUEL CONSUMPTION MODELING, AND THE 3DSS	67	Resource Management	83



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Communication Management	83	<i>BT4U mobile application</i>	112
Change Management	84	BT4U mobile app RFP	112
Risk Management	84	BT4U mobile app description and functionality.....	119
Procurement Management.....	84	iBeacons	121
APPENDIX B: DEMAND ASSESSMENT.....	85	<i>Demand-assessment algorithm</i>	122
<i>Virginia Tech Institutional Review Board</i>	85	Demand assessment flow chart	123
<i>Survey summary report</i>	86	APPENDIX C: FUEL CONSUMPTION MODELING	124
Summary report	86	<i>Details of Problems and Solutions with the HEM</i>	
Campus traffic survey	101	<i>Data Logger</i>	124
<i>Focus group summary report</i>	103	<i>Bus Fuel Consumption Model — additional graphs</i>	125
Focus Groups.....	103	<i>Fuel Consumption Model Validation — additional graphs</i> ...	127
Participants	103	APPENDIX D: DYNAMIC DEMAND DISPATCHING	
Participant Protection	103	SUPPORT SYSTEM (3DSS).....	131
Qualitative Approach.....	103	<i>Dynamic Routing Implementations and Issues</i>	131
Findings	103	<i>3DSS Input Variables</i>	131
<i>Bus stop observation</i>	107	APPENDIX E: MARKETING	136
<i>BT4U website description of technology</i>	110	<i>TIGGER Marketing Plan</i>	136
History of BT4U	110	<i>Collegiate Times Article: Blacksburg Transit develops</i>	
BT4U Classic, web version description and functionality... ..	110	<i>first ever official mobile app</i>	140
		<i>Collegiate Times Article: BT4U introduces mobile app</i>	141
		10. REFERENCES	143



Transit Bus Routing On-Demand: Developing an Energy-Saving System

LIST OF FIGURES

Figure 2-1 Document Map — Conceptual Diagram of Project Flow.	4	Figure 3-18 Adhesive Passive RFID Tag with Barcode.	26
Figure 2-2 Night Festival in Blacksburg.	5	Figure 3-19 Wi-Fi and Bluetooth Logos.	27
Figure 2-3 Blacksburg Transit Bus on Virginia Tech Campus.	5	Figure 3-20 Document Map — Historical Demand.	30
Figure 2-4 Virginia Tech CRC Entrance and Sign.	6	Figure 3-21 Document Map — Demand Assessment Algorithm.	31
Figure 2-5 HHHunt Hethwood and Foxridge Sign.	6	Figure 3-22 Time Band per Trip and Stop.	33
Figure 2-6 Blacksburg Transit 60 ft. (18.2 m) Bus in Service Bay.	7	Figure 3-23 Decision Tree for Demand-Assessment Algorithm.	34
Figure 2-7 VTTI Smart Road Control Room.	8	Figure 3-24 Forecasting error reported for multiple methods, years, and alpha levels	35
Figure 3-1 Document Map — Demand Assessment.	9	Figure 3-25 Total number of riders, from fare data, collected by Blacksburg Transit for each school year since 2011.	36
Figure 3-2 Document Map — Components of Demand Assessment.	10	Figure 3-26 Absolute forecasting error reported for multiple methods, years, and alpha levels.	37
Figure 3-3 Document Map — Select Candidate Technologies.	10	Figure 4-1 Document Map — Fuel Consumption Modeling.	39
Figure 3-4 Document Map — Select Test Routes.	11	Figure 4-2 VTTI MiniDAS Vehicle Data-Collection Instrument with AA battery (left) and Mounted on a Bus (right).	43
Figure 3-5 Test Route Maps.	11	Figure 4-3 HEM Data Logger.	43
Figure 3-6 Hethwood B Bus on Test Route.	12	Figure 4-4 DashDAQ Vehicle Data-Collection Instrument.	44
Figure 3-7 Document Map — Survey and Focus Group.	12	Figure 4-5 Typical Power vs. Fuel Consumption Functional Form	47
Figure 3-8 Document Map — Bus Stop Observation.	15	Figure 4-6 Concave Aspect Bus Fuel Consumption Model; Bus 1911 as Example.	47
Figure 3-9 Graph of bus rider arrival location comparing shelter vs. no shelter (no time check stops included).	16	Figure 4-7 Example for Individual Model Validation for Two Conventional Diesel Buses.	49
Figure 3-10 Graph of bus rider arrival location comparing time check vs. not a time check (only sheltered stops included).	17	Figure 4-8 Example for Series Model Validation for Two Conventional Diesel Buses.	49
Figure 3-11 Bus Stop Arrival Distribution.	17	Figure 4-9 Individual Model Validation for Two Hybrid Buses.	49
Figure 3-12 Document Map — Evaluating Real-Time Demand Assessment Technologies.	18	Figure 4-10 Impact of Cruise Speed on Fuel Consumption Rate.	51
Figure 3-13 BT4U Icon.	18	Figure 4-11 Impact of Passenger Load on Fuel Consumption (left) and CO ₂ Emission (right) on Hybrid and Conventional Buses.	52
Figure 3-14 Student with BT4U Mobile App.	19		
Figure 3-15 BT4U Mobile App Home Screen.	20		
Figure 3-16 Typical Blacksburg Transit Bus Stop.	24		
Figure 3-17 Kiosk Installed at Blacksburg Transit Bus Stop.	25		



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Figure 4-12 Relative Fuel Consumption (left) and CO ₂ Emission (right) of 80-Passenger Hybrid and Conventional Buses (6011 and 1900 Series).....	53	Figure 9-7 BT4U Website LiveMap, Welcome Page.	111
Figure 4-13 Relative Fuel Consumption (left) and CO ₂ Emission (right) of 107-Passenger Hybrid and Conventional Buses (6021 and 6320 Series).....	53	Figure 9-8 BT4U Website LiveMap, Bus Stop Display..	111
Figure 4-14 Relative Fuel Consumption (left) and CO ₂ Emission (right) of 80-Passenger Hybrid and Conventional Buses when Cruising and when Stopped (6011 and 1900 Series).	54	Figure 9-9 BT4U Website LiveMap, Bus Stop Details Popup.	112
Figure 4-15 Relative Fuel Consumption (left) and CO ₂ Emission (right) of 107-Passenger Hybrid and Conventional Buses when Cruising and when Stopped (6021 and 6320 Series).	54	Figure 9-10 BT4U Mobile App Home Screen (Appendix).	119
Figure 4-16 Relative Fuel Consumption (left) and CO ₂ Emission (right) of One 107-Passenger Hybrid Bus and Two 80-Passenger Hybrid Buses.	55	Figure 9-11 BT4U Mobile App Screens, from Left to Right: Routes and Schedules, Route Details, Go Home!, and Visitors.	119
Figure 5-1 Document Map — 3DSS Algorithm.....	56	Figure 9-12 BT4U Mobile App Screens, from Left to Right: Entering Location and Destination, Selecting Timing Option, and Bus Arrival Times.	120
Figure 5-2 The 3DSS Framework.	60	Figure 9-13 BT4U Mobile App Screens: Contact BT.....	120
Figure 5-3 Comparison of Fuel Consumptions with and without 3DSS for October 2014.....	64	Figure 9-14 Demand Assessment Algorithm Flow Chart.....	123
Figure 5-4 Comparison of Greenhouse Emission of CO ₂ with and without 3DSS for October 2014.....	65	Figure 9-15 Fuel Consumption Model, Additional Graphs 1.	125
Figure 5-5 Comparison of LOS (wait time) with and without 3DSS for October 2014.....	65	Figure 9-16 Fuel Consumption Model, Additional Graphs 2.	126
Figure 6-1 Document Map — Supporting systems.	67	Figure 9-17 Fuel Consumption Model Validation for Conventional Diesel Buses, Additional Graphs 1.....	127
Figure 6-2 Framework of Supporting Systems.....	68	Figure 9-18 Fuel Consumption Model Validation for Conventional Diesel Buses, Additional Graphs 2.....	128
Figure 7-1 Tabletop Display at the BT/TIGGER Open House.....	71	Figure 9-19 Fuel Consumption Validation for Conventional Diesel Bus Series, Additional Graphs 1.....	129
Figure 9-1 Project Management Structure.	80	Figure 9-20 Fuel Consumption Validation for Conventional Diesel Bus Series, Additional Graphs 2.....	130
Figure 9-2 Passenger Arrival Rate Comparison by Headway.....	108	Figure 9-21 Fuel Consumption Validation for Hybrid Buses, Additional Graphs.....	130
Figure 9-3 Passenger Arrival Rate Comparison by Route for Stops with 15 min Headway.	108		
Figure 9-4 Passenger Arrival Rate Comparison by Stop for Stops with 10 min Headway.	109		
Figure 9-5 BT4U Website Screenshot, Setting Route Name and Stop Code.....	110		
Figure 9-6 BT4U Website Screenshot, Stop Times Displayed.	110		



Transit Bus Routing On-Demand: Developing an Energy-Saving System

LIST OF TABLES

Table 2-1 Project Goals and Objectives	3
Table 3-1 Respondent Willingness to Use Technology for Collecting Ridership and/or Real-Time Demand Data	13
Table 3-2 Number of iBeacon Events	22
Table 3-3 Demand Assessment Technologies Evaluation Summary	29
Table 3-4 Demand Assessment Technologies Testing Summary . . .	30
Table 4-1 Parameters Required for Model Calibration	42
Table 4-2 Manufacturer Information for Blacksburg Transit Buses	46
Table 4-3 Calibration Results for Individual Model and Series Model	48
Table 4-4 Coefficients of Determination for Validation	50
Table 4-5 Optimum Fuel Economy Cruise Speed for Each Bus and Each Bus Series	51
Table 5-1 3DSS Recommendations on Sunny Days	62
Table 5-2 Measured Results on Sunny Days	62
Table 5-3 3DSS Recommendations on Rainy Days	63
Table 5-4 Measured Results on Rainy Days	63
Table 6-1 Data Import Methods	69
Table 9-1 Technology Themes	104
Table 9-2 Bus Stop Observation — Stops and Observation Times	107
Table 9-3 Input Variables for 3DSS	131



Transit Bus Routing On-Demand: **Developing an Energy-Saving System**

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Transit Bus Routing On-Demand: **Developing an Energy-Saving System**

ABSTRACT

The goal of this project was to reduce greenhouse gas emissions by transit buses by using dynamic bus scheduling and size selection. Collaborators included Blacksburg Transit, the Virginia Tech Transportation Institute, and private consultants. The project had three major components: measuring and predicting demand for transit buses; calculating transit bus fuel consumption; and using both demand and fuel consumption data to generate recommendations for optimizing bus schedules and sizes to satisfy customers and reduce greenhouse gas emissions. Results include a thorough evaluation of nine technologies that could be used to measure demand, four of which were tested in a transit environment. The first fuel consumption model specific to transit buses was created, and shed light on the extent of fuel savings possible. A dynamic dispatching algorithm was developed that recommended changes to bus schedules and sizes in real time. Testing indicated that when the algorithm was run, buses consumed 10.6 percent less fuel than when buses followed the normal schedule, and wait times were kept below the 10-min threshold. This project demonstrates that collaborations between transit operators, research institutions, and industry consultants can produce high-quality research with positive applications for day-to-day transit operations.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

1. EXECUTIVE SUMMARY

This project's goal was to develop a dynamic, on-demand transit bus system responding to passenger demand by changing bus schedules and bus sizes. The transit system's response to demand occurred as close to real time as the team could achieve, and attempted to reduce fuel usage, and thus greenhouse gas (GHG) emissions, while maintaining or improving the level of service (LOS).

The project team included Blacksburg Transit, an agency with over 50 buses and a history of innovation and customer satisfaction, and the Virginia Tech Transportation Institute, the second-largest transportation research organization in the United States. Stakeholders included citizens of the Town of Blacksburg, students and employees at Virginia Tech, and the owners of residential and corporate facilities in the area, and the Federal Transport Administration.

The project team began in a test bed conducive to innovation, with an already-modern and reliable transit system, with the goals to better serve customers, save fuel, and reduce GHG emissions by tailoring bus services to rider demand. To achieve these goals three primary areas of research and development were targeted: passenger demand assessment, fuel consumption modeling, and the dispatch demand decision support system (3DSS). The team developed innovative approaches to meet this project's novel needs, including new hardware applications, software development, and communications systems development.

Multiple approaches were used to measure passenger demand. Historical stop-level ridership data shed light on how passengers have behaved in the past, and a variety of technologies were assessed for collecting real-time ridership data. Surveys and focus groups assessed passenger openness to an on-demand system and their attitudes towards passenger-counting devices. Technologies for passenger counting including analytical cameras at bus stops, radio frequency identification (RFID) tags, interactive kiosks at bus stops, thumbprint scanners, and Wi-Fi/Bluetooth media access control (MAC) identification were evaluated. A mobile device application was developed that provided users with information about bus routes, schedules and arrival times, allowed users to plan trips, and collected data regarding rider locations and destinations. iBeacons coupled with the mobile application tracked riders throughout the transit system. Of all the technologies evaluated, four were advanced into the testing stage: the BT4U mobile app, the BT4U mobile app with iBeacon integration, an interactive touch screen kiosk, and Wi-Fi MAC detection. The mobile BT4U app coupled with iBeacons proved the most promising demand-assessment technology, but further research is needed to better correlate demand data with actual ridership numbers. Historical ridership data were also used as part of an algorithm to predict near-term rider demand within a dynamic dispatching algorithm that provided recommendations to dispatchers for modifications to operations. Dispatchers could then remove buses from routes, replace a bus with one of a different size, and change bus schedules to reduce fuel consumption while maintaining or improving the overall LOS. The team gained valuable knowledge regarding all of the investigated demand-assessment technologies and the full report contains detailed recommendations regarding their potential use in transit.

In parallel with the demand-assessment portion of the project, a novel fuel-consumption model specific to transit buses was developed. The model incorporated engine type and efficiency, global navigation satellite system (GNSS) global positioning system (GPS) data, roadway slope, bus capacity, passenger load, and other factors, and estimated the amount of fuel consumed under various scenarios. That information was also used to inform the dynamic dispatching algorithm regarding decisions on bus scheduling and size selection. New approaches were developed to collect detailed bus-performance data, including installing multiple data-collection devices (i.e., data loggers) in various bus models, programming them to function in a transit environment, and ensuring accurate data acquisition and transfer. The fuel-consumption model was developed and validated for each bus type and was demonstrated as accurate, with an average coefficient of determination, R^2 value of 0.77 that varied depending on bus model. A detailed analysis was performed regarding the effects of bus capacity, bus powertrain type (conventional diesel vs. diesel-electric hybrid), and bus speed on fuel consumption. Hybrid buses were found to consume less fuel than conventional buses, and the optimal cruising speed for buses was found to be 40-50 km/h (25-31 mph). This portion of the project revealed clearly that many gains can be made regarding transit bus efficiency.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

The next portion of this project involved incorporating the passenger demand and fuel-consumption model data into an algorithm to determine whether or not rescheduling or removal/replacement of bus should be recommended to dispatchers. The algorithm, called the dynamic dispatching decision support system, or 3DSS, employed historical ridership and detailed fuel-consumption data as inputs, and as outputs recommended changes to the bus schedule and size selection on a minute-by-minute basis. The model was calibrated and tested by running a simulation using one month's data for the year 2014. Results indicated that when 3DSS was run on one bus route for one month, buses consumed 10.6 percent less fuel overall than when 3DSS was not run. Field operational testing was not performed because the project concluded before the low-ridership summer months, the best time to test new systems, and because of other logistical hurdles.

Demand assessment, fuel consumption modeling and the 3DSS algorithm relied on database and communications systems. A large amount of disparate data had to be collected, transferred, and stored before it could be used by 3DSS, and the team devised methods to do so largely using existing systems. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies are maturing, and could be easily applied to similar efforts.

Throughout the project marketing efforts educated riders and community stakeholders on the benefits of adaptive transit bus scheduling. Early in the project an open house was held to inform the community of the project and its partners, and goals. The team also worked with stakeholders at Virginia Tech and the Town of Blacksburg, including the mayor. When marketing the mobile application, Blacksburg Transit employees utilized a boots-on-the ground approach, visiting popular bus stops, to let riders know about the mobile application and its benefits. Team members informed riders of the benefits of adaptive scheduling and bus size selection, how they could participate in the project, and how they could keep track of bus arrival times.

The transit community can learn a great deal from the results of this project. The team gained a better understanding of multiple technologies that could be used for demand assessment, including camera analytics (computer vision) and mobile-application development. The team created a novel fuel-consumption model for transit buses, requiring new applications for bus-monitoring hardware and communication systems. By introducing the concept of dynamic bus scheduling and size selection, the team challenged the status quo of transit, a necessary step towards developing a more environmentally-friendly transit network, needed as societies move towards more sustainable transportation alternatives.

This project was the result of a collaboration between academicians, transit operators, and industry consultants, leading to a more valid and applicable outcome than could be achieved by any one of these entities alone. The team approached the project with academic rigor, but also kept the project's real-life applications in focus throughout. The product of this project, the 3DSS algorithm, was vetted by the final client – transit operators – and has demonstrated the potential to reduce transit bus GHG emissions by 10 percent or more.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

2. BACKGROUND

INTRODUCTION

A major goal of the United States Environmental Protection Agency is reducing greenhouse gas (GHG) emissions. Fossil fuel combustion comprises most anthropogenic GHG emissions, with electricity generation producing 38 percent and transportation producing 32 percent [1].

When run at capacity transit buses can get more than six times the passenger miles-per-gallon of fuel than a typical passenger car carrying only one person [2]. That comparative fuel efficiency, though, assumes the bus operates at capacity, which is rarely the case, and that passenger cars carry only the driver, which is not always the case either [3]. Thus, when run with few or no passengers, transit buses produce significantly more GHGs than typical passenger vehicles [3] on a per passenger-mile basis.

To optimize transit buses so they consume less fuel per passenger than cars, transit agencies must run buses at as close to capacity as possible. When demand is low this can be accomplished by running smaller or fewer buses. Passenger expectations must be met, though, because passengers will choose transit options that best suit their needs. If transit buses are unpredictable and inconvenient, passengers are more likely to drive personal vehicles, possibly resulting in more GHG emissions. A balance must be struck between on-demand service and passenger convenience, and this project sought to do so.

GOALS AND OBJECTIVES

TABLE 2-1 PROJECT GOALS AND OBJECTIVES

GOAL	OBJECTIVES
Reduce Fuel Use and Thus CO ₂ Emissions	Upon project completion, the team will have reduced transit bus emission rates and fuel usage by managing bus schedules and sizes to match passenger demand. Bus schedules and size will also depend on demand, bus fuel usage, and route geography.
Increase Overall System Efficiency	Upon project completion, bus scheduling will be more efficient. Buses will be sent where and when they are needed using a custom dynamic-modeling algorithm.
Increase Customer Satisfaction	Upon project completion, customers will be more informed about bus arrivals and schedule changes. They will experience less overcrowding because more buses will be deployed during times of heavy demand. Customers will also be informed of the team's efforts to save energy.

CHALLENGES AND CONSIDERATIONS

There are a number of challenges when it comes to collecting rider-demand data; creating a model for fuel consumption for all possible buses, passenger loads, and routes; developing an algorithm for determining when a route change is necessary; and disseminating the information to dispatchers and bus operators in time for them to re-route or change buses.

Finding a technology that can collect accurate rider-demand data in real time without violating passenger privacy is a major obstacle, as is securing or deleting any data that might be considered sensitive, such as video data of bus stops. Modeling fuel consumption is a complex, multi-faceted problem, requiring collaboration between geographic-information-systems specialists, vehicle-instrumentation specialists, and software developers. The infrastructure and communications technology to collect and transfer the demand and fuel-consumption data must also be developed.

Lastly, passenger responses to dynamic scheduling should be considered. Passengers need to be reasonably confident that a bus will show up as scheduled. Dynamic scheduling and bus selection should not violate that expectation. Riders should be familiarized with, and sympathetic to, the goals of the dynamic-scheduling and bus-size-selection system, and all changes to the schedule must be communicated to all potential riders in order to avoid issues.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

PROJECT AND REPORT OVERVIEW

This chapter continues to describe the project's test bed, stakeholders, and collaborators. The following sections describe the project's main components, into which such a large undertaking was necessarily broken down. The project flow is illustrated conceptually in Figure 2-1 below. Portions of this diagram will be broken out for reference as each concept is described more fully in this document.

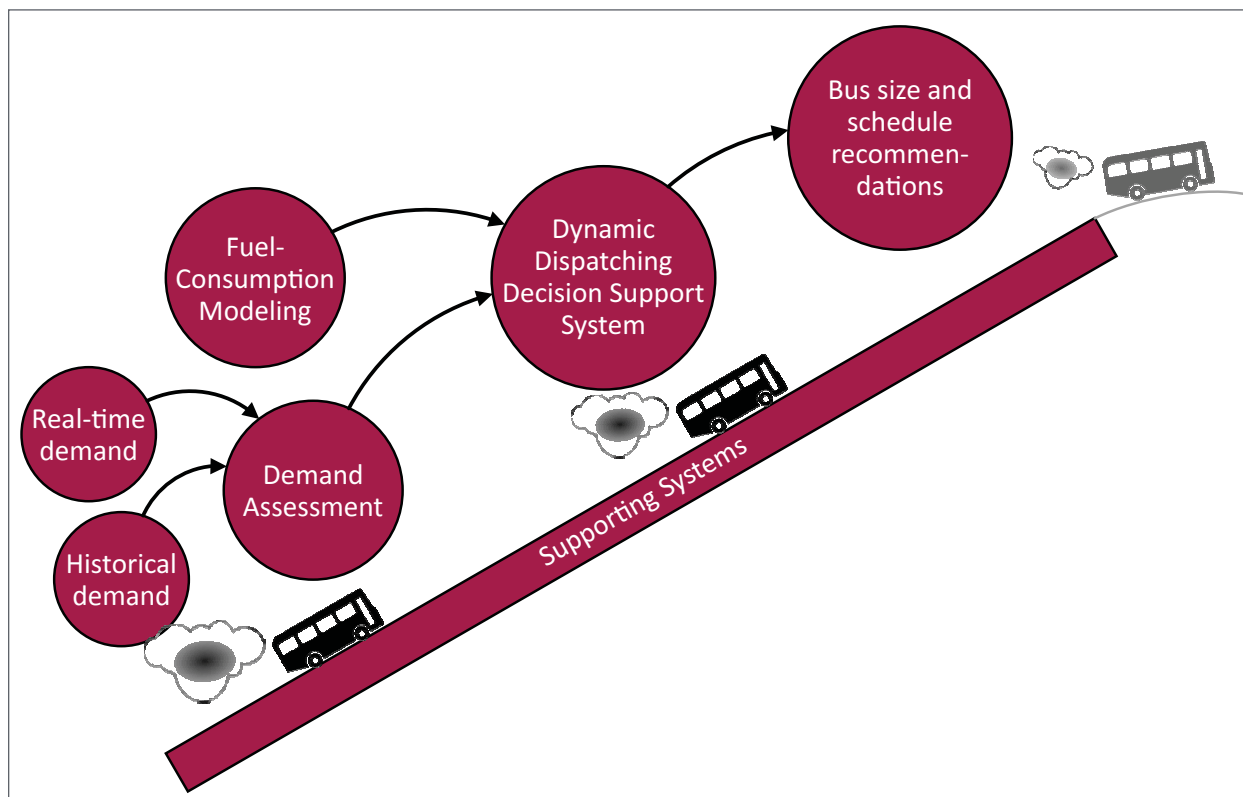


FIGURE 2-1 DOCUMENT MAP — CONCEPTUAL DIAGRAM OF PROJECT FLOW

To create a transit bus system that reacts in real time to passenger requirements that demand must be measured. Section 3.0, Assessing Demand for Transit Buses, describes the team's efforts to measure demand at bus stops using a variety of technologies and the team's development of a forecasting algorithm that can predict demand at a bus stop for a given date and time of day.

To help measure the effect changes in bus scheduling and size selection would have on a bus' fuel consumption and GHG emissions, the fuel consumption rates of Blacksburg Transit's fleet were accurately modeled using specially-developed modeling techniques. That modeling process is described in Section 4.0, Modeling Fuel Consumption.

Data regarding passenger demand and fuel consumption both influence the optimization of transit bus schedule and size selection, because the project goals are twofold – reduce GHG emissions and meet passenger expectations. Section 5.0, The Dynamic Dispatching Decision Support System (3DSS), describes the development of an algorithm that takes as inputs both fuel-consumption and passenger demand data, and recommends to transit dispatchers changes to bus schedules and sizes.

The interaction of demand assessment, fuel-consumption modeling, and the 3DSS algorithm require complex data communications and database integration, described in Section 6.0, Supporting Systems for Demand Assessment, Fuel Consumption Modeling, and the 3DSS. Throughout the project, the team worked to include and inform project stakeholders, efforts described in Section 7.0, Engaging Stakeholders. Each project section and subsection includes lessons learned, conclusions, and take-away messages for other transit agencies interested in pursuing any of the work performed here. The report ends with Section 8.0: TIGGER Project Results and Conclusions.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

AN IDEAL TESTING ENVIRONMENT

The overlap of research, innovation, and transit make the Blacksburg area an excellent location to test research targeted by programs like TIGGER.

The Town of Blacksburg

Blacksburg has a population of approximately 42,000 and is heavily influenced by Virginia Tech – 60 percent of Blacksburg residents are students. In 2011, Blacksburg was named by Businessweek as the “Best Place in the U.S. to Raise Kids” and by Southern Living as the “Best College Town in the South.”

Many Blacksburg residents are environmentally aware [4], amenable to new technology, and forward thinking [5], making the area excellent for testing energy-saving transit innovations.



FIGURE 2-2 NIGHT FESTIVAL IN BLACKSBURG

Blacksburg Transit

Blacksburg Transit serves Blacksburg and Virginia Tech, where over 22,000 undergraduate and graduate students live off campus. Blacksburg Transit links Blacksburg’s major residential areas with the university, making transit an integral part of the community. Blacksburg Transit has the seventh highest ridership in Virginia, with 45.9 passengers per revenue hour, and is a major employer of Virginia Tech students and community members. It has a history of innovation, uses hybrid buses, and has developed a custom online and phone accessible service, BT4U, to keep its riders updated on actual (not scheduled) bus arrival times. Blacksburg Transit’s high ridership, excellent service history, and technological awareness makes it well suited for transit innovation.

Virginia Tech and the Virginia Tech Transportation Institute (VTTI)

Virginia Tech is one of the nation’s top research universities, with seven interdisciplinary research institutes and dozens of departmental-level research centers. It has a dynamic and innovative population and vibrant student life, with hundreds of student clubs and organizations, and a popular football program.

VTTI is one of the nation’s top transportation research institutions, and is home of the Smart Road, a dedicated vehicle and infrastructure test bed.

Ninety percent of Blacksburg Transit riders are Virginia Tech students, five percent are Virginia Tech faculty, and five percent are other community members. Its ridership, being young, educated, and affiliated with a large research university, are potentially more amenable to participating in research to reduce fuel consumption and GHG emissions than residents in typical areas served by transit, making the Blacksburg area an excellent test bed for this TIGGER-funded project.



FIGURE 2-3 BLACKSBURG TRANSIT BUS ON VIRGINIA TECH CAMPUS



Transit Bus Routing On-Demand: Developing an Energy-Saving System

STAKEHOLDERS

Town of Blacksburg

Blacksburg's approximately 42,000 residents could benefit from a more efficient and environmentally-friendly transit service.

Virginia Tech

Virginia Tech is home to about 31,000 graduate and undergraduate students, and the Virginia Tech community would benefit from more efficient and dependable buses, and lower transit fees, because 90 percent of riders are Virginia Tech affiliates.

Virginia Tech Corporate Research Center

The Virginia Tech Corporate Research Center (CRC) was created in 1985 and is located less than a mile from campus. It houses local businesses, including startups and established corporations, and is home to the Virginia College of Osteopathic Medicine. Students and professionals use Blacksburg Transit buses to travel to CRC from campus.



FIGURE 2-4 VIRGINIA TECH CRC ENTRANCE AND SIGN

Hethwood

Hethwood is a housing development in Blacksburg, VA. Hethwood is owned by HHHunt, a real estate group headquartered in Blacksburg that has developments throughout the region. In Blacksburg, Hethwood contains Foxridge, a popular student-housing complex served by Blacksburg Transit buses. If off-campus housing were better served by public transportation, real-estate companies like Hethwood would benefit from more demand for that housing.

Hethwood management allowed the project team to observe bus stops at and near Foxridge, to hold focus groups at a Hethwood location, and helped the project team disseminate information about the project via email and newsletters.



FIGURE 2-5 HHHUNT HETHWOOD AND FOXBRIDGE SIGN

The stakeholder groups listed here are not mutually-exclusive; Blacksburg residents include Virginia Tech students, who might work at the Corporate Research Center and live in Hethwood housing.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Organization of project team

The Special Projects Manager at Blacksburg Transit was the leader for this research effort. His team included information-technology systems and project-administration specialists. He collaborated with VTTI's directors of the Eco-Transportation and Alternative Technologies group and the Center for Sustainable Mobility, as well as the president of Automation Creations, Inc. and managing director of Nomad Mobile Guides, Inc., to coordinate project tasks. The overall project was managed by representatives of Kimley-Horn and Associates (Kimley-Horn). A diagram of the project management structure and staff is in "Project management structure" in Appendix A: Project collaborators, stakeholders, and consultants.

COLLABORATORS

Blacksburg Transit

Blacksburg Transit serves the Blacksburg area, home to Virginia Tech, a large research university, as well as the surrounding communities. Half of BT's revenue comes from Virginia Tech, which charges students a yearly fee; in return, students can board Blacksburg Transit buses using their Virginia Tech ID card, called a Hokie Passport. Operating since 1983, Blacksburg Transit has grown from five buses to over 50, including 35-foot, 40-foot, and articulating 60-foot buses; each bus type has a different capacity and fuel-consumption profile, adding flexibility to bus-size selection. Blacksburg Transit has a department dedicated to information-technology services, and, in 2009, developed an application allowing riders to text, phone or use the web to look up predicted departure information for stops they commonly use, called

BT4U. In 2013, a version of BT4U including a map and near-real-time bus tracking was released. Using the 2013 app, users could get real-time information on bus location, passenger load, and the next three predicted stop times. Blacksburg Transit also has a marketing department experienced at outreach and rider education, crucial for preparing the community for changes in transit services.

Blacksburg Transit also follows a variety of schedules, depending on Virginia Tech's academic calendar and special events, so schedule changes are customary and less disruptive for Blacksburg Transit staff than for other, more traditional, transit organizations.

Blacksburg Transit has the range of traits needed for testing new technologies: an amenable ridership; a decades-long service history; scheduling flexibility; a variety of buses; and dedication to new technologies and communication with the community. For more information on BT, please see "Blacksburg Transit [31]" in the Appendices.

The Virginia Tech Transportation Institute

The Virginia Tech Transportation Institute (VTTI) is a leading transportation research organization, with over 350 employees and over \$40 million annually in sponsored-research expenditures. Throughout its history, research from VTTI has influenced public policy to increase safety and reduce the environmental impact of transportation. Two research teams at VTTI contributed expertise to this TIGGER project. The Eco-Transportation and Alternative Technologies (ETAT) group is dedicated to developing sustainable transportation, including researching technologies that reduce fuel consumption and GHG emissions, and was the primary group collaborating with Blacksburg Transit on this



FIGURE 2-6 BLACKSBURG TRANSIT 60 FT. (18.2 M) BUS IN SERVICE BAY



Transit Bus Routing On-Demand: Developing an Energy-Saving System



FIGURE 2-7 VTTI SMART ROAD CONTROL ROOM

project. The ETAT group includes specialists in industrial engineering, in-vehicle data acquisition, and project management. VTTI's Center for Sustainable Mobility (CSM) conducts research relevant to society's transportation mobility, sustainability, dynamic traffic assessment, environmental modeling, and safety needs, and has developed and tested eco-routing, eco-drive and eco-cooperative adaptive cruise control systems. CSM is world renowned for vehicle energy and emission modeling, and brings high-level transportation modeling knowledge to the project. See "Virginia Tech Transportation Institute [32]" in the appendices for more information on VTTI

SUBCONTRACTORS

Kimley-Horn

Kimley-Horn is one of the top civil engineering consulting firms in the United States. They provide project management services, technical support, and systems engineering expertise. Kimley-Horn was chosen primarily to provide project management support, including the creation of a project schedule, facilitation of team meetings, and risk management and mitigation. They have also used a systems engineering approach to assist with technical support and meet federal guidelines. The project management plan is included in "Appendix A: Project collaborators, stakeholders, and consultants."

Automation Creations, Inc. and Nomad Mobile Guides

Automation Creations, Inc. and Nomad Mobile Guides, Inc. partnered to deliver a custom mobile application for this project. Automation Creations developed the interactive data management system for the mobile application, while Nomad Mobile Guides, Inc., created the custom user interface. More information about both companies is available in Appendix A: Project collaborators, stakeholders, and consultants.

Dynamic Data Systems, LLC

Dynamic Data Systems, LLC, helped create the database and communication channels to support the project's efforts. The database provides an organized structure for fuel consumption, demand assessment, and operational data.

Virginia Tech Center for Survey Research

The Virginia Tech Center for Survey Research (CSR) was subcontracted to perform surveys regarding demand assessment and rider attitudes about demand-assessment technology. The CSR performs social and demographic research via the web, phone, and mail for Virginia Tech community members, and public and private organizations.



3. ASSESSING DEMAND FOR TRANSIT BUSES

OVERVIEW

The goal of demand assessment (Figure 3-1) was to collect real-time demand data and to analyze historical demand data, which, in combination, can be used to forecast a transit system's demand at the stop level. That demand data was fed into the 3DSS algorithm, which incorporated it with fuel-consumption data to output bus size and schedule recommendations for minimizing GHG emissions while satisfying passenger expectations.

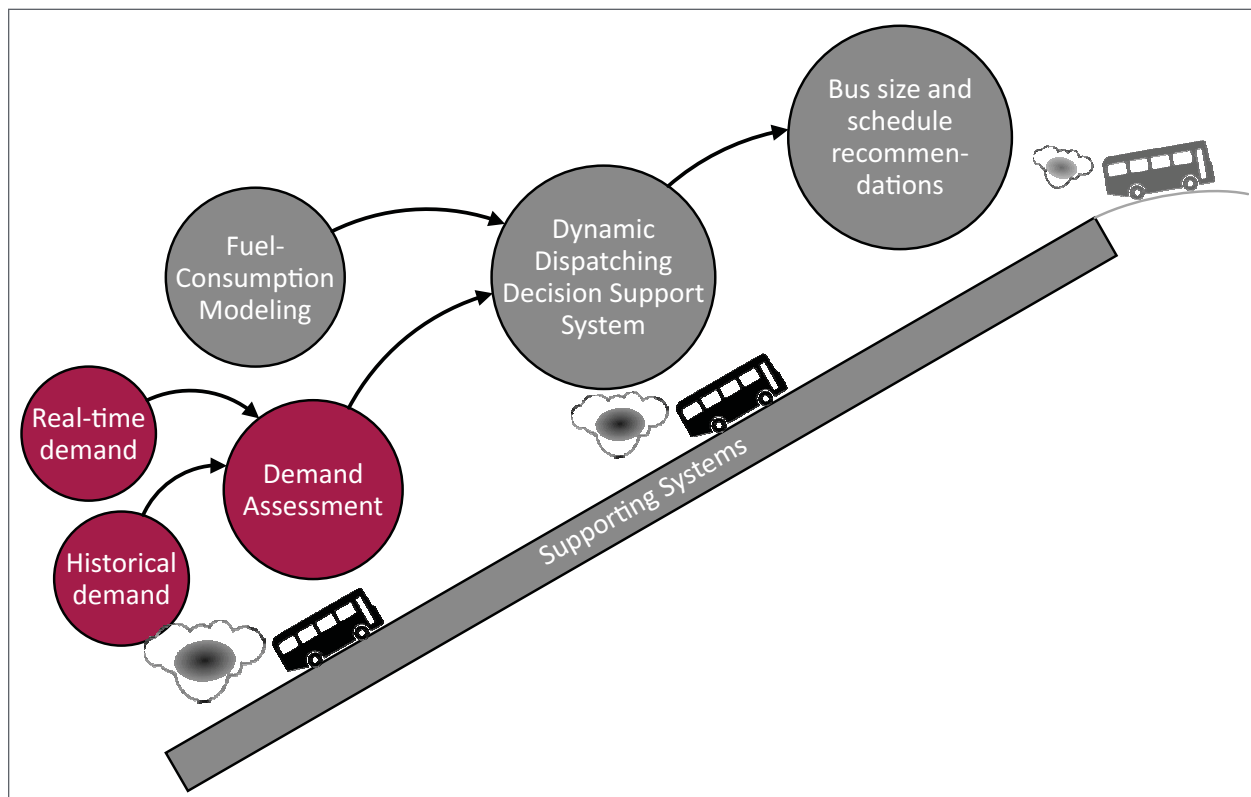


FIGURE 3-1 DOCUMENT MAP — DEMAND ASSESSMENT

Assessing demand was the first and most complex of this project's components, and incorporated a number of subcomponents, as diagrammed in Figure 3-2 and described below the figure.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

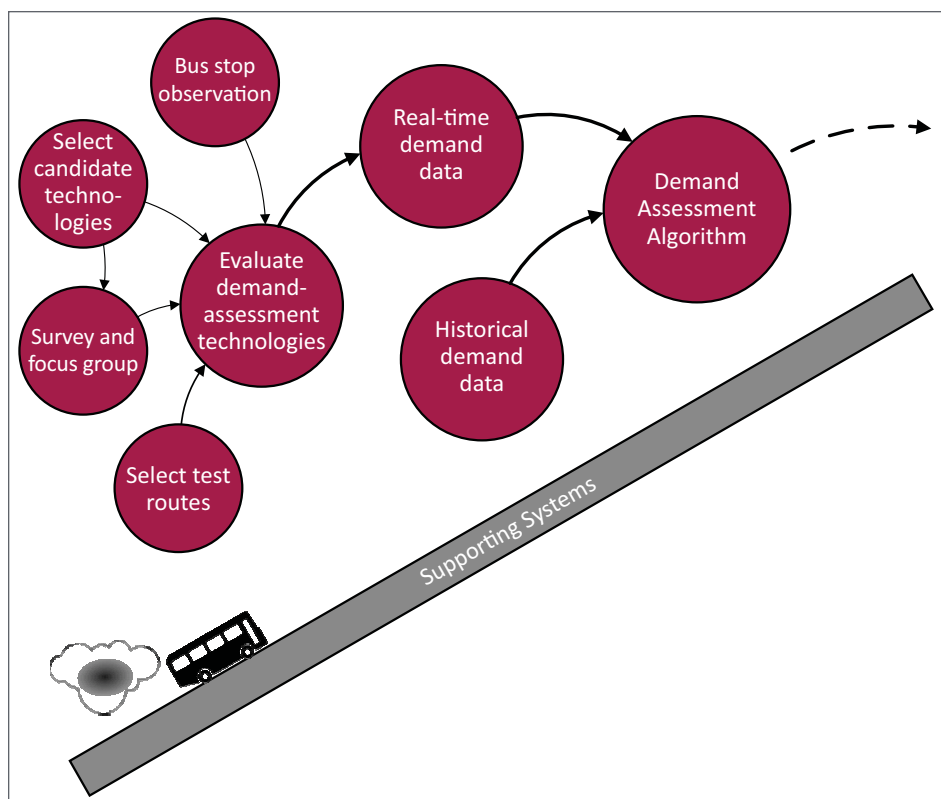


FIGURE 3-2 DOCUMENT MAP — COMPONENTS OF DEMAND ASSESSMENT

The first component of demand assessment was researching and testing technologies for assessing real-time demand. Investigating demand-assessment technologies was the largest and most complex of the three demand-assessment components, and included four subcomponents: selecting candidate demand-assessment technologies; determining test routes; conducting a survey and focus group collecting data on how accepting Blacksburg Transit's riders would be of the candidate technologies; observing rider behavior at bus stops and assessing how that behavior affects technology selection. The information from those subcomponents was used to inform the research and evaluation of the candidate demand-assessment technologies. The second component of the research on demand assessment was collecting and analyzing historical demand data. The third component was developing of an algorithm to forecast demand based on the data provided by the first two components. The results of the algorithm were incorporated by the 3DSS algorithm.

SELECTING CANDIDATE DEMAND-ASSESSMENT TECHNOLOGIES

The project team attempted to evaluate as many varied demand-assessment technologies as possible. Key criteria were that any system measuring the number of passengers intending to take buses must accurately count passengers, predict or collect information on their destinations, and be able to communicate that data in real time to the necessary databases and algorithms. The system should also be nonintrusive, protect passenger privacy, be easy to use, encourage passenger compliance. Nine demand-assessment technologies were identified, and are listed below. The technologies, their evaluation and testing, and recommendations to other transit agencies are provided after a description of the test routes and rider characterization.

- Modifying the **BT4U** phone, text and web interfaces to collect demand data;
- Designing a **BT4U mobile application**, where passengers can check in and input their destination;
- Integrating **iBeacons** with the BT4U mobile application so passengers can be tracked through the system using wireless technology;
- Using **cameras** and image analysis at bus stops to count waiting passengers;
- Having passengers swipe their **Hokie Passport** cards, or another type of bus card, at bus stops;
- Equipping bus stops with **kiosks**, where passengers can check in and input their destinations;
- Having passengers carry radio-frequency identification (**RFID**) mechanisms that are read at the bus stops and tracked throughout the transport system;
- Having passengers **scan their thumbprints** at bus stops; and
- Tracking passengers by detecting their **Wi-Fi- or Bluetooth** MAC IDs.

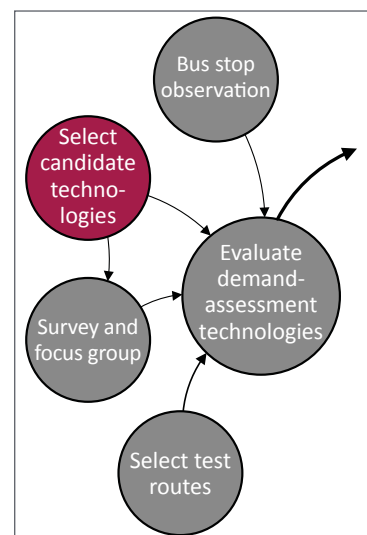


FIGURE 3-3 DOCUMENT
MAP — SELECT CANDIDATE
TECHNOLOGIES

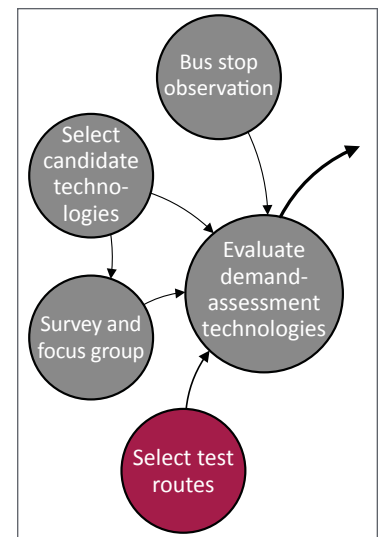


Transit Bus Routing On-Demand: Developing an Energy-Saving System

The investigation into demand-assessment technologies did not occur concurrently; instead, it evolved as the team gained knowledge and experience, as some technologies once considered promising were ruled out, and other technologies were identified. Therefore, some technologies listed here were not included in the survey and focus groups because they had not been identified at that point in the project. For simplicity, the technologies are listed and described together, despite differences timing of in their evaluation.

SELECTING TEST ROUTES

Test routes were selected for evaluating the demand-assessment technologies. The first test route, a combination of the Hethwood A and B routes, serves a popular area of student housing, and the routes' ridership mostly consists of students commuting to and from Virginia Tech. Other Blacksburg Transit routes also have high student ridership, but serve shopping areas and off-campus study areas, reducing the percent of student commuters. The Hethwood B route travels through more of the student-housing area than the Hethwood A route, and both are shown in Figure 3-5. The second test route serves the Corporate Research Center (CRC) at Virginia Tech. That route's riders were thought to consist of faculty, staff and professionals commuting to and from work, as well as medical students and professionals working at the Virginia College of Osteopathic Medicine, located in the CRC. It is also shown in Figure 3-5.



**FIGURE 3-4 DOCUMENT MAP
— SELECT TEST ROUTES**

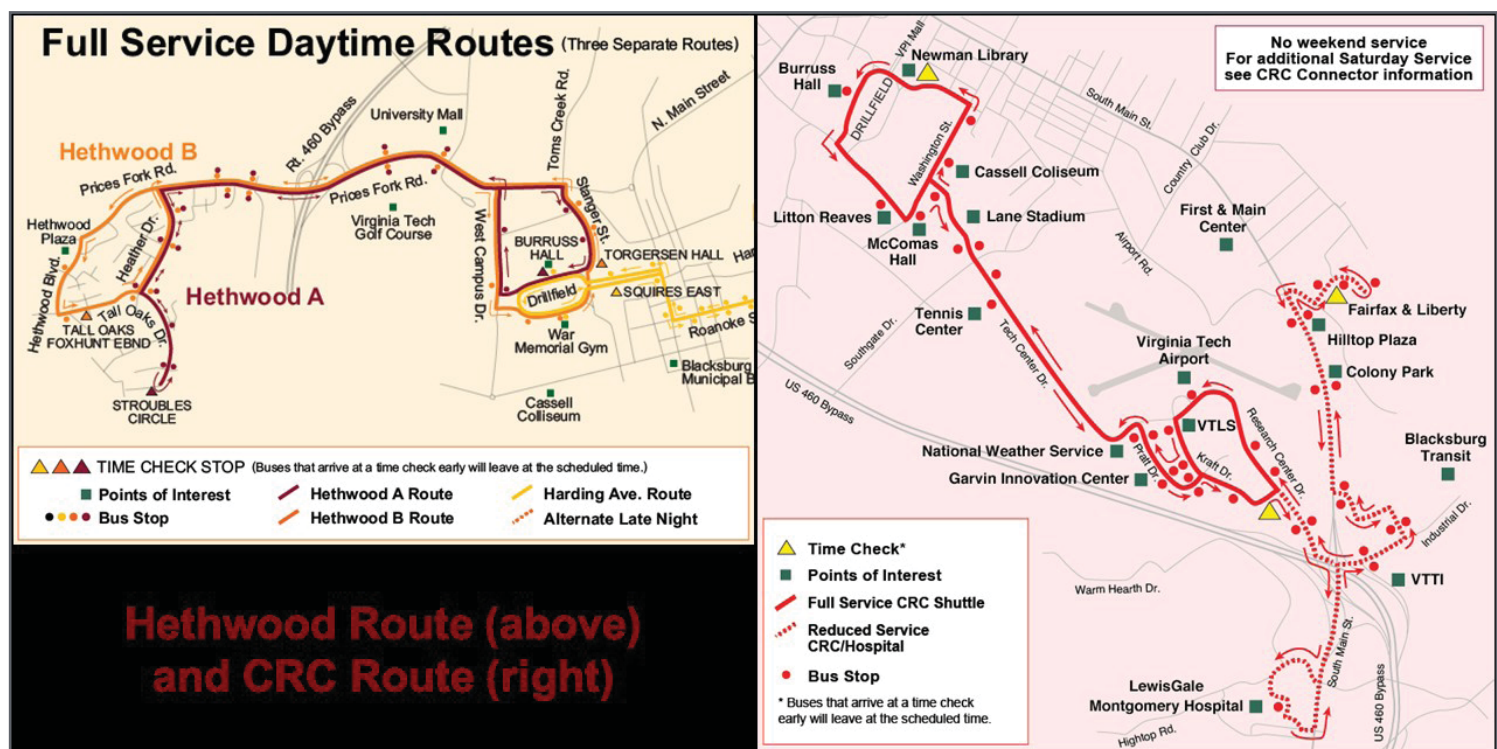


FIGURE 3-5 TEST ROUTE MAPS



Transit Bus Routing On-Demand: Developing an Energy-Saving System

The combination of the test routes encompasses a number of rider demographics. Also, the selected routes are mostly isolated from other routes, so the team can assume riders at a bus stop on each of the selected routes intend to travel on that route.

The rider survey, focus groups, and bus-stop observation were focused on the test routes, and the demand-assessment technologies selected for testing were tested on the test routes to the extent possible.



FIGURE 3-6 HETHWOOD B BUS ON TEST ROUTE

CHARACTERIZING RIDERSHIP

Survey purpose and design

The research team wanted to collect information on ridership, including rider demographics, motivation for using Blacksburg Transit buses, and opinions on technologies that could be used to collect real-time demand data. To do so, Blacksburg Transit and VTTI retained the Virginia Tech Center for Survey Research (CSR) to design and administer a survey and analyze its results.

Representatives from Blacksburg Transit worked with members of the CSR to develop the survey. Most survey questions fell into three categories: (a) rider usage and satisfaction, (b) rider willingness to accept on-demand scheduling, (c) rider willingness to use various technologies for real-time demand assessment.

The survey was administered via email and sent to 7,000 randomly-selected individuals affiliated with Virginia Tech, of whom 1,182 responded.

Survey results

Demographics and ridership

Of those who responded, 537 were students, 645 were faculty or staff at Virginia Tech. Over a third (35 percent) ride a Blacksburg Transit bus once a week. Of those, 40 percent ride the bus more than once a day. Most riders (62 percent) were under 25 years old, 22 percent were 25-34, and only 16 percent were over 35. Most riders used Blacksburg Transit to save time (60 percent), avoid having to park (60 percent), avoid inclement weather (55 percent), and avoid traffic (28 percent). About a third of riders use each of the three most-used routes: University City Boulevard; Toms Creek; and Main Street. The test routes for this project, Hethwood and CRC/Hospital, were used by 20 percent and 17 percent of respondents, respectively. The majority of riders (91 percent) were satisfied or very satisfied with the Blacksburg Transit service, and only 2 percent were very dissatisfied.

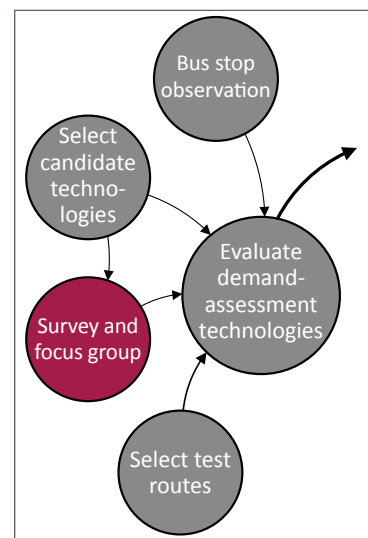
Rider response to technology and energy-saving measures

More than half (65 percent) of riders were willing to wait a couple of minutes longer for a bus if it meant reducing GHG emissions, even though time was a major reason for using Blacksburg Transit in the first place.

Most riders own a smart phone (82 percent), which could be used for the Wi-Fi and mobile application methods for collecting demand data. Younger respondents were more likely to own smartphones.

Positive rankings for all technologies were lower for non-riders compared to riders, some more so than others.

Some technologies (i.e., camera, Wi-Fi/Bluetooth, App, and thumb scanner) were accepted more by younger responders than older responders. This is likely because younger riders likely have more exposure and familiarity to these technologies.



**FIGURE 3-7 DOCUMENT MAP
— SURVEY AND FOCUS GROUP**



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Results for respondent willingness to use technology for collecting ridership and real-time demand data, indicated by a response of “very likely” or “somewhat likely,” are shown in order of most willing to least willing in Table 3-1.

TABLE 3-1 RESPONDENT WILLINGNESS TO USE TECHNOLOGY FOR COLLECTING RIDERSHIP AND/OR REAL-TIME DEMAND DATA

SCENARIO	RIDER WILLINGNESS TO USE TECHNOLOGY (RESPONSE OF “VERY LIKELY” OR “SOMEWHAT LIKELY”)
Imaging system counts riders at stops	62.0%
Riders swipe Hokie ID card when boarding and exiting bus	56.1%
Rider enters planned trip into kiosk at bus stop	48.8%
Rider enters boarding and exiting stops into mobile app	43.7%
A reader counts and tracks Wi-Fi devices (i.e. rider smart phones) at bus stops	41.5%
RFID tags are issued to passengers, and are used to count and track paddings	39.1%
Riders use the current version of BT4U to call, text, or use the internet, to report boarding and exiting bus stops.	33.4%
Riders scan their thumbs when they board and exit buses.	23.2%

Analysis of the free-response question asking what riders would improve in the Blacksburg Transit bus service showed that many riders would like a mobile application for finding out bus arrival times, more service at peak times, more efficient routes, and more punctuality.

For details on the survey design, question, and responses, refer to the “Survey” section in the appendices.

Focus group purpose and design

To gather more detailed information on rider willingness to use technology to decrease GHG emissions from transit buses, VTTI assembled three focus groups of Blacksburg Transit riders. The first group was composed of professionals who typically ride the Virginia Tech CRC Center bus route, the second and third groups were composed of Hethwood residents. Each group discussed why and how often they ride the Blacksburg Transit buses and their general comfort with technology. After that, the groups brainstormed on how they felt about using each demand-assessment technology.

All potential participants were screened for eligibility based on age (over 18) and Blacksburg Transit ridership (must be Blacksburg Transit riders).

Focus group results

A data-analyst listened to the focus-group tapes and reviewed notes to identify themes brought up by participants regarding the demand-assessment technologies. In general, participants wanted a reliable, easy-to-use and easy-to-access system that they can opt in or out of using, and that would not track their identities. Specific themes affecting rider comfort and satisfaction are reported below; themes not relevant to their comfort and willingness to use the technology, like participants wondering how a technology would work or be implemented, are not reported in this section. The appendices contain a “Focus group summary report.”



Transit Bus Routing On-Demand: Developing an Energy-Saving System

BT4U

- *Accessible* – It works on multiple devices and via multiple modalities (positive). Users have to know the stop names for it to work (negative).
- *Convenience* – Users have to listen to the whole message even if they know the number they want to punch (negative). Is helpful, efficient, and low-cost (positive).
- *Reliability of Technology* – The current version of BT4U has bugs, freezes up, stops working at night, is slow during peak hours, and can be inaccurate.
- *Recommendations* – Participants suggested the system alert people when the schedule changes, with people able to opt out of alerts.

BT4U mobile application

- *Education* – Riders would have to be educated on how to use the app, and how to not confuse the BT4U mobile app for another app.
- *Inclusiveness* – The app would need to be usable on diverse platforms, and alternatives to the app, like BT4U, would have to be provided to those without smart phones.
- *Privacy* – Participants said they preferred having to check in/opt in to the app, instead of having the app track demand automatically.
- *Reliability* – The app should provide accurate, up-to-date information on bus arrivals.

Cameras

- *Accessibility* – Riders would not be required to do anything for the camera system to collect data.
- *Cost* – Riders might not want ticket prices to go up to pay for camera technology.
- *Education* – Blacksburg Transit would need to explain what the cameras are for, because they might be confused for a security feature.
- *Privacy* – The cameras might be hacked and their images could be seen.
- *Security* – Cameras could add security to bus stops.
- *Vandalism* – Cameras might be vandalized, affecting bus service.

Hokie Passport swipe

- *Convenience* – No additional action would be required by riders, who would swipe their cards.
- *Education* – Riders would have to be educated to know to swipe their cards so the system can collect demand data.
- *Inclusiveness* – Riders who do not have Hokie Passports could not use the system.
- *Privacy* – The Hokie Passport is a non-invasive and impersonal way to collect rider-demand data.
- *Reliability* – Because it would require riders to perform an action, and they might not do so, it might not be the most accurate way to collect demand data.
- *Recommendations* – Have riders swipe cards at the bus stop, instead of upon boarding, so they wouldn't have to wait to board. Have cards be scanned instead of swiped, because it is faster.

Kiosks

- *Comparative technologies* – Kiosks might be outdated compared to other technologies, and are prone to vandalism and weather.
- *Cost* – Rider fees might go up to purchase expensive kiosks.
- *Inclusive* – Kiosks would let riders without smartphones or other devices access the bus-scheduling system.
- *Inconvenient* – Riders might not want to use them because it would take time, or because they might be unsanitary.
- *Reliability* – Vandalism, riders not checking in, and riders checking in multiple times might affect reliability.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

RFID

- *Convenience* – Riders might not want to carry another card or keychain.
- *Recommendation* – Feedback should be given, so riders know they have been counted.
- *Privacy* – The RFID information should not be linked to identity information.

Thumb scan

- *Convenience* – Riders might not want to wait to scan their thumbs.
- *Hygiene* – A thumb scanner might harbor germs.
- *Privacy* – The thumb-scanner system could be hacked and identities stolen.
- *Reliability* – Thumb scanners sometimes do not work correctly. Riders could scan multiple fingers to get the bus to come more quickly.

Wi-Fi or Bluetooth detection

- *Cost* – Wi-Fi and/or Bluetooth detection technology could be costly.
- *Inclusiveness* – Not all passengers have a Wi-Fi/Bluetooth device.
- *Invasiveness* – Wi-Fi detection is a non-invasive solution for assessing demand (positive); a system that requires people to check in might be better (negative).
- *Security* – The system could be hacked.

Bus stop observation

Bus stops were observed to collect data on passenger behavior to complement the data on rider attitudes and preferences. The goal of the bus stop observation was twofold: (1) to characterize rider behavior at bus stop and identify demand-assessment technologies compatible with that behavior; and (2), to count passenger arrivals and find an arrival-time distribution. If passenger arrival distributions are consistent, the arrival rate at one point in time could predict that at a future point in time, and be potentially accurate to the minute.

Data collection

To collect bus stop arrival data, research team members first went to bus stops and observed rider behavior. Then, VTTI equipped a solar-powered trailer with a five-megapixel IP camera, and placed it near eight different bus stops for between 10.5 and 120 hours each. The stops and days/times of observation were selected to reflect multiple routes, headways, and stop order with respect to time checks, which serve to regularize arrival times. Details regarding selected stops and the days/times they were observed are listed under Bus stop observation in Appendix B: Demand assessment.

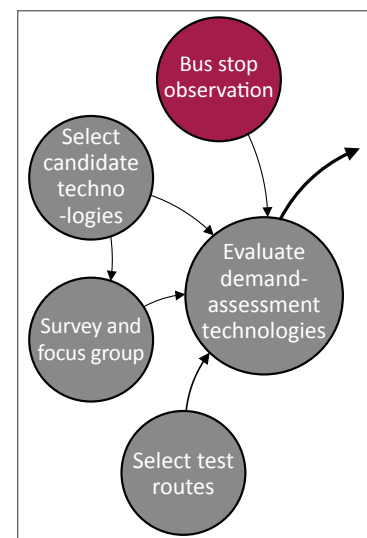
Data reduction and analysis

Where the rider stood when they arrived at the bus stop was recorded as one of three categories:

1. Standing more than 5 m (16 ft.) from the bus stop
2. Standing less than 5 m (16 ft.) from the bus stop (also included riders boarding the bus immediately upon their arrival to the stop)
3. Standing under shelter (for stops with shelters)

Passenger arrival location was analyzed with respect to route (Hethwood and CRC), position relative to a time check (time check and not time check), headway (10, 15, 30, and 60 min), and availability of a shelter.

To calculate passenger arrival with respect to bus arrival, average bus arrival time was used, because riders adjust their behavior according to their experience with actual bus arrivals. The average bus arrival time for the three months preceding bus stop observation was calculated



**FIGURE 3-8 DOCUMENT MAP
— BUS STOP OBSERVATION**



Transit Bus Routing On-Demand: Developing an Energy-Saving System

and used for bus stop observation calculations, and for developing the forecast, ensuring consistency between observation data and implementation.

The standard deviation of bus arrival times was calculated, and the bus stops were divided into two groups (time check and not time check) with respect to that value, which also corresponded with their distance after a time check.

Observations were divided between headways of 10, 15, 30 or 60 min. Some stops had different headways depending on day/time, so there was overlap between the stop and headway groups.

The video footage was analyzed by a team of trained data reductionists, who recorded when passengers arrived relative to the average bus arrival time and actual bus arrival time, and where they stood with respect to the bus stop while waiting for the bus.

Passenger arrival distribution was analyzed with respect to route (Hethwood and CRC), position relative to a time check (time check and not time check), and headway (10, 15, 30, and 60 min). Results and application to demand assessment technology

Rider positioning: Overall 17 percent of riders stood more than 5 m (16 ft) from the bus stop leaving 83% to stand less than 5 m (16 ft) from the stop or under the shelter. Some riders moved around the bus-stop area, and other riders stood 20 m (66 ft) or more from the bus stop and only approached the bus stop as the bus arrived. It was determined that if the stop was a time check and if it had a shelter significantly affected the arrival location. Figure 3-9 shows that more riders are drawn closer to the stop if there is a shelter. Figure 3-10 shows that more riders are drawn closer to the stop if it is a time check. This is due to the fact that it is more common at time checks for the bus to be waiting for riders instead of the other way around. Therefore, riders more frequently board the bus immediately at time checks.

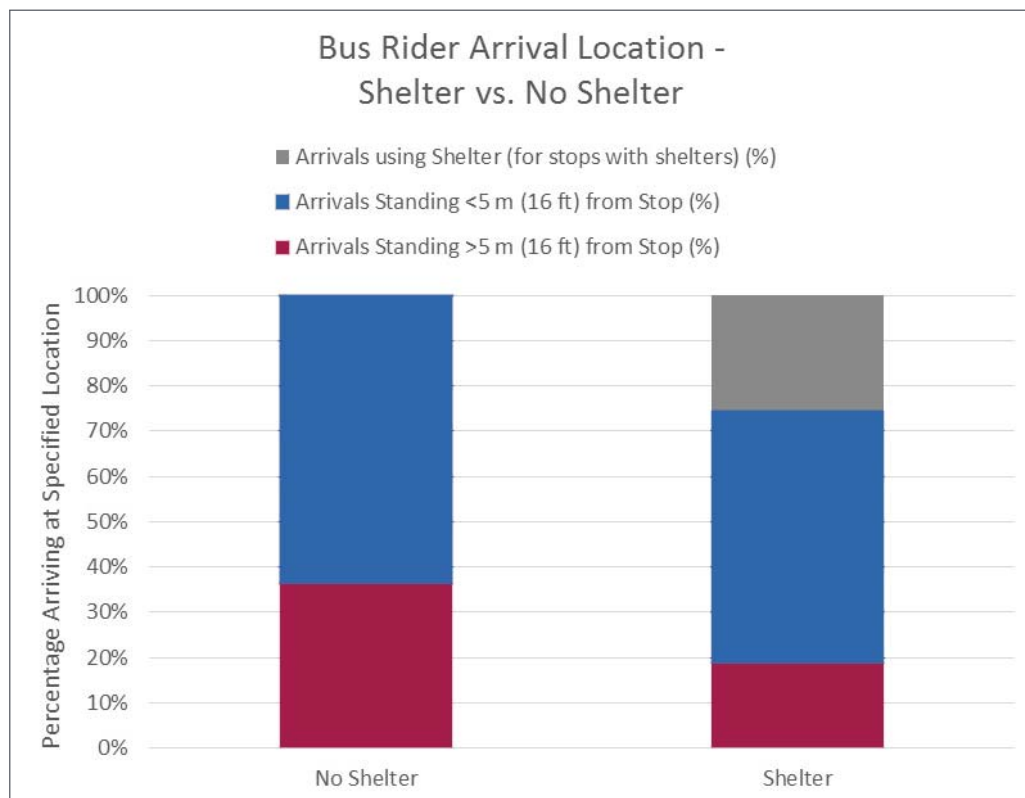


FIGURE 3-9 GRAPH OF BUS RIDER ARRIVAL LOCATION COMPARING SHELTER VS. NO SHELTER (NO TIME CHECK STOPS INCLUDED).



Transit Bus Routing On-Demand: Developing an Energy-Saving System

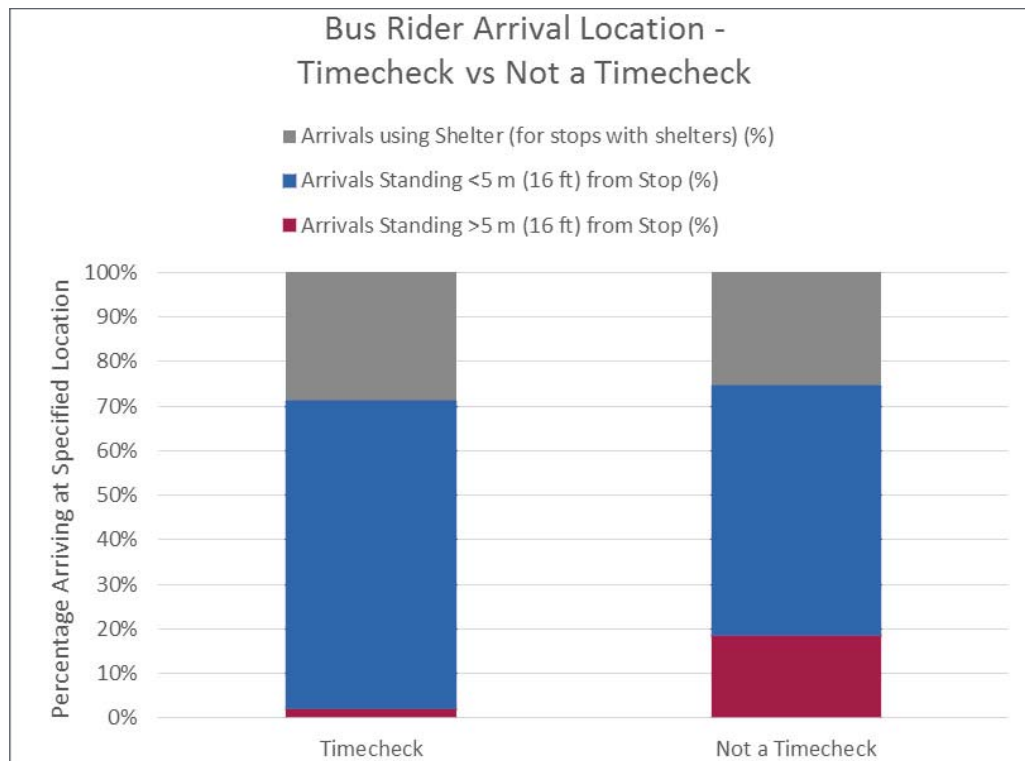


FIGURE 3-10 GRAPH OF BUS RIDER ARRIVAL LOCATION COMPARING TIME CHECK VS. NOT A TIME CHECK (ONLY SHELTERED STOPS INCLUDED).

Rider behavior impacted the evaluation of the demand-assessment technologies. If riders move around and/or do not stand close to the bus stop, technologies passively detecting them at the bus stops would have to have a wide range to give accurate passenger counts. Passersby, like runners and walkers, would be more likely to affect passenger counts made with wide-range technologies, so such technologies would require additional programming to determine the likelihood each detection is a passenger. Thus, passive technologies that do not require riders to check in face a number of hurdles before they would be able to produce accurate passenger counts.

Arrival rate: Arrival rate was expressed in minutes a passenger arrived at the bus stop before the average bus arrival time. Route, stop position relative to a time check, and headway did not significantly affect passenger arrival distribution. Results for those factors are shown under Bus stop observation in Appendix B: Demand assessment, and combined results are shown in Figure 3-11 below. That arrival rate distribution was used to develop the forecast and the demand assessment algorithm.

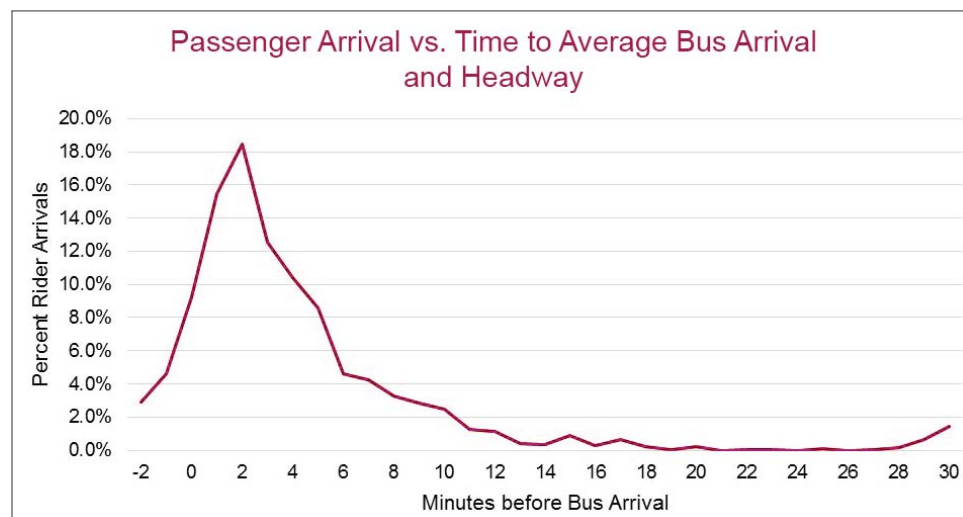


FIGURE 3-11 BUS STOP ARRIVAL DISTRIBUTION



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Conclusions

Arrival rates were very tightly clustered around about 2 min prior to average bus arrival times. In most cases, the standard deviation for bus stop arrival was under 2 min (see Table 9-2 in Appendix B: Demand assessment for details), so Blacksburg Transit riders appear fairly confident that the bus will arrive as expected, and do not feel the need to travel to the bus stop ahead of time. One caveat to interpreting these results is that Blacksburg Transit is the most reliable transit system in Virginia; therefore, passenger arrival rates might be more tightly distributed than those in other municipalities, where transit is less reliable or scheduled differently.

Weather and time of day was recorded in the observations, but not enough information was gathered to make any reliable conclusions. The team also would have liked to compare arrival rates at stops in different environments, for example downtown, on campus, residential, or industrial. However, it was difficult to place the large solar-powered trailer with the camera in high-traffic and built-up areas, so the team was unable to perform that analysis.

Arrival patterns are a complex phenomenon affected by a number of factors, only a few of which were investigated here. For instance, passengers might use multiple nearby stops, depending on bus arrival time, making it difficult to determine which stop they may use on a given day. Bus operators waiting for late passengers might also affect passenger arrival patterns. Future analyses could consider more factors affecting arrival rates.

Considerations for transit agencies

The arrival rates for Blacksburg Transit are probably not representative of those at larger municipalities with working populations, different scheduling schemes, and less-reliable bus arrival times. Transit agencies wanting to use arrival-rate distribution in demand-assessment schemes should perform their own arrival-rate measurements using the best methodology for their environment.

Transit agencies considering using camera systems to measure arrival rates should consider incorporating weather and time-of-day data, and could use smaller camera systems to collect data at a larger variety of stop types.

The results of the bus stop observations suggested that technologies passively counting passengers might not yield as reliable results, because passengers don't always cluster tightly around the bus stops. Urban transit agencies with less space surrounding stops might find different results regarding passenger positioning. Evaluating real-time demand-assessment technologies

The nine candidate demand assessment technologies were evaluated to varying extents depending on a number of factors, including survey and focus group responses, their ability to gather demand data given passenger behavior at bus stops, and cost and complexity of implementation. Some technologies were not evaluated beyond basic research into their cost and acceptability to passengers, and others were tested, validated, and their data incorporated into demand-assessment. Each technology, its evaluation procedure, and any results of testing are described here. BT4U website

Background

BT4U is a digital service providing users with up-to-date information about buses and bus stops. Users can access the service using a web browser, by texting, and over the phone using interactive voice response. The classic version of the system provides users with the next three times a bus will depart from a particular stop; the LiveMap version, only available on the web, provides users with bus locations, time stamps, and passenger loads. Users can access a web version of BT4U on their mobile phones, but they must use a mobile web browser.



FIGURE 3-13 BT4U ICON

At first, BT4U provided users with static schedules, but later was able to improve static schedules with real-time bus location data. BT4U works first by collecting data in the general transit feed specification (GTFS) format. Transit agencies publish their routes, stops, trips, and other data as a GTFS feed, making it compatible with many software programs and applications. Unfortunately, that GTFS data are quickly obsolete because, even though BT4U calculates new data for its GTFS feed every day, companies like Google take a week to

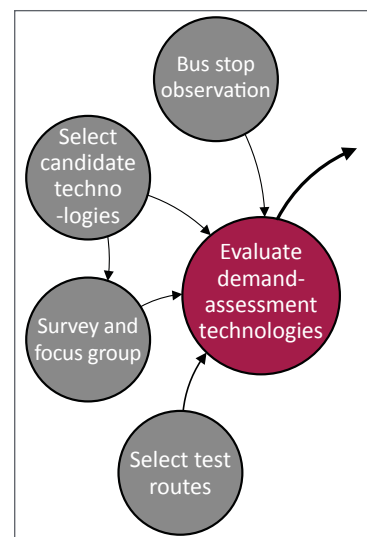


FIGURE 3-12 DOCUMENT
MAP — EVALUATING REAL-
TIME DEMAND ASSESSMENT
TECHNOLOGIES



Transit Bus Routing On-Demand: Developing an Energy-Saving System

process new data. Therefore, the GTFS data are updated with real-time bus information collected by Blacksburg Transit using four Intelligent Transportation Systems (ITS) components: Computer Aided Dispatch (CAD), Automatic Vehicle Location (AVL), Automatic Passenger Count (APC) and Passenger Payment Information and transferred wirelessly to a database accessible to BT4U.

Calculating individual bus arrivals using ITS data can be very time-intensive, so the system uses a combination of bus-schedule data from the GTFS feed and bus-position data based on ITS components. When someone queries the system for a bus arrival, BT4U checks to see if the present departure is close to the historical departure. If so, it returns the predicted arrival based on historical data. If not, it calculates the arrival time based on current conditions. If used to collect demand-assessment data, a destination-request feature would be added, where users would enter their desired departure point, departure time, and destination. That data would then be made available to the demand-assessment algorithm. One possible issue would be that riders choosing origins and destinations might not actually use the transit system, and statistical analyses would have to account for that gap.

Unfortunately, BT4U began as a proof-of-concept that grew organically, and user statistics were not built into it from the beginning, and cannot be reported here. A detailed description of BT4U, including screenshots, is in appendix section: BT4U website description of technology.

Implementation and testing

Because usage statistics were not built into the BT4U website from the beginning, it was difficult to pull demand information from website usage information. One way to do so would have been to install cookies on users' computers or collect computer IP addresses, but that created a number of privacy issues. Additionally, IP addresses can help find a computer's location, but on the Virginia Tech network, doing so would have been highly intrusive. Tracking rider demand using the texting engine would have also been problematic, and would have required a system redesign. For those reasons, the BT4U website was not tested as a demand-assessment technology.

Conclusions and considerations for transit agencies

BT4U allowed riders to make better choices of which stop to go to and which bus to ride, it raised the level of accountability for Blacksburg Transit, and helped raise the LOS. Blacksburg Transit also stopped printing paper schedules, which are expensive and time consuming to print and distribute. Blacksburg and Virginia Tech have high adoption rates, which helped Blacksburg Transit make the digital transition, so phasing out paper schedules might not be a viable option for transit agencies with a more-traditional ridership.

Website, texting engine, and interactive voice response services enables a transit agency to reach a broader audience, including blind passengers and those who cannot afford or do not want to purchase smart phones.

Agencies considering tracking demand using a website or texting engine should identify the data they want to collect, and ensure anonymity, and incorporate those approaches into the service starting in the design phase.

BT4U mobile application

Background

As the project progressed it became apparent that an app operating on mobile devices such as smart phones provided one the best opportunities to assess rider demand while also providing timely transit information to clients. Third-party applications existed for helping transit passengers plan their trips but these were found to be inadequate for the needs of the project. To that end, Blacksburg Transit developed a request for proposal for a developer to create an application, driven by the same database as the BT4U website, but that would also collect demand data by associating a phone's universally unique identifier (UUID) with the stop about which the user queried the app for bus-arrival information. When combined with real-time information on bus locations, the bus-arrival information the app provides users would be accurate, despite real-time schedule changes.

ACI/Nomad responded to the proposal and created the BT4U mobile app, compatible with iOS and Android, the two market leaders. The app provides customer service, a possible survey outlet, and a mechanism for possible advertisement revenue. Demand data can be collected when users plan trips (Figure 3-15) by entering their current and end locations, and when users request information for particular stops. A full description of the app's features and functionality can be found in Appendix B: Demand assessment.



**FIGURE 3-14 STUDENT WITH
BT4U MOBILE APP**



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Problems the team anticipated with the app were, that Like the BT4U website, some users might plan trips but not ride the bus. Also, mobile app usage can be hard to predict, so it was unknown how much demand data the app could collect.

Implementation and Testing

The app underwent user testing in February and March 2014, and was soft launched in April 2014. The soft launch was accompanied by a boots-on-the-ground approach, where Blacksburg Transit employees stood at bus stops to help users download and use the app. As of May 1, 2015 there were about 9,700 installations of the BT4U mobile app on iOS devices, and about 3,000 installations on Android devices.

To determine the effectiveness of the BT4U Mobile Application in predicting passenger trips, the team compared the number of users who used three application features with the number of passengers on a bus route. The three features were a trip plan, a route information request, and a stop information request. Comparisons were made daily for a number of days to determine if there was a stable trend between how many people use the app and the number of bus riders. All testing was performed on the Hethwood A route.

Trip plan: When a user plans a trip, the app displays three possible solutions. App users are not required to pick a solution, so for this testing, the total number of users receiving “Hethwood A” as the top solution for their trip plan were compared with the number of riders on that route for a given day. If more than one trip was planned within 30 min using the same device, only one was counted. For 63 days between January 21, 2015 and May 6, 2015, “Hethwood A” appeared as the top trip solution in 1,016 cases. On those same days, according to fare collection data, there were 132,270 Hethwood A passengers, so top trip solutions for “Hethwood A” formed about 0.8 percent of Hethwood A passengers on average. Percentages varied by day with a standard deviation of 0.5 percent.

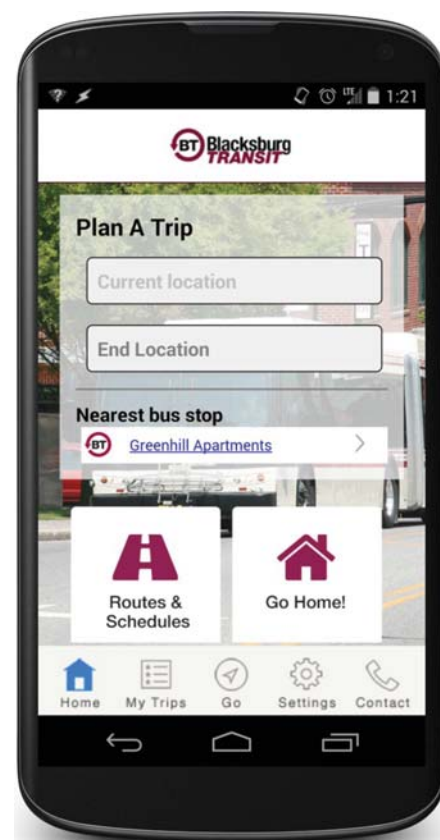
Route information request: When users request information regarding a route, the app provides information about bus arrival times at stops on that route. The total number of requests for information on the Hethwood A route was compared with the number of riders on that route for 51 days between January 21, 2015 and May 6, 2015. If multiple requests were made within 30 minutes on the same device, only one was counted. There were 3,060 requests for information for the Hethwood A route. On those days, there were 132,270 Hethwood A passengers, so route requests for “Hethwood A” formed a daily average of 2.4 percent of Hethwood A passengers. Percentages varied by day with a standard deviation of 1.0 percent.

Stop information request: When users request information regarding a stop, the app provides information about bus arrivals at that stop. The total number of requests for stop information for 7 stops on the Hethwood A route was compared with the number of riders on that route for 51 days between January 21, 2015 and May 6. Again, multiple requests within 30 minutes on the same device were counted as a single request. On those days and at those stops, there were 647 stop information requests, compared to 49,135 passenger trips originating from those stops. Thus, stop information requests accounted for a daily average 1.0 percent of passengers. Percentages varied by day with a standard deviation of 0.5 percent

Conclusions

When the three app-usage methods are combined and compared to passenger trips, they form a daily average of 4.2 percent of passenger trips with a standard deviation of 1.6 percent.

These comparisons between app usage and ridership are rough evaluations on a day-by-day basis. A more in-depth analysis could reveal that even though the number of app users is low compared to the number of riders, there is still a very strong correlation between the two. Additionally, evaluations on an hourly, trip, or stop basis and evaluations using more app features might prove more informative, and enable stakeholders to better predict demand based on app usage.



**FIGURE 3-15 BT4U MOBILE APP
HOME SCREEN**



Transit Bus Routing On-Demand: Developing an Energy-Saving System

The BT4U Mobile App was designed to be informative and easy to use, and automatically displays the next four arrival times for the bus stop closest the user. The data the app receives when automatically displaying those stop times is not as informative as that received when users plan trips or request information. Thus, the app's design for convenience likely reduces its utility as a data-collection instrument, and future design changes would be a balancing act between providing a user-friendly app and a data-rich app. One possibility considered to encourage users to plan trips or otherwise provide the app the demand data is to include gamification, but doing so was outside the scope of this project.

Considerations for transit agencies

The project team learned a great deal about developing a mobile application for transit. Problems with creating the app include that developing, deploying and supporting a mobile app was more expensive and time-consuming than the team initially thought. Also, there was a communication gap between the mobile app developers and Blacksburg Transit; the developers did not understand transit, and Blacksburg Transit did not understand application development. After the communication problems were overcome and the app was developed and launched, the team realized that the buses could not communicate their real-time location data fast enough to have their locations displayed on a map, so the maps incorporated into BT4U do not show the buses as originally planned.

The team suggests other transit agencies interested in developing mobile applications invest a great deal of time in the request for proposal and in communication with the application-development bidders before the project begins, and understand that no reasonable amount of app testing can identify all problems before launch.

The main problem with using the app to collect demand data was that not enough users planned trips with it, the intended data-collection method. Forcing users to plan trips before showing them bus-arrival information might encourage them to use third-party transit apps. Therefore, the team suggests that transit agencies attempt to predict app feature usage before making assumptions regarding usage rates, and suggests the app require as little input as possible from the users to collect transit demand data.

Despite the above issues and the fact that app development can be time-intensive and costly, using the BT4U mobile app to collect demand data has a number of major benefits. It does not require infrastructure, like adding power to bus stops, and the technology is mature, unlike vision software. If developed optimally, it would require little from passengers to collect demand data. It was especially promising among Blacksburg Transit's young, technologically-familiar ridership. When coupled with iBeacon technology to detect riders, the BT4U mobile app is even more promising, because it would require even less user input to collect demand data. iBeacons are described next.

BT4U mobile application with iBeacons

Background

iBeacon technology interfaces with mobile applications like the BT4U mobile app. iBeacon transmitters are small Bluetooth devices providing location services where GPS and Cellular do not work, such as inside buildings with thick walls. iBeacons use a low-energy Bluetooth signal, can last for months, but are typically detected from 40 m (131 ft) away. They broadcast a packet of information including a calibration measurement for the expected signal strength at one meter, and the receiving device uses this value to estimate the rough distance to the iBeacon, usually categorized as far, near, and very-near, and mobile applications can use that data in a variety of ways. The first suggested use-case for this technology was retail stores targeting promotions to customers depending their location in the store. The BT4U mobile app use iBeacons to determine whether a passenger carrying a smartphone is at a bus stop or on a bus, collecting ridership and demand data without users having to plan trips through the app.

Blacksburg Transit designed an iBeacon system to augment the BT4U mobile app and detect riders waiting at bus stops estimate ridership demand. The initial idea was to deploy iBeacons at bus stops and have the BT4U mobile app detect and report the presence of the iBeacon. However, that system would not be able to differentiate between riders boarding different buses, or riders who gave up waiting and walked off. Adding additional iBeacons to buses would allow the system to detect riders throughout their trips, and was an effective solution for gathering origin and destination information by comparing rider and bus GPS data. Therefore, the team placed iBeacons on stops and buses, and used different UUID families for iBeacons at bus stops and those on buses, with the BT4U mobile app reporting detection and loss of iBeacons in either family. Using separate UUID families allowed the smart phone apps to determine when users transition from a bus stop to bus and vice-versa, and when users left the system. To ensure a detection is a passenger, and not a passerby, the mobile app



Transit Bus Routing On-Demand: Developing an Energy-Saving System

first “detects” an iBeacon, and then “recognizes” it after it had been detected for a period of time. To do so, the apps report to the central system’s database detection, recognition, loss between detection and recognition, and loss after recognition as separate events. Intermediate detections might occur when a mobile app detects and recognizes a bus stop’s iBeacon, but the passenger does disembark. Those detections can be filtered out when the bus moves on, the bus iBeacon is still recognized, and the bus-stop iBeacon is lost. More notes on iBeacons at Blacksburg Transit are in Appendix B: Demand assessment.

Implementation and testing

The Blacksburg Transit Android and iOS BT4U mobile apps began collecting iBeacon data at the beginning of January 2015, before the start of the spring semester at Virginia Tech.

In the first two months of operation the team collected the following events:

TABLE 3-2 NUMBER OF iBEACON EVENTS

EVENT	NO. OF EVENTS
Bus stop detection	65,732
Lose bus stop iBeacon before recognition	851
Bus stop recognition	64,790
Loss of bus stop iBeacon after recognition	62,851
Bus detection	28,682
Lose bus iBeacon before recognition	378
Bus recognition	28,235
Loss of bus iBeacon after recognition	27,321

The collect data had limitations. Users could stop the app at any time, so the expected sequence of iBeacon events was not necessarily recorded. For example, of the 28,235 buses recognized, 27,321 were lost after recognition, suggesting that user stopped the app while on the bus. Users could also start the app while on a bus, making the first iBeacon event a detection of a bus’ iBeacon. Also, if a rider was on a bus at a busy stop, smart phones might have simultaneously recognized several bus iBeacons. These limitations might require the team perform a semantic analysis of iBeacon event sequences for meaningful conclusions regarding ridership to surface.

Despite the above limitation, the BT4U Mobile Application with iBeacons was tested with respect to predicting passenger trips. To do so, the team compared the number of app users the iBeacons detected at seven stops on Hethwood A with the number of passengers starting trips from those stops. The iBeacons had to detect a mobile device for more than 1 min to be counted. Data were collected between February 19, 2015 and May 6, 2015, resulting in 1,152 qualified iBeacon detections. During those same days, according to fare data, there were 42,267 passenger trips originating from those stops, so iBeacon detections were, on average, 2.4 percent of passengers. Percentages varied by day with a standard deviation of 0.8 percent.

A brief review of iBeacon data for other stops revealed that there was a higher rate of passengers detected at stops on campus and downtown than in other locations, indicating that iBeacons might be producing false positives from nearby foot traffic. Further evaluation would be needed to confirm this.

Additional notes regarding iBeacons as a demand assessment technology is available in Appendix B: Demand assessment.

Conclusions and recommendations for transit agencies

iBeacons are a promising technology for measuring transit-bus demand, but are not yet mature in this application. Therefore, transit agencies wishing to use them to assess demand must be willing to invest in developing the companion mobile application, installing iBeacon devices, and in testing and algorithm development to determine the best parameters and processes to correlate iBeacon detections with ridership.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Camera Analytics

Background

At the onset of the project, the research team thought counting passengers at bus stops using cameras and machine vision, people-counting software was the most promising option for assessing origin demand. Camera systems were in use for crosswalk detection, and the team thought cameras could also count people at bus stops to assess demand. Cameras are a passive detection system, would count passengers as they waited at a stop, and would not require passengers perform any additional actions. Camera data would be transferred either wirelessly or via cable to a database, where it would be processed by people-counting software.

The team researched machine-vision technology for over a year and discovered that, while indoor people-counting software was reliable, changing lighting conditions and weather made counting people outdoors more difficult, and that no software available could reliably perform the task. Current software can estimate people counts, but for those estimates to be accurate enough to assess demand, hundreds of hours of video would have to be analyzed by human technicians to normalize the software's estimates using statistics. Doing so, or paying a consultant to do so, was outside of the scope of the project. Bus stop observation results found that, to get reliable passenger counts, cameras would have to be positioned to count passengers standing up to 20 m (66 ft) from the stops, and those cameras would likely also count passers-by. Purchasing cameras for each bus stop and incorporating power and communication at all stops would also have been prohibitively expensive.

Testing

Cameras were not tested as a demand assessment technology. However, they found use in this project by enabling the team to perform the bus stop observations, described above.

Conclusions and considerations for transit agencies

Using cameras and machine-vision software to assess demand at bus stops is not feasible given the current state of the technology. Once the technology is improved and can reliably function under variable outdoor conditions, it might be possible to reevaluate for use in a transit environment to count passengers.

Hokie Passport swipe

Background

Hokie Passports are Virginia Tech student, faculty, and staff identification cards with magnetic stripes (mag cards) and are an integral part of students' lives. Virginia Tech students make up approximately 90 percent of Blacksburg Transit ridership. Students use them at the library, to enter dormitories, and to pay for meals and other items on campus. To board buses, students must show their cards to the driver or pay a fee. Using the passports to collect demand-assessment data, riders would swipe their cards at the bus stop, and the data would be transmitted via cellular to a database, where it would be secured and anonymized. Each card is associated with a unique passenger, but the identity of the passenger would not be recorded. The data would then be transferred wirelessly to a database and made available to the demand-assessment algorithm.

To collect demand data, riders would swipe their Hokie Passports at bus stops, and the system would collect demand information. That approach would not slow down boarding and bus dwell time, because by the time a bus arrived, most of the waiting riders will have already swiped their cards at the stop. Riders would not be able to swipe their cards multiple times to inflate demand, because each card is unique, and the system would recognize and discard multiple swipes. The system could collect both origin and destination data by requiring passengers to swipe when boarding and alighting, and more passenger data means a better results from the demand-assessment algorithm. That method would increase bus dwell time at stops, because passengers would have to queue up at the bus doors to swipe their cards. Card-swipe data, along with other data, would be transferred wirelessly to a database, where it could be accessed by the demand-assessment algorithm.

Possible problems with using Hokie passport swipes to collect demand data are:

- destination information might not be collected,
- non-VT-affiliated riders would have to be issued cards to be counted,
- individuals not intending to ride might swipe their cards,



Transit Bus Routing On-Demand: Developing an Energy-Saving System

- the cards do not include information on whether the card is valid, and doing so would require Virginia Tech restructure its database, and
- this method requires action on the part of riders, although it would be easy to habituate riders to swipe cards, because they already do for many on-campus tasks.

Additionally, mag cards are an older technology. Newer technologies, like RFID, do not require a swipe and would decrease boarding time, and will be discussed in subsequent sections.

Implementation and testing

No testing was performed on using Hokie Passport swipes to assess demand, because survey results showed that passengers were not favorable towards the technology. Also, using any sort of mag-card swipe would require Blacksburg Transit invest in mag-card readers on every bus and/or at every stop, a considerable expense, especially because most bus stops do not have power or communication. Therefore, more promising demand-assessment technologies were pursued.

Conclusions and considerations for transit agencies

Using Hokie Passports to assess demand would be more attractive if Virginia Tech moved towards smart cards and worked with Blacksburg Transit to structure the rider database. One positive result of the team's investigation of mag cards is that Blacksburg Transit now communicates annually with the Hokie Passport office to see how updates to the Hokie Passport system might align with Blacksburg Transit's efforts to improve service and reduce GHG emissions.

If other transit agencies are considering using mag cards to control access, they should consider the percent of riders who might be using fraudulent cards, and whether forcing passengers to carry and swipe cards is worth the extra cost of purchasing card readers and issuing cards. Blacksburg Transit performed a study in the mid-1990s and found that less than 1 percent of cards used to board busses were invalid. That could be because most riders are active students, and it is expected metropolitan transit agencies would have a higher fraud rate. For transit agencies serving large student populations, access control might not be worthwhile. Transit agencies should also assess passenger needs and opinions so they can avoid making decisions that will drastically affect riders. A future application of using cards with magnetic strips is developing a regional or national transit network that operates off a single card. Huge amounts of data could be collected, and passengers would only need one card to travel in multiple regions.

Any mag-card swipe system would require a transit agency purchase a great deal of expensive hardware and invest in creating and distributing mag cards to riders, a considerable investment in an ageing technology.

Kiosks

Background

A kiosk, for the purposes of this project, is a public-access computer at a bus stop. Riders could interface with the kiosk and enter their destination, the system would pass origin and destination information to the database and then be made available to the demand-assessment algorithm.

The first kiosk option investigated was having longtime Blacksburg Transit collaborator, Industry Weapons, develop kiosk software. Industry Weapons helps companies create digital signage and target advertisements to regional or local audiences. Although Industry Weapons built the tools to display real-time arrival and departure information, they found that showing bus locations on a map was impossible, because the map data would not refresh quickly enough. So, the Industry Weapons version of kiosk software was shelved, and subcontractors ACI/Nomad were tasked with developing the BT4U mobile application into a tablet-based kiosk design. The kiosk version of BT4U collects origin and destination information, and riders are able to see when the next bus or busses would arrive.



FIGURE 3-16 TYPICAL BLACKSBURG TRANSIT BUS STOP



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Kiosk hardware consists of an off-the-shelf tablet and an off-the-shelf weather- and theft-proof enclosure. In total, the kiosk hardware is less expensive than magnetic card readers, RFID readers, and Wi-Fi detectors, but deploying kiosks at every stop is still a significant expense. Like the other technologies, kiosks require power and communication (either wireless or via cable), which is not supported by the infrastructure at most bus stops. Limited data could be collected from stops with power, but that would limit the accuracy of the demand assessment algorithm influencing the 3DSS.

Implementation and Testing

Because of the expense of implementing kiosks and delays in developing working kiosk software, kiosk testing was delayed until later in the project schedule. One kiosk was installed, consisting of a communications and power box wired to a tablet computer, which was encased in a weatherproof shell, as shown in Figure 3-17.



FIGURE 3-17 KIOSK INSTALLED AT BLACKSBURG TRANSIT BUS STOP

To determine the effectiveness of the kiosk in predicting passenger trips, the team compared the number of users who used three application features with the number of actual passengers boarding the bus at the stop with the kiosk (stop 1211). The three features were a trip plan, a route information request, and a stop information request – the same ones used for evaluating the BT4U mobile application, which was run on the kiosk, so they will not be described in detail again here. Comparisons were made between March 24th and May 6th, 2015.

Trip plan: There were 192 instances where someone used the kiosk to plan a trip beginning at the kiosk stop. On those days, according to fare collection data, 8,329 passengers began trips at the kiosk stop, so kiosk trip plans formed 1.9 percent of passengers boarding at the kiosk stop. Percentages varied by day with a standard deviation of 2.6 percent.

Route information request: There were 61 route information requests for Hethwood A made from using the kiosk. On those days there were 8,329 passenger trips originating from the kiosk stop, so route information requests accounted for a daily average of 0.7 percent of passengers boarding at the kiosk stop, with a standard deviation between days of 0.8 percent.

Stop information request: There were 67 requests for information about the kiosk stop made from the kiosk. On those days, according to fare collection data, there were 8,329 passenger trips originating from the kiosk stop, so stop information requests accounted for a daily average 0.7 percent of passengers boarding at the kiosk stop, with a standard deviation of 0.7 percent.

Conclusions

When the number of kiosk usages for the three features are combined, it comprises a total daily average of 3.8 percent of passenger trips made beginning from the kiosk stop, and these percentages varied by day with a standard deviation of 1.8 percent. As with the BT4U mobile app, it could be that even though kiosk usages are low compared to ridership, if there is a high degree of correlation between the two, it would allow Blacksburg Transit to accurately predict demand. More research needs to be performed to determine whether that could be the case. Additionally, evaluating by hour or stop may reveal more useful information enabling better demand predictions.

There was likely such low kiosk usage to plan trips and request information, because riders can see the next few arrivals for the kiosk's stop on the kiosk home screen. Like the BT4U mobile app, any design modifications that would attempt to extract more trip information from users must balance doing so with providing a user-friendly device.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Considerations for transit agencies

Transit agencies where the infrastructure is still being built, so power and data communication can be added to stops, are more amenable to kiosk technology. So are bus rapid transit systems and underground transit systems, where stops already have electricity. For other transit systems, the expense of installing kiosks makes them less ideal than other demand-assessment technologies. Focus group results found that riders might be concerned about germs being spread on kiosks, and individuals might check in a kiosk and then not ride the bus. Therefore, transit agencies should perform limited field testing to see how passengers use the kiosks before a full implementation. The design of the application run on the kiosk must also balance user-friendliness with data-richness.

RFID

Radio-frequency identification (RFID) describes technologies where electromagnetic fields are used to transfer data between a reader and RFID tags. RFID tags are similar to barcodes, but the information stored on an RFID tag can be read and sometimes modified. Tags can either be passive, battery-assisted passive, or active. Passive tags have no power source, and must be read with an active reader subjecting the tag to electromagnetic radiation many times stronger than the signal the tag subsequently emits. Battery-assisted passive tags only transmit their information when in the presence of an active reader, which triggers them to transmit. Active RFID tags constantly transmit their data, and are read by passive readers. Any tags equipped with batteries would require new batteries on occasion.

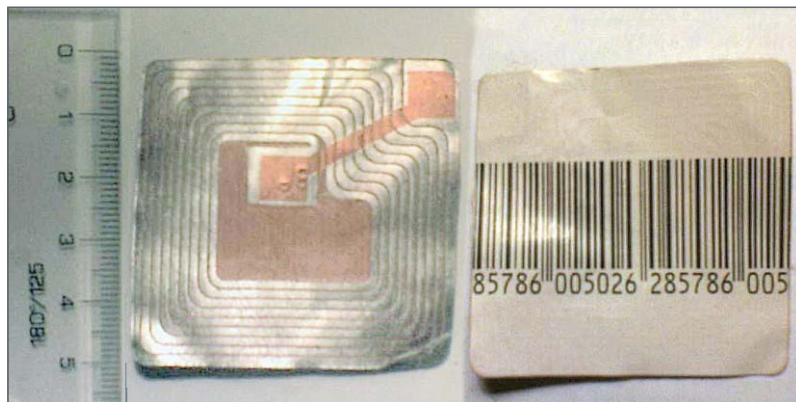


FIGURE 3-18 ADHESIVE PASSIVE RFID TAG WITH BARCODE

Using RFID tags to track rider demand would require Blacksburg Transit program and distribute RFID tags to passengers and equip buses or bus stops with tag readers. Tags could be, for example, small clip on devices that students could attach to their backpacks. Otherwise the tags could be stickers attached to an ID card (like the Hokie Passport,) or “smart cards” with RFID technology. Depending on the tag type, location, and strength of the readers, passengers may or may not have to hold their tags up to the reader to be read. With the correct setup RFID cards could be read as passengers stand at the bus stop, board the bus, ride the bus, and alight. RFID data, along with other data, would be transferred wirelessly to a database, where it could be accessed by the demand-assessment algorithm.

One concern is, depending on the location of the tag, riders may not always remember to bring the tag with them when they plan to ride the bus. Incorporating the RFID technology into a card like the Hokie Passport would be the easiest to implement, because students already need to carry their Hokie Passports to ride the bus. However, Virginia Tech does not intend to implement RFID tags in Hokie Passports in the near term. Additionally, passengers carrying the RFID tags might be counted inflating demand numbers. Last, RFID technology would require expensive equipment, including readers and thousands of tags, and a high initial infrastructure outlay.

Implementation and testing

Blacksburg Transit was unable to find an RFID manufacturer willing to sell small quantities at a reasonable cost to develop a system prototype. An RFID-based demand-assessment system would also have a high cost of implementation, so RFID technology was considered a lower priority for this project, and not investigated within the project’s timeframe.

Conclusions and considerations for transit agencies

RFID has excellent potential to collect transit demand data, especially when it would not require riders’ active participation for the tags to be read, but it requires a large initial investment. Additionally, passengers would have to be issued RFID tags, possibly keep batteries charged, and remember to carry tags when traveling. Despite those issues, passengers would likely find it convenient to not have to perform any action, other than carrying a tag, to board a transit bus, and bus dwell times could be drastically reduced. Large transit agencies with highly-mobile passengers concerned with saving time would likely benefit the most from such a system.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Thumb scan

Background

Fingerprint or “thumb” scanners are relatively simple and inexpensive devices that can be used to identify a user based on the biometrics, in this case, the unique geometric patterns created by the ridges and valleys of the skin on the fingertip. A small tactile pressure sensor is used to map these patterns and a digital map of the contact area is created. Integrated software then uses this digital map along with mathematical and statistical algorithms to create a numerical identifier for the user’s thumbprint. This numeric signature is compared to other users to provide a statistical confidence level of associated unique identification.

It should be noted that thumbprint scanning, as well as other biometrics identification methods, do not require any association with personally identifiable information (PII) and typically operate in a local topology without access to external databases. Users may be assigned a unique identity and tracked within a system with complete anonymity. However, thumbprint scanning with subsequent access to an external criminal enforcement fingerprint database may be used to assign personal identify to those using a thumbprint scanner.

Testing

Participants in the survey and focus groups felt thumb scanners were invasive, time-consuming and susceptible to misuse. Also, legal sources suggested avoiding their use based on widely recognized related public perceptions. Therefore, the team did not evaluate thumb-scanning technology.

Conclusions and considerations for transit agencies

Thumbprint scanners are a relatively effective and inexpensive method for assigning temporary identification for rider tracking without requisite access to PII. However, their implementation in a transit system for rider tracking would likely be unsuccessful because of the widely held perception that they are personally invasive or dirty.

Wi-Fi and Bluetooth detection

Background

Wi-Fi and Bluetooth are two protocols for wireless communication. Wi-Fi has a longer range and faster data transfer, and is used in home and business internet access. Bluetooth has a shorter range and slower data-transfer speed, and is used to connect devices that are close together, like hands-free headsets to mobile phones.



FIGURE 3-19 Wi-Fi AND BLUETOOTH LOGOS

A Wi-Fi or Bluetooth-detecting system would sense the unique signals from bus passengers’ mobile devices and count them, thus approximating the number of passengers at a stop. That data would then be passed to a database, secured, and made available to the demand-assessment algorithm.

The technology has been used to track travelers. Newer passenger cars have Bluetooth, and each vehicle has its own MAC address, and Bluetooth is already used to detect vehicles on I-66 in Northern Virginia and in parts of Arlington County. Also, one study conducted in Washington DC used Bluetooth to attempt to describe passenger transfer behavior [6].

The team initially focused on detecting Bluetooth signals to assess demand, because that method had already been used in transportation research. To do so, however, would require that the Bluetooth be enabled on transit passenger’s phones. Headsets for mobile phones are a common device requiring Bluetooth be enabled, but are mostly used by drivers, not transit passengers who can hold their handsets. Therefore, the team examined using Bluetooth for demand assessment within the context of iBeacons, described above.

Wi-Fi detection could work in a number of ways; the team decided to investigate detecting passenger Wi-Fi using Digi devices already installed on Blacksburg Transit buses. Digi appliances transfer GPS, fare data, and passenger counts from buses to Blacksburg Transit headquarters, but can also detect Wi-Fi signals from passengers’ mobile phones and tablets, and transfer that data as well. The data could be coupled with GPS data to determine the stop where the Wi-Fi device entered the bus (origin) and where it exited the bus (destination). The ridership data could then be used in demand-assessment calculations. Additionally, if a Wi-Fi-detecting device were installed at bus stops, it could detect passengers waiting at the bus stop.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Using Wi-Fi to detect passenger demand would require no action on the part of passengers who have Wi-Fi turned on, so it would not slow down boarding or disembarking times. Since Digi devices are already installed on the busses, the implementation cost would be lower than another technology requiring new hardware on buses or at bus stops. If Digi devices were installed at bus stops, the cost would be similar to that of purchasing magnetic readers or RFID tag readers, and more expensive than kiosks. As with other technologies deployed at bus stops, the Wi-Fi detector would have to be powered, making it difficult to implement at most of BT's bus stops.

One problem with using Wi-Fi and Bluetooth signals to assess demand was that one passenger might have more than one Wi-Fi-enabled device, and that some passengers might not have any Wi-Fi-enabled devices. Also, the Wi-Fi/Bluetooth technology must be turned on. Lastly, some Wi-Fi devices might belong to people near bus stops, but who are not transit passengers. Any algorithm using Wi-Fi and/or Bluetooth signals to determine passenger counts would have to determine probabilistically the chances a particular signal can be counted as a transit passenger. The team thought such an algorithm could be developed.

Implementation and testing

To determine the effectiveness of the Wi-Fi system in predicting passenger trips, the team compared the number of MAC addresses detected by the Wi-Fi system to the number of passenger trips originating at the stop where the Wi-Fi detection system was installed (stop 1211). To qualify as a Wi-Fi detection, the system had to detect a signal for longer than 1 min, but less than the headway of the closest bus approaching the stop. Comparisons were made for May 1, 2015. There were 1,806 qualified Wi-Fi detections and 699 passenger trips from the Wi-Fi stop – so Wi-Fi detections were 391 percent of passengers.

The Wi-Fi probably detected such a high number of signals compared to passenger numbers because the system detects MAC address within about 100 m, far larger than the waiting area for a bus stop. Because so many devices were detected, it was difficult to differentiate between passenger devices and devices passing through the detection zone. The system tested for this project did not allow for range adjustment, but future systems could be designed with ranges more appropriate for the size of a bus stop. It is also possible that the number of detections and the number of passengers are highly correlated, but further analysis not possible in the timeframe of this project would be needed to determine if that is the case.

Conclusions and considerations for transit agencies

Using Wi-Fi or Bluetooth technology to assess demand would vary in expense, depending on if a transit agency has devices capable of Wi-Fi/Bluetooth detection installed on its buses, and if the agency has bus stops with power and communication. Because it relies on passengers having devices with Wi-Fi/Bluetooth enabled, passenger counts using this method would be more accurate if a high percentage of passengers owned and used such devices, such as in high-technology and high-income areas.

The algorithm used to analyze Wi-Fi/Bluetooth data and produce accurate passenger counts would have to be customized for each agency and potentially each bus stop, because it would depend on geography, location of the detector, detector range, and numbers of passers-by. Developing that algorithm could represent a considerable investment.

Demand Assessment Technology Summary

Evaluation

Many of the demand-assessment technologies initially identified for this project were evaluated (results listed in Table 3-3), but not pursued to the testing phase. Privacy concerns and data access prevented Blacksburg Transit from using data from the BT4U website to assess demand. Cameras proved an immature technology, and not accurate enough in outdoor settings. Using a Hokie Passport swipe or RFID tags embedded in Hokie Passports to count waiting passengers would have required expensive equipment and changes to Virginia Tech policies that were not feasible. Survey respondents found the idea of a thumb scanner intrusive and unsanitary. The technologies not pursued further here, though, might prove the best choice for other transit agencies. Agencies with card readers or RFID scanners already installed might gravitate towards those options, and agencies with mostly indoor waiting areas could possibly use camera detection. The project team hopes that the evaluation performed here provides other transit agencies a starting point from which to research demand assessment and dynamic scheduling, with the goal of reducing GHG emissions.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

TABLE 3-3 DEMAND ASSESSMENT TECHNOLOGIES EVALUATION SUMMARY

TECH	PASSIVE OR ACTIVE?	INFRASTRUCTURE REQUIRED	PROVIDES ADVANCE DEMAND NOTIFICATION	DETECTS RIDER PRESENCE AT STOPS	PROVIDES ORIGIN INFO	POTENTIAL TO PROVIDE DESTINATION INFO	IS TECHNOLOGICALLY FEASIBLE	COST
BT4U WEB, PHONE, & TEXT	Active	Intensive Software, Some Hardware	Yes	No	Yes	No	Yes	Moderate
BT4U MOBILE APP	Active	Intensive Software, Some Hardware	Yes	No	Yes	Yes, if trip planned	Yes	High
IBEACONS	Both	Communications, Software, Hardware	No	Yes	Yes	Yes, but not in advance	Yes	High
CAMERA	Passive	Intensive Hardware, Software, Power, Communications	No	Yes	Yes	No	No	High
HOKIE PASSPORT	Active	Power, Communications, Software, Hardware	No	Yes	Yes	No	Yes	Moderate
KIOSK	Active	Power, Communications, Intensive Software, Hardware	Yes	Yes	Yes	Yes, if trip planned	Yes	High
RFID	Either	Intensive Hardware, Software, Power, Communications	No	Yes	Yes	Yes, but not in advance	Yes	Moderate-High
THUMB-SCANNER	Active	Power, Communications, Software, Hardware	No	Yes	Yes	No	Yes	Moderate
WI-FI/BLUE-TOOTH	Passive (if turned on)	Power, Communications, Software, Hardware	No	Yes	Yes	No	Yes	Moderate-High



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Testing

The demand assessment technology evaluation resulted in four technologies being selected for field testing, the results of which are listed in Table 3-4. iBeacons proved the most promising technology for assessing demand for transit bus usage, but only marginally so, and the BT4U mobile application and kiosk (running the mobile app) both have the potential to provide transit operators with advance demand information and rider origin and destination information. Any mobile app attempting to collect origin and destination information must balance ease of use with the richness of data collected. Wi-Fi also has the potential to collect demand information, but problems with range and reducing false positives make doing so challenging. More research is required before Blacksburg Transit can definitively say which demand-assessment technology best fits its needs, and the best-suited demand-assessment technology will likely differ between transit agencies.

TABLE 3-4 DEMAND ASSESSMENT TECHNOLOGIES TESTING SUMMARY

DEMAND ASSESSMENT TECHNOLOGY	TESTING PERFORMED	DETECTIONS VS. PASSENGERS (PERCENT)	STANDARD DEVIATION (PERCENT)
BT4U Web, Phone, & Text	No		
BT4U Mobile App	Yes	4.2	1.6
iBeacons	Yes	2.4	0.8
Camera	No		
Hokie Passport	No		
Kiosk	Yes	3.8	1.8
RFID	No		
Thumb-scanner	No		
Wi-Fi/ Blue-tooth	Yes	391	

HISTORICAL DEMAND

Historical demand data can be used to help predict ridership. Data such as past ridership and other environmental conditions can be used to accurately “predict” future demand. However, historical data are just that. It can only be used to predict what future demand might be.

Passenger count data

Blacksburg Transit has collected and stored ridership data since January 2011. Passenger counts came from the Trapeze system, which has two units. One is a ranger a console that the drivers use to enter passenger type as the passengers enter the bus and part of a fare-tracking system. The other is an IR sensor on the bus that counts passenger entries, called an automatic passenger counter (APC) and is about 80 percent accurate. The passenger counts from the Trapeze system are transferred wirelessly to a database, where they can be accessed by the demand-assessment algorithm.

The Blacksburg Transit passenger-count database was a foundation for demand assessment. To get an idea about how passenger demand varies, historical ridership data were analyzed for ridership totals and trends, and the team learned that ridership varies with respect to time of year, time of day, the Virginia Tech academic and event calendars, and public holidays.

Although historical data were informative, they did not allow the team to accurately predict ridership solely based on Virginia Tech’s academic calendar and scheduled events.

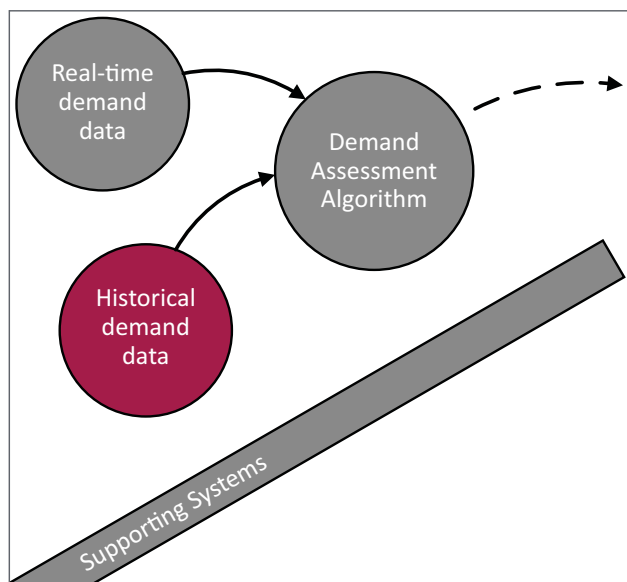


FIGURE 3-20 DOCUMENT MAP — HISTORICAL DEMAND



Transit Bus Routing On-Demand: Developing an Energy-Saving System

FORECASTING RIDER DEMAND WITH THE DEMAND-ASSESSMENT ALGORITHM

Background

Forecasting is used to predict demand for a product or service, such as transit bus service, based on historical demand for that product or service and other related factors. Transit forecasting can be performed at a number of levels, from system to route to stop, but for a transit system to make real-time changes to service, stop-level forecasts must be created so the system can adapt to demand at the stop level. Stop-level forecasts utilize detailed historical and real-time ridership data at stops, and gathering the real-time data was the goal of the demand-assessment technologies investigated for this project. The section begins with a description of factors affecting historical demand and of prior work on forecasting in transit, and continues to detail the development of the forecasting algorithm, including the algorithm's inputs, framework, outputs, and implementation.

Factors contributing to ridership

The factors contributing to ridership on Blacksburg Transit buses are different from those of most municipal and urban transit systems. About 95 percent of Blacksburg Transit riders are affiliated with Virginia Tech, have pre-paid, and can board the bus with their Hokie Passports, so cost is not a strong contributing factor. The Virginia Tech calendar, however, is. When classes are not in session, demand for bus transit is significantly lower than when classes are in session. Students, about 90 percent of riders, primarily use bus transit to travel to and from class, so class schedules significantly affect demand. Virginia Tech enrollment, the ratio of residents to commuters, and the availability and cost of on-campus parking may play a role in yearly bus ridership. Special events, such as graduation and football games, also heavily influence daily ridership demand.

Forecasting levels

Transit ridership forecasts can be performed on different levels. According to Boyle [7], most transit systems forecast at the route level and use the 4-Step method, which primarily uses land use and population trends as inputs and produces long-term, multi-year forecasts. Correspondingly, there has been a great deal of research focused on route-level forecasting [8-11]. Segment-level models have also been developed [12, 13]; however, neither route- nor segment-level forecasts provide detailed enough information to make real-time changes to a transit system, e.g., bus selection and scheduling, included in the goals of this project. To make changes in real time, stop-level forecasts must be made.

Strathman, Dueker [14] examined stop-level analysis and concluded that stop-level models are not appropriate for service planning, instead arguing that route- or segment-level analysis was appropriate for service-level impact assessment. However, Chu [15] argued that changes in service, such as proposed here in response to demand, can impact transfers at the stop level.

The first attempts to forecast at the stop-level were by Kikuchi and Miljkovic [16]. They used fuzzy inference, which quantifies the relationship between stop parameters and stop ridership. This approach did not utilize historical ridership data, instead relying solely on the service quality, accessibility, condition, and demographics at each stop. Kerkman, Martens [17] also identified key factors for predicting demand at the stop-level, but, like Kikuchi and Miljkovic [16] did not incorporate historical ridership data. A more complete stop-level model (T-BEST) was created by Chu [15] and the Center for Urban Transportation Research. The model used socio-economic, transit network, and passenger count data, and incorporated time-of-day variations, important to Blacksburg Transit. It also incorporated spatial and temporal accessibility, and route/stop competition and complementarity. Unfortunately, the T-BEST model did not consider seasonal factors, important for this project, because Virginia Tech's calendar hugely impacts demand for Blacksburg Transit's service.

The main hindrance to stop-level forecasts is a lack of accurate and thorough stop data [7]. Fareboxes, technology to track rider payments, are the most common stop-level data source, but is only available for boardings, not for alightings. However, recent technological advances in APC technology and efforts by transit agencies have increased the availability of more accurate and thorough historical stop-level data that can be

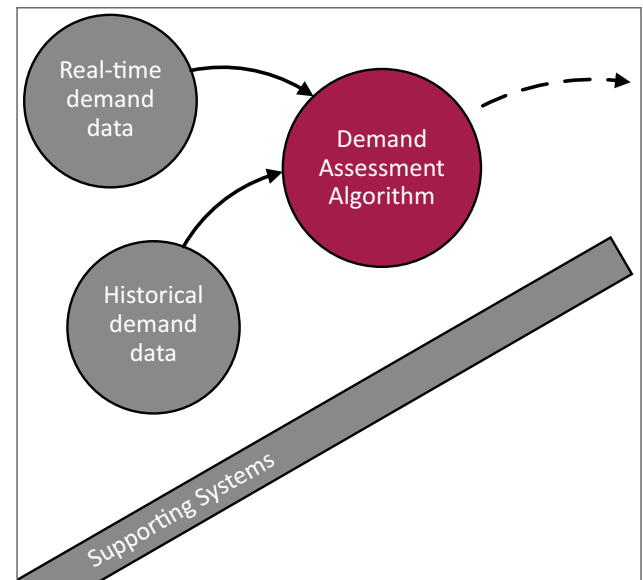


FIGURE 3-21 DOCUMENT MAP — DEMAND ASSESSMENT ALGORITHM



Transit Bus Routing On-Demand: Developing an Energy-Saving System

input to forecasting algorithms. For example, Blacksburg Transit has recorded boardings and alightings from its Trapeze system, described in the Historical demand section above, and consisting of both fare and APC data, for all stops since January 2011. This historical stop-level data can be used to help forecast stop-level demand.

Origin-destination data, where all riders' trips through the system are collected, would be even more informative regarding demand, but it is currently not available for all trips via bus transit, because origin-destination data are typically only collected via surveys and interviews performed on a limited number of riders. Blacksburg began investigating ways to collect origin-destination data during this project, and two demand assessment technologies that were carried through to the end of the project were able to do so: the BT4U Mobile Application and BT4U Mobile Application with iBeacons. That demand data could not be incorporated into the demand-assessment algorithm before the end of the project.

The forecasting model developed for this project was informed by historical stop-level ridership data, which includes seasonal factors related to the Virginia Tech community and the community at large. Other data can also be included, including real-time APC data and demand data collected from smart phones. This approach is justified in a university community, with its unique schedule, ridership patterns, and conduciveness to technology. Other municipalities would need to carefully approach demand data collection, and choose or adapt the technology best suited to their riders. For example, the team did not proceed with RFID technology, because of complications involving Virginia Tech's Hokie Passports and reluctance to invest in an older technology. However, a transit system with a RFID technology in place would have a wealth of historical ridership data, and could potentially adapt the technology to collect demand data.

Demand assessment algorithm

Inputs

A great deal of stop-level data have been collected by Blacksburg Transit and was used in the forecasting model. Since January of 2011, the Trapeze system (farebox and APCs) has collected the following data for each stop, whether or not the bus even stopped:

- trip name,
- date,
- time,
- number of fares,
- number of boardings, and
- number of alightings.

Manual counts performed by Blacksburg Transit have shown that APC counts are approximately 80 percent accurate. Crowding and maintenance both affect APC accuracy, and Blacksburg Transit has both high ridership, creating crowding, and APCs installed throughout its entire fleet, making maintenance and calibration time-consuming. Thus, Blacksburg Transit's APC data may be less accurate than that of other transit systems. Because APC data are less reliable than fare data for Blacksburg Transit buses, for boardings, fare data were used. However, only APC data were available for alightings, and were therefore used. Together, boarding and alighting data were used to calculate bus load, albeit with a level of uncertainty. Bus load was used as the main forecasting variable, because it is important for determining the relationship between demand and capacity, used in the 3DSS algorithm. Bus load was also an input for the fuel-consumption model, described in the next chapter.

Transit planners typically use socio-economic data to estimate commutes, but Blacksburg is a small college town where students comprise 90 percent of riders. Students often take multiple trips to and from campus in one day, and are driven by class schedules, not typical commuting hours. Thus, typical socio-economic data, such as employment type and location, is not as tied to ridership patterns in Blacksburg as it is in most municipalities. An example of useful socio-economic data for Blacksburg would have been employment and enrollment records from Virginia Tech, or parking pass sales. These data were reviewed and no significant factors were found. For other communities, data regarding employment levels and locations for the communities served could possibly be used instead. Relevant to both community types are holiday calendars, which were incorporated into the algorithm's inputs.

Bus schedules were used to identify differences between the schedule in the forecasted year and that of the previous year. Differences include stop changes and changes to the times and types of service, and would require adjustments to the forecast algorithm before accurate comparisons could be made.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Framework

Blacksburg transit had three full school years' of APC data, from which to generate demand forecasts. The APC data were in the form of date, trip (a single loop for a single bus along a route), time, and stop. Demand at a certain date does not necessarily align with demand at the same date in a different year, because day of the week, holidays, bus service schedules, delays, unscheduled trips and academic events do not fall on the same dates. Therefore, the forecast used similar weeks and days from each historical year to forecast for those weeks and days in the current year.

The first step to map data from prior years to the current year was to create a yearly calendar with weeks numbered 1 to 52 or 53, with week 1 as the first week of full bus service in August, before Virginia Tech's first week of fall semester classes, week 15 the week of Thanksgiving, and other key weeks similarly mapped. After weeks were assigned, days of the week were assigned starting with Monday. The result was a calendar for each year with week numbers 1 to 52 (or 53) and days Monday through Sunday. Once the calendar was created, historical data from prior years was assigned a week and day. Anchoring the forecast data on Virginia Tech's calendar was the best solution for Blacksburg Transit; other transit systems can map their calendars using anchors relevant to their communities, such as commercial schedules, holidays, and tourism seasons.

After data were aligned by day, it had to be aligned by stop and trip (the time a bus on a particular loop would arrive at that stop). Instead of using bus schedules to determine the time a bus on a trip would arrive at each bus stop, time bands were created, because APC and fare data do not necessarily reflect demand at a certain bus stop at a certain time, day and week, because a tripper bus might arrive just before or after a scheduled bus, and the passengers might board both that bus and the tripper at varying times.

Time bands were created using average stop times calculated using stop times marked in the APC data for the past three to six months for that same stop and trip, the same calculation used for GTFS data. Times were calculated as adjacent time bands centered on the average stop time, as shown in Figure 3-22 The figure shows a simplified time band; in reality, time bands varied and were accurate to the second, not minute.

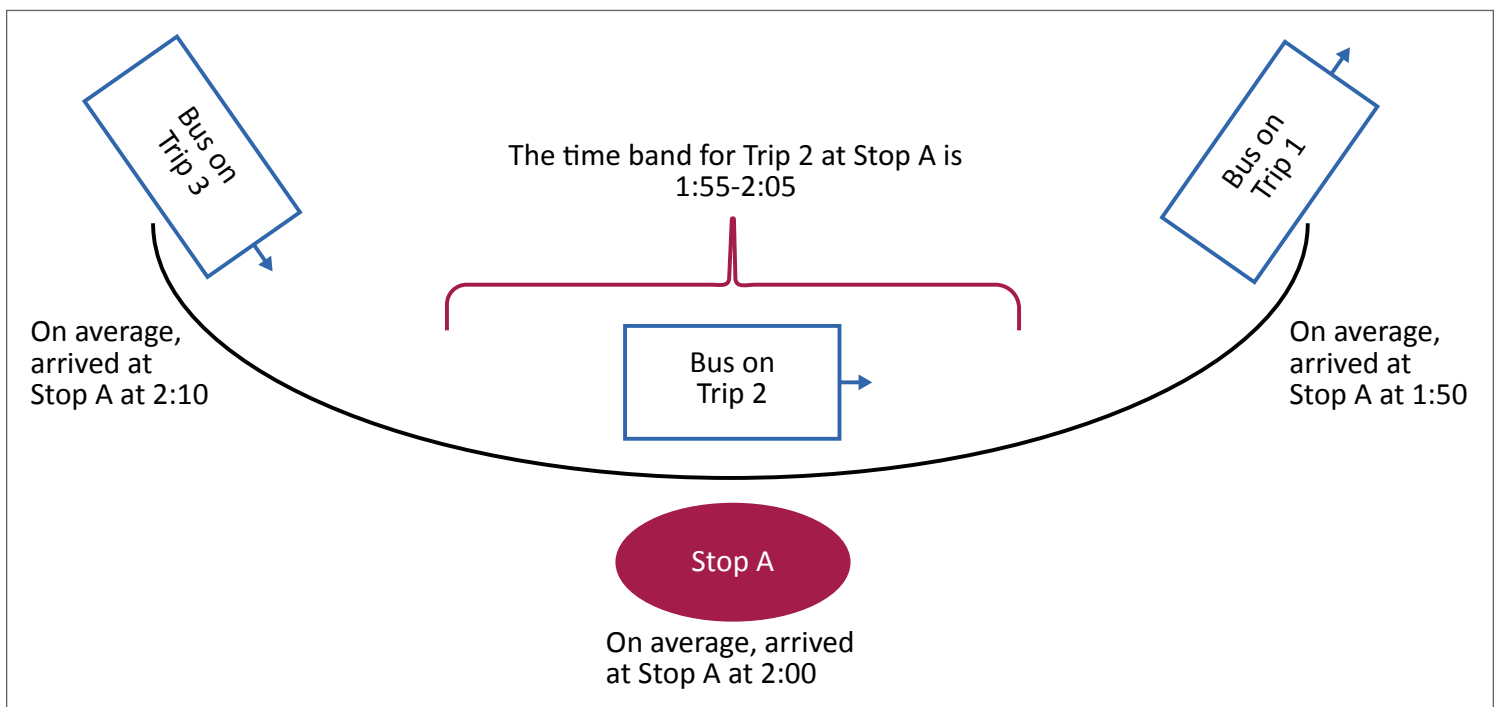


FIGURE 3-22 TIME BAND PER TRIP AND STOP



Transit Bus Routing On-Demand: Developing an Energy-Saving System

With historical passenger count data now mapped to time bands corresponding to passengers boarding at each stop during each time band, the data for the past three years were used to forecast demand for the current year. Both constant and trend exponential smoothing algorithms, commonly used in demand forecasting, were used to forecast demand [18]. The constant method assumed constant demand from year to year, and the trend method assumed there was a trend in the data from year to year and incorporated that trend into the forecast. The algorithms were able to account for some missing data, but no forecast was created if data were inadequate.

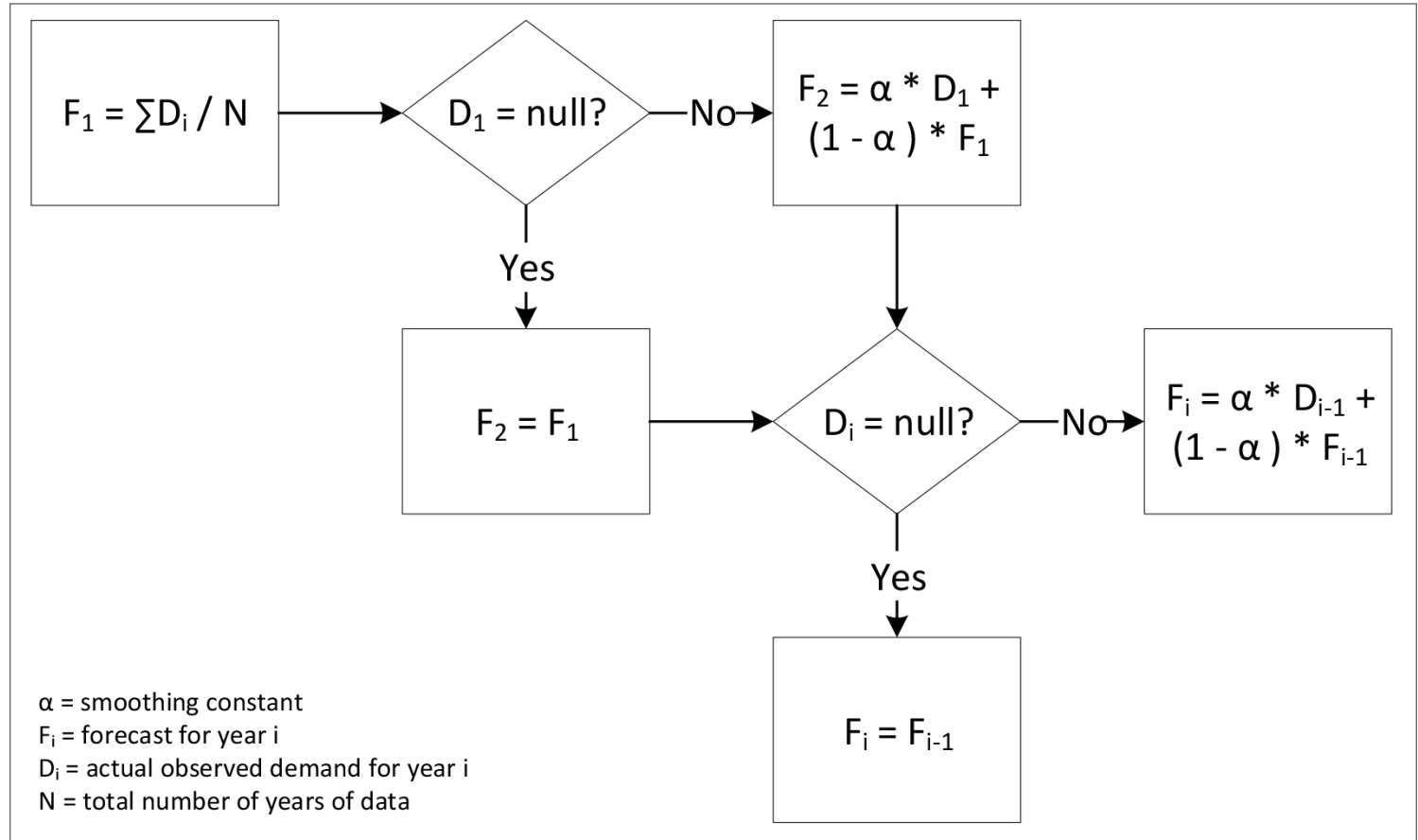


FIGURE 3-23 DECISION TREE FOR DEMAND-ASSESSMENT ALGORITHM

Finally, to create an even more precise demand forecast, a minute-by-minute distribution calculated from the Bus stop observation was applied to the forecast to create a forecast by minute for each stop.

Outputs

The main demand-assessment algorithm output was forecasted bus boardings and alightings. From boardings and alighting, forecasted bus load was calculated as the current bus stop load plus the difference between boardings and alightings at that stop. Load was used, because it is the most important metric for the 3DSS algorithm, since it is directly related to LOS (required capacity) and fuel consumption. The demand-assessment algorithm output also included forecasted passenger numbers waiting at bus stops on a minute-by-minute basis, which, when combined with estimated bus arrival time, resulted in average wait times, a measure of LOS. The forecasts were only calculated by the demand-assessment algorithm for the Hethwood, Hethwood, A, Hethwood B, and CRC routes.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Implementation and validation

Several transit agencies have reported that comparing a forecast to actual ridership is the most common way to validate forecasts [7], and the validation for this project was performed in the same manner. Validation of the forecasting algorithm was performed on the Hethwood A route by comparing forecast outputs to actual ridership data, as collected by the Trapeze system, in the form of bus load when the bus left each stop.

The validation consisted of creating a forecast for the 2013-2014 academic year using data from August 2011-August 2013. In addition, a forecast was created using an additional year of historical data (2013-2014) to forecast the 2014 fall semester. Data for the constant and trend exponential smoothing methods were used to determine which was more accurate, and several α values were tested for each. The value of α is between zero and one, and it determines the dependence of the forecast on the most recent ridership data. When α is closer to one, the most recent ridership data affects the demand to a greater extent than less-recent data.

The errors resulting from validation, calculated in number of riders and shown in Figure 3-24, were low for both smoothing methods and all alpha values, typically less than plus or minus one rider, showing that, on average, the forecast was accurate, and that lower alpha values typically resulted in lower errors.

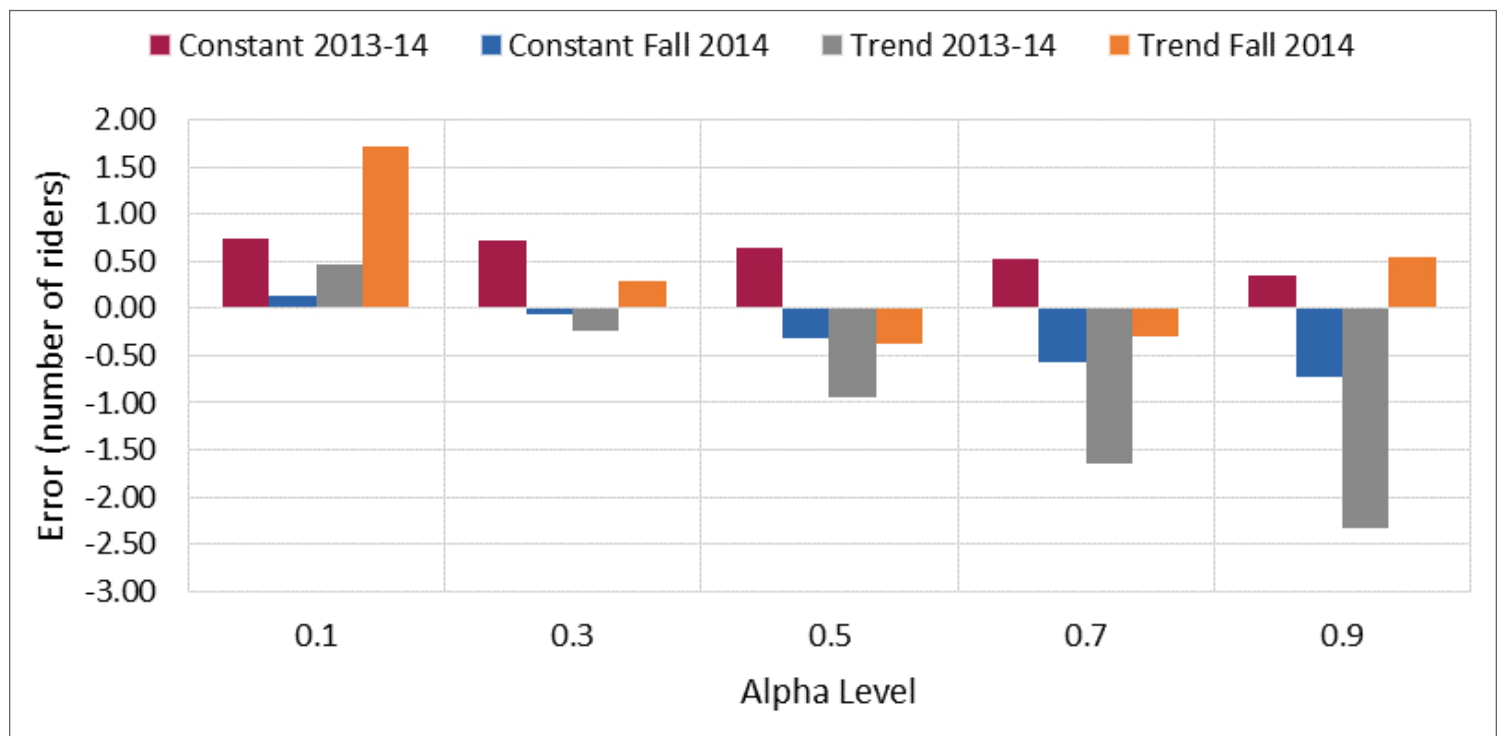


FIGURE 3-24 FORECASTING ERROR REPORTED FOR MULTIPLE METHODS, YEARS, AND ALPHA LEVELS



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Lower alphas likely resulted in lower error due to the fluctuating and inconsistent quantity of ridership demand as seen below in Figure 3-25, which shows boarding (fare) data recorded for Hethwood A over the past three school years, and projected numbers for 2014-15 by doubling boardings from Fall 2014, because data from spring 2015 were unavailable.

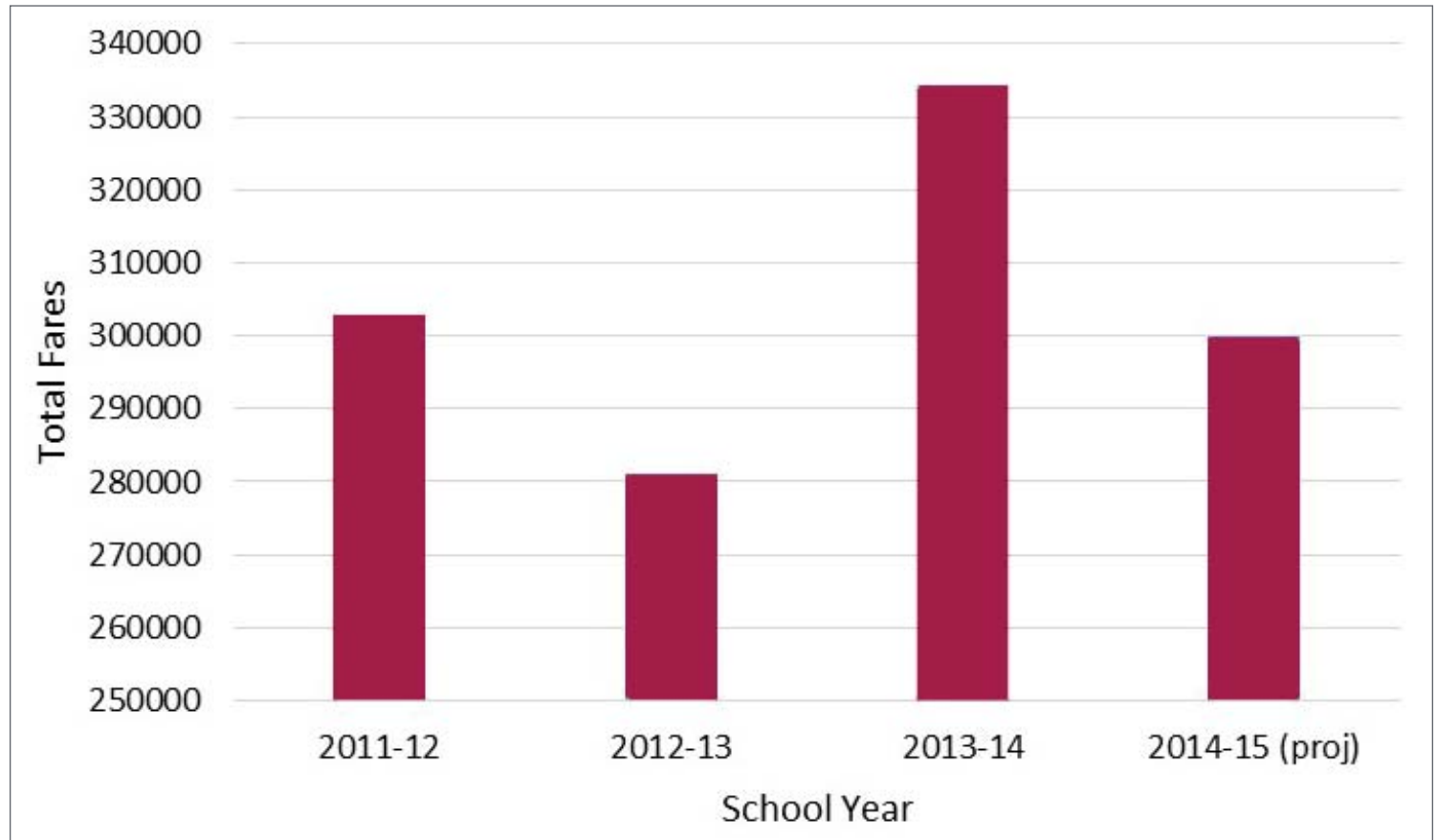


FIGURE 3-25 TOTAL NUMBER OF RIDERS, FROM FARE DATA, COLLECTED BY BLACKSBURG TRANSIT FOR EACH SCHOOL YEAR SINCE 2011

Figure 3-25 shows an increase in ridership between the 2012-2013 and 2013-2014 school years. The team is unsure of exactly why that increase was observed, but speculated that it could have been because of changes in bus scheduling, campus parking availability, or rentals at Hethwood.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

To provide a more complete assessment of accuracy, Figure 3-26 shows absolute errors of each forecast method and year with varying alpha levels. The results are consistent with those in Figure 3-24, and led to the selection of the constant forecasting method with an alpha value of 0.1.

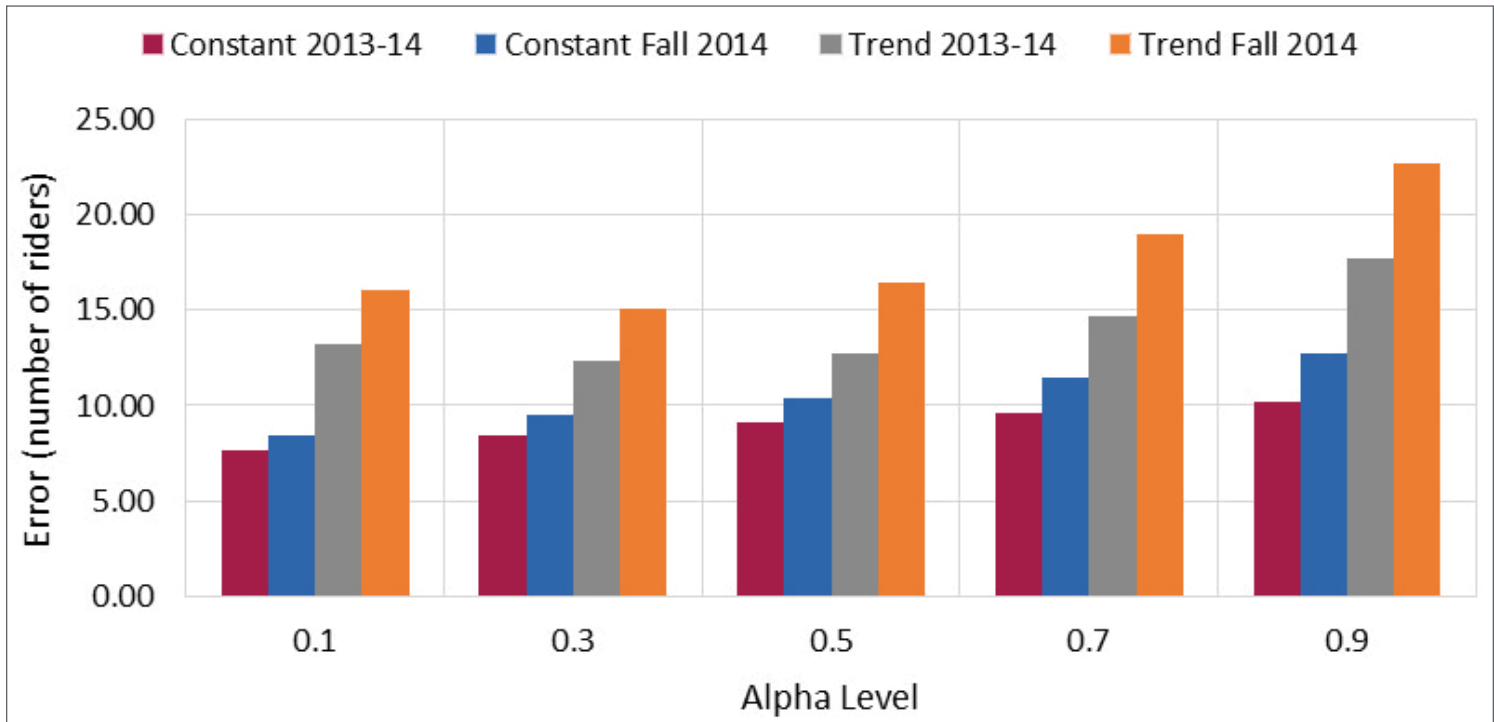


FIGURE 3-26 ABSOLUTE FORECASTING ERROR REPORTED FOR MULTIPLE METHODS, YEARS, AND ALPHA LEVELS

Forecasting conclusions

The goal of this project was to save fuel and reduce GHG emissions, and assessing demand was the first step. The demand assessment algorithm provided an estimate of minute-by-minute arrivals at every stop on the test routes throughout the year based on historical demand. The results of the demand-assessment algorithm were passed to the 3DSS algorithm, which optimized the bus schedules and bus sizes to satisfy demand and save fuel. It was also designed to be expanded to support measurements of real-time demand to dynamically augment the forecast. Forecasts will enable the 3DSS to determine the effect of any real time schedule or bus timing changes in terms of rider wait times, work anticipated to be performed in a follow-on project.

The forecast was reasonably accurate for the purposes of this project, especially considering the available data and the innovation required to develop stop-level forecasts for transit. Fuel consumption analysis shows that passenger load does not have a major effect on fuel usage, so the LOS calculation was the metric most affected by this forecast. More informative inputs could significantly improve the forecast. Using richer ridership data collected for a longer term could allow the models to identify and account for yearly trends. For example, origin-destination data collected with iBeacons in the BT4U Mobile App could be used to enhance the long-term forecasting model. Incorporating data collected from the demand assessment technologies could allow for real-time assessment of ridership, enabling Blacksburg Transit to respond to rider needs. Historical weather data could also prove to be a useful factor, related to rider demand, and incorporated into the forecast model. Blacksburg Transit began collecting this data in 2014 and will be able to include it in future forecasts. Forecasts were partly based on historical data from APCs, and Blacksburg Transit's APCs are about 80 percent accurate.

A more detailed description of the demand-assessment algorithm, including a flow chart, is included under Demand-assessment algorithm in the appendices.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

CONCLUSIONS AND CONSIDERATIONS TO OTHER TRANSIT AGENCIES

Nine technologies to measure demand for transit buses were evaluated based on their accuracy, cost, ease of use, and passenger preferences, among other criteria. Due to cost, privacy concerns, and/or issues with implementation, the BT4U website, camera detection, Hokie Passport swipe, RFID tags, and thumb scan technologies were pursued to the testing phase. The remaining four technologies were tested by using them to collect rider demand data, and comparing the number of demand data points with the number of riders on a route or stop corresponding with that demand-assessment technology. The BT4U Mobile App using iBeacons was the most promising technology and had the lowest standard deviation between data-collection days, but only marginally so. The BT4U mobile application and kiosk (running the mobile app) could both provide transit operators with advance demand information and rider origin and destination information, but any mobile app attempting to collect origin and destination information must balance ease of use with the richness of data collected. Wi-Fi also has the potential to collect demand information, but problems with range and reducing false positives make doing so challenging. More research is required before Blacksburg Transit can definitively say which demand-assessment technology best fits its needs, and other transit agencies may choose different technologies.

As part of demand assessment, historical ridership data were collected and correlated with months and days throughout the year. That data were incorporated into an algorithm predicting demand for transit buses, and testing proved the algorithm accurately predicted ridership to within a handful of riders. Demand forecasting could be even more accurate if demand-assessment technology were further refined, and if richer historical data were incorporated, both of which are possible in an extension of this project.



4. MODELING FUEL CONSUMPTION

OVERVIEW

Fuel consumption models can predict how much fuel a bus consumes given bus type, route, passenger weight, and many other factors. A fuel consumption model was developed for this project to help the team predict the extent changes in scheduling and bus size affect GHG emissions, and to incorporate that factor into the dynamic dispatching decision support (3DSS) algorithm (Figure 4-1). The 3DSS algorithm minimized fuel consumption while meeting passenger expectations through generation of recommendations for bus size selection and scheduling.

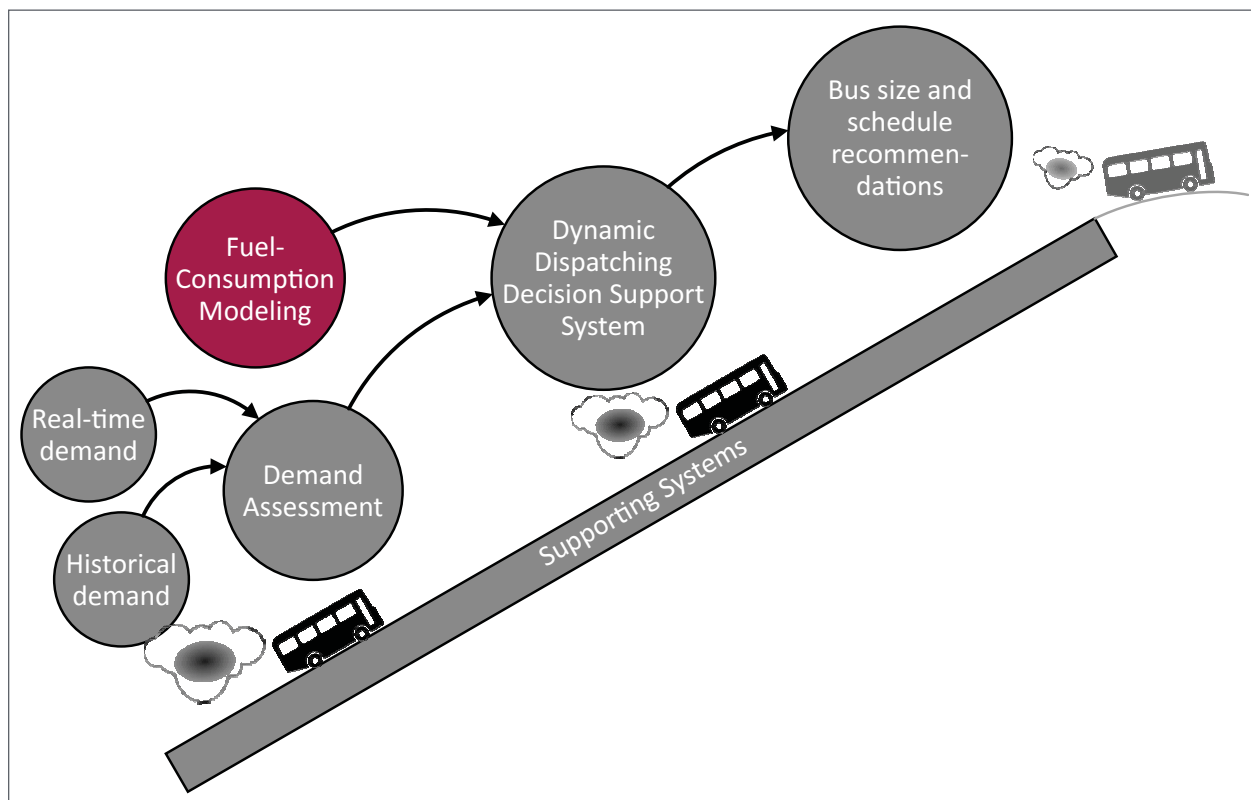


FIGURE 4-1 DOCUMENT MAP — FUEL CONSUMPTION MODELING

BACKGROUND

Fuel consumption models input data such as road profile, vehicle type and weight, and engine performance, and output predictions for the vehicle's fuel-consumption rate. Fuel consumption is closely linked to GHG emissions. Fuel consumption has been modeled in the past, but no prior models were fully applicable to diesel buses. For example, numerous models predict fuel consumption in light-duty vehicles (LDV), but only a few models apply to heavy-duty vehicles (HDVs). Examples of models for HDVs include that of Barth, George [19], who expanded and adapted the comprehensive modal emissions modeling (CMEM) from LDVs to HDVs. Nam [20] developed the physical emission rate estimator (PERE) to supplement the motor vehicle emissions simulator (MOVES) to capture HDV fuel consumption. Those two models are the most popular analytical methods for estimating HDV fuel consumption; however, CMEM and PERE cannot avoid bang-bang control. Bang-bang control may arise when the partial derivative of fuel consumption with respect to the engine torque is not a function of torque [21], implying optimum fuel economy is achieved at full throttle acceleration, and suggesting drivers drive as aggressively as possible. That is obviously not ideal. A model avoiding bang-bang control is needed to better estimate bus fuel consumption.

The Virginia Tech comprehensive power-based fuel consumption model (VT-CPFM) for LDVs was developed by Rakha, Ahn [22] and was the first to circumvent bang-bang control. The other advantage of the VT-CPFM is that it can be calibrated using readily available data, unlike other models which require a large amount of vehicle-specific laboratory or field data. However, the VT-CPFM was now developed for HDVs, so it had to be adapted to model bus fuel consumption in Blacksburg Transit's conventional diesel and diesel-electric hybrid buses.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Overview of the VT-CPFM

The Center for Sustainable Mobility (CSM) at the Virginia Tech Transportation Institute (VTTI) developed the VT-CPFM, which produces fuel consumption estimates with a coefficient of determination of 0.96, indicating that model predictions correlate very accurately with actual observed fuel consumption.

VT-CPFM is a dual-regime model formulated as follows:

$$FC(t) = \begin{cases} \alpha_0 + \alpha_1 P(t) + \alpha_2 P(t)^2 & \forall P(t) \geq 0 \\ \alpha_0 & \forall P(t) < 0 \end{cases} \quad (4-1)$$

Where:

α_0 , α_1 , and α_2 , are vehicle-specific parameters calibrated for each vehicle, and P is the instantaneous vehicle power, computed using Equation (4-2):

$$P(t) = \left(\frac{R(t) + (1 + \lambda) m a(t)}{3600 \eta_d} \right) \times v(t) \quad (4-2)$$

Where:

λ is the mass factor accounting for rotational masses, 0.04 for LDV and 0.1 for HDV [23],

m is the mass of the bus (kg),

a is instantaneous acceleration (m/s²),

η_d is the driveline efficiency (0.95 in this study),

v is instantaneous vehicle speed (km/h), and

R is the resistance force, computed as a sum of aerodynamic, rolling and grade resistance forces as expressed in Equation (4-3):

$$R(t) = \frac{\rho}{25.92} C_D C_h A_f v(t)^2 + 9.8066 m \frac{C_r}{1000} (c_1 v(t) + c_2) + 9.8066 m G(t) \quad (4-3)$$

Where:

ρ is air density at sea level at a temperature of 15 °C (59 °F) (equal to 1.2256 kg/m³),

C_D is the vehicle drag coefficient (unitless),

C_h is a correction factor for elevation (which equals 1 – 0.085H where h is elevation (km)),

A_f is the vehicle frontal area (m²),

$G(t)$ is roadway grade, and

C_r , c_1 and c_2 are unitless rolling resistance parameters.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

The model coefficients are calibrated using Equation (4-4)-(4-6):

$$\alpha_0 = \max \left\{ \frac{P_{mfo} \omega_{idle} d}{22164 \times QN}, \frac{(F_{city} - F_{hwy} \frac{P_{city}}{P_{hwy}}) - \xi(P_{city}^2 - P_{hwy}^2 \frac{P_{city}}{P_{hwy}})}{T_{city} - T_{hwy} \frac{P_{city}}{P_{hwy}}} \right\} \quad (4-4)$$

$$\alpha_2 = \frac{(F_{city} - F_{hwy} \frac{P_{city}}{P_{hwy}}) - (T_{city} - T_{hwy} \frac{P_{city}}{P_{hwy}}) \alpha_0}{P_{city}^2 - P_{hwy}^2 \frac{P_{city}}{P_{hwy}}} \quad (4-5)$$

$$\alpha_1 = \frac{F_{hwy} - T_{hwy} \alpha_0 - P_{hwy}^2 \alpha_2}{P_{hwy}} \quad (4-6)$$

Where:

P_{mfo} is the idling fuel mean pressure (Pa),

ω_{idle} is the idling engine speed (rpm),

d is the engine displacement (liters),

Q is the fuel lower heating value (J/kg),

N is the number of cylinders,

F_{city} and F_{hwy} are the fuel consumed for city and highway test cycles respectively (liters),

P_{city} and P_{hwy} are the sum of the power used for each cycle calculated using Equation (4-2),

P_{city}^2 and P_{hwy}^2 are the sum of the power squares, and

T_{city} and T_{hwy} are the duration of the cycle (seconds).

The ξ term is used to ensure that the second order coefficient does not equal zero. For LDVs, ξ equals 1E-06 fixes the optimum fuel economy cruising speed in the 60-80 km/h (37-50 mph) range, typical for LDVs. For buses, the ξ value should be lower to align with a lower optimum cruising speed for fuel economy. A detailed list of required parameters and potential sources for the VT-CPFM can be found in Table 4-1. Parameters not readily available for Blacksburg Transit buses are shaded.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

TABLE 4-1 PARAMETERS REQUIRED FOR MODEL CALIBRATION

NOTATION	DESCRIPTION	DATA SOURCE
m	Vehicle mass	Vehicle manufacture's website
η_d	Driveline efficiency	EPA 2012 [24]
C_D	Vehicle drag coefficient	[25-27]
C_h	Elevation correction factor	Calculated from field data
A_f	Vehicle frontal area	Vehicle manufacture's website
C_r	Vehicle frontal area	[28]
c_1	Tire rolling resistance	[28]
c_2	Tire rolling resistance	[28]
d	Engine displacement	Unavailable for Blacksburg Transit (BT) buses
Q	Fuel lower heating value	Unavailable for BT buses
N	Number of engine cylinders	Unavailable for BT buses
P_{mfo}	Idling fuel mean pressure	Unavailable for BT buses
ω_{idle}	Idling engine speed	field data
F_{city}, F_{hwy}	Fuel consumed during dynamometer cycle	Unavailable for BT buses
P_{city}, P_{hwy}	Power used during entire driving cycle	Calculated using Equation (2)
P_{city2}, P_{hwy2}	Power used during entire driving cycle	Calculated by P square
T_{city}, T_{city}	Duration of driving cycle	Calculated from field data
ξ	Constraining term	[29]
H	Elevation	Recorded using GPS receiver

For the fuel-consumption model to be as accurate as possible, the parameters listed in Table 4-1 should also be as accurate as possible. Therefore, that data were collected directly form Blacksburg Transit buses as described in the next section.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

ON-BOARD DATA COLLECTION

To collect data unavailable from public (non-proprietary) sources, the research team tested a number of devices for collecting data directly from Blacksburg Transit buses.

MiniDAS

The MiniDAS is VTTI's newest data acquisition system (Figure 4-2). The system can collect J1939 data, a commercial vehicle standard data and communication format. It has an inertial measurement unit (IMU) capturing linear and angular acceleration on three axes, a three-axis magnetometer providing additional data on vehicle orientation, a satellite receiver, and two video cameras, one facing the driver, and one facing the road. Video collection was not necessary for this project, so the cameras were disabled. The system stores data on an onboard 128-BG secured digital (SD) card. Installation, maintenance, data collection, and de-installation of the system and its software is performed through a wireless connection. System health checks, system maintenance, and trip counts can also be performed via the MiniDAS' built-in cellular interface with nationwide coverage.

The MiniDAS was plugged into a bus' standard 9-pin J1939 diagnostic port and installed on the back of the bus equipment cabinet (behind the driver) and the window, where researchers could access it, and where it had GPS signal. Data were retrieved by swapping the MiniDAS' SD cards and uploading it to secure servers. The data was then examined by the fuel-consumption modeling team.



FIGURE 4-2 VTTI MiniDAS VEHICLE DATA-COLLECTION INSTRUMENT WITH AA BATTERY (LEFT) AND MOUNTED ON A BUS (RIGHT)

The team encountered several problems with MiniDAS data collection. For some variables, data were not recorded at all, and for others, there were gaps in the data files. The problems were caused by improper network file coding, and re-coding the network file would require time and resources outside of the scope of this project. So, the research team decided not to use the MiniDAS to collect data for fuel-consumption modeling.

Suggestion for transit agencies

VTTI has a great deal of experience in on-board light-duty vehicle data collection using the MiniDAS, and the team had hoped the MiniDAS would be a plug and play solution for bus data collection. However, that proved not to be the case. The MiniDAS' simple power system was an advantage, but data collection was not automated and time consuming. If VTTI would to update and test the MiniDAS' network files, it could prove very effective and reliable for collecting long-term naturalistic data from active buses. Additionally, of the three technologies tested, only the MiniDAS has video capability. So, transit systems hoping to collect video data of the driver and road as well as data related to fuel consumption should seriously consider similar technology.

HEM

The HEM data logger, manufactured by IOSiX LLC and sold by HEM Data Corporation, acquires J1939, J1708 and raw controller area network (CAN) data from heavy-duty trucks and off-road vehicles. The team chose the HEM data logger because it collects data autonomously, saves it on a microSD card, and automatically uploads the data to a server via Wi-Fi.

The team plugged the HEM data logger into the J1939 port and installed it between the equipment cabinet behind the driver and the window. It collected data from ignition-on to ignition-off, and saved it periodically to two files, one with J1939 and the other with GPS data. When the ignition was turned off, if the bus



FIGURE 4-3 HEM DATA LOGGER



Transit Bus Routing On-Demand: Developing an Energy-Saving System

was in Blacksburg Transit's garage, the data was uploaded to a server, requiring no action by the maintenance crew. If the data upload was successful, the two files were combined into one comma-separated (*.CSV) file, which was imported into the TIGGER database and used by the fuel-consumption model.

Most of the problems with the HEM data logger involved data upload. The data loggers would not reliably upload their data to the server, a problem solved by installing more Wi-Fi access points. The data loggers would power down shortly after the bus was turned off, and before data upload was complete, an issue addressed by adding an uninterruptable power supply (UPS) to the equipment cabinet. To reduce the amount of data to upload, the data-collection rate and number of variables were adjusted to keep the data file small. Another problem was with the logger's firmware, overcome with firmware updates. A more detailed description of the problems the team encountered and solutions found is in Appendix C: Fuel consumption modeling.

These problems were overcome, and the HEM data logger proved the best of the tested technologies for fuel-consumption data collection, so the fuel-consumption model was calibrated and validated using HEM data.

Considerations for transit agencies

The main benefit of the HEM data logger was its small size and automatic operation. Transit agencies hoping to fully automate fuel-consumption data upload should review and learn from the team's problems and solutions in Appendix C: Fuel consumption modeling.

DashDAQ

The DashDAQ Series II, manufactured by Drew Technologies, Inc., is an automotive data logger designed to easily acquire OBDII and GPS data, and to allow users to visualize that data. It is marketed to vehicle enthusiasts to measure their vehicle's performance in real time, but it can also log vehicle data onto an SD card. In addition to OBDII data, the DashDAQ can incorporate additional drivers allowing it to collect data from analog sensors, custom ECUs, fuel/air ratio meters, GPS receivers, and J1939 data. The research team used the DashDAQ to collect J1939 and USB GPS data.

The DashDAQ was plugged into a bus' standard 9-pin J1939 diagnostic port and installed where operators, maintenance crew, and passengers could not touch its touch screen and alter its settings. Its exact location depended on the J1939 port's location for a particular bus model. A USB GPS sensor was also used, and installed in a convenient location for the bus model. Prior to each run, the DashDAQ had to be configured for the bus series, and after the run, data collection had to be manually stopped. The data was saved to a comma-separated file on the DashDAQ's SD card, and the file was sent to VTTI for analysis by the fuel-consumption modeling team.

Data from the DashDAQ were compared to those of the HEM mini logger. The devices performed very similarly, and any discrepancies were caused by human error or bus-operator error. However, the DashDAQ cannot log or upload data automatically, it could not collect as much data as the HEM data loggers, so the HEM data were used for fuel-consumption model calibration and validation.

Recommendation for transit agencies

The main benefit of the DashDAQ is that it had an intuitive, easy to use touch screen. The main problem is that it cannot log data unattended, impractical for gathering data during everyday bus operations. However, the DashDAQ could be used for limited data-collection runs for preliminary data collection.



FIGURE 4-4 DASHDAQ VEHICLE DATA-COLLECTION INSTRUMENT



Transit Bus Routing On-Demand: Developing an Energy-Saving System

FUEL CONSUMPTION MODEL FRAMEWORK

Data processing

A number of operations were performed on the raw data. The original data contained noise, so exponential smoothing, specified in Rakha, Anh [29], was used to remove it. The data collected by the HEM data logger were recorded at a frequency of 2 Hz or 10 Hz. To generate a second-by-second record, required by the model, the original data were averaged within each second. Additionally, null data where longitude, latitude, and/or altitude had a value of zero were removed.

Thereafter, acceleration, ridership, road grade, altitude correction factor and total bus weight (including total passenger weight) were also computed for each second-by-second data point. Road grade was computed using Equation 4-7 below:

$$grade = \frac{elevation(t) - elevation(t - \Delta t)}{\sqrt{(D(t) - D(t - \Delta t))^2 - (elevation(t) - elevation(t - \Delta t))^2}} \quad (4-7)$$

where:

$elevation(t)$ is the altitude (m) at time t and $t - \Delta t$, and

$D(t)$ is the distance (m) a bus traveled at the interval of Δt .

The elevation was collected by the HEM data logger, and the distance traveled was computed from speed data.

The total bus weight was the sum of the empty bus weight and the passenger weight. Passenger weight was computed by multiplying the ridership by 150 pounds (68.18 kg) per passenger, an assumed average human weight.

Separating data into calibration and validation sets

Before a fuel-consumption model can accurately predict the amount of fuel a bus would consume and the emissions it would generate, it must be calibrated with data as specific as possible to that bus, such as bus weight, engine displacement, and speed. After a model is calibrated, it must be validated. During validation, a calibrated model is used to “predict” a known amount of fuel consumption. Then, the predicted fuel-consumption rates are compared to actual fuel consumption rates. If they are similar, the model is considered valid, and can be used to predict future, unknown fuel consumption, as required by the 3DSS algorithm.

For this study, the HEM data were divided into inputs for calibration, such as engine performance, and data for validation, the actual fuel consumed.

Model calibration

The VT-CPFM tool is designed to input vehicle test data collected by the EPA, available for LDVs, but not for buses. Consequently, for buses, Equations 4-4 to 4-6 cannot be used to calibrate the VT-CPFM model, forcing the CSM team to develop and use regression instead.

Fuel-consumption models for a total of 14 conventional diesel buses and two diesel-electric hybrid buses were calibrated by the CSM team members. When possible, a fuel-consumption was also calibrated from data from buses in a series, and the series model was compared to the individual buses in that series. That approach was tested because it is easier to develop a series model using data from a subset of buses than to collect data for each individual bus in a transit system. Fuel-consumption models for the two different diesel-electric hybrid buses, 6011 and 6021, were only created for the individual buses, because those individual buses did not form a series.

Thus, data for buses 1911, 1912, 1913, 1919, 1920, 1921, and 1923 were used to calibrate a model for 1900 series; data for buses 6201, 6203, and 6204 were used to calibrate a model for the 6200 series; data for buses 6307 and 6308 were used to calibrate a model for the 6300 series, and data for buses 6323 and 6324 were used to calibrate a model for the 6320 series. Detailed information about the buses is listed in Table 4-2. All buses had Cummins engines and used low-sulfur diesel fuel.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

TABLE 4-2 MANUFACTURER INFORMATION FOR BLACKSBURG TRANSIT BUSES

BUS NO.	SERIES	YEAR	MAKE & MODEL	SIZE (FT.)	ENGINE MODEL	HORSEPOWER	EMPTY WEIGHT (LBS.)	TYPE
1911	1900	2009	New Flyer SR-1360 D40LFR	40	ISL-07	250-330	28,300	Diesel
1912	1900	2009	New Flyer SR-1360 D40LFR	40	ISL-07	250-330	28,300	Diesel
1913	1900	2009	New Flyer SR-1360 D40LFR	40	ISL-07	250-330	28,300	Diesel
1919	1900	2009	New Flyer SR-1360 D40LFR	40	ISL-07	250-330	28,300	Diesel
1920	1900	2009	New Flyer SR-1360 D40LFR	40	ISL-07	250-330	28,300	Diesel
1921	1900	2009	New Flyer SR-1360 D40LFR	40	ISL-07	250-330	28,300	Diesel
1923	1900	2009	New Flyer SR-1360 D40LFR	40	ISL-07	250-330	28,300	Diesel
6201	6200	2012	New Flyer SR-1614 XD35	35	ISL-2010	280-330	26,750	Diesel
6203	6200	2012	New Flyer SR-1614 XD35	35	ISL-2010	280-330	26,750	Diesel
6204	6200	2012	New Flyer SR-1614 XD35	35	ISL-2010	280-330	26,750	Diesel
6307	6300	2013	New Flyer SR-1733 XD35	35	ISL-2010	280-330	26,750	Diesel
6308	6300	2013	New Flyer SR-1733 XD35	35	ISL-2010	280-330	26,750	Diesel
6323	6320	2013	New Flyer SR-1734 XD60	60	ISL-2010	280-330	39,675	Diesel
6324	6320	2013	New Flyer SR-1734 XD60	60	ISL-2010	280-330	39,675	Diesel
6011	n/a	2010	New Flyer- hybrid SR-1439 DE40LFR	40	ISL-07	280	31,140	hybrid
6021	n/a	2010	New Flyer- hybrid SR-1440DE60LFR	60	ISL-07	330	45,860	hybrid

Vehicle power was estimated using Equation 4-2. The results indicated that the relationship between fuel-consumption rate and vehicle power was the same for each bus, as shown in Figure 4-5, a plot for bus 1911 that is representative of the results. The figure shows two trends. For positive vehicle power, fuel consumption is parabolic and can be modeled with a second-order polynomial function. The VT-CPFM uses a second-order polynomial to capture vehicle fuel consumption, so that result indicates the VT-CPFM is applicable bus fuel consumption. Because the model is a second-order polynomial, general linear regression, the applicable statistical method, was used to calibrate it. Outliers were removed using three prevailing statistical techniques, studentized residual, leverage, and cook's distance, as introduced in Montgomery, Runger [30], to enhance the accuracy of the calibration.



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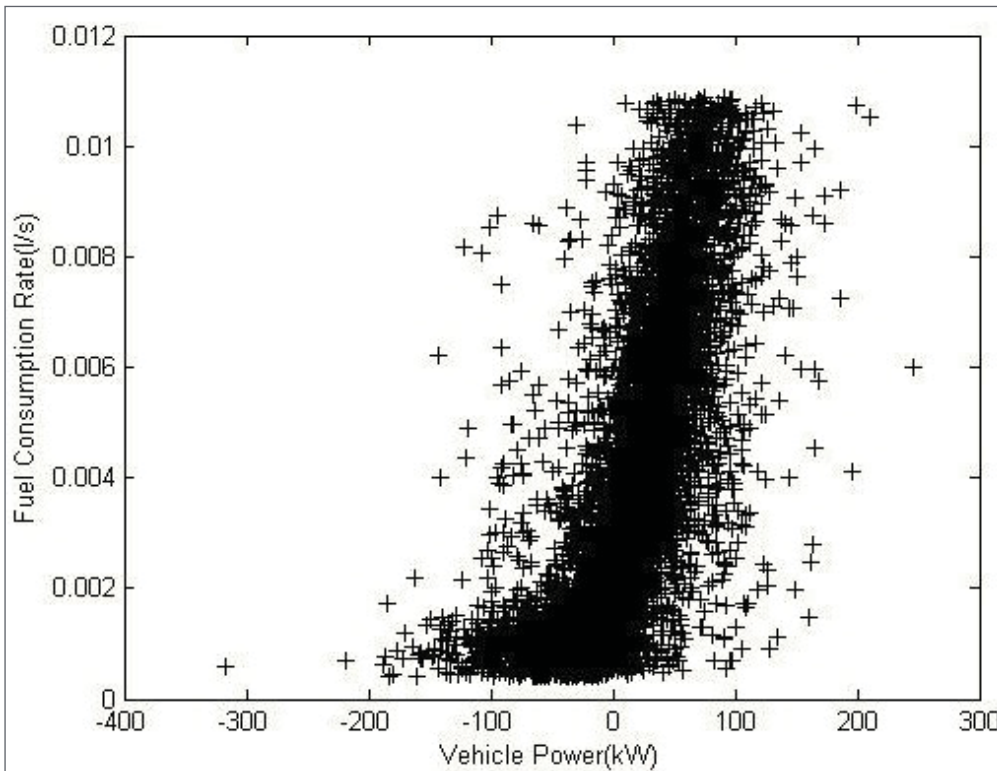


FIGURE 4-5 TYPICAL POWER VS. FUEL CONSUMPTION FUNCTIONAL FORM

After removing outliers, the resulting relationship between fuel-consumption rate and vehicle power was supralinear – fuel consumption rate increases with vehicle power to a lesser extent at higher vehicle powers than at lower vehicle powers, as shown in Figure 4-6, with other plots included in Appendix C: Fuel consumption modeling. That supralinear relationship is different from the relationship between fuel consumption rate and vehicle power for LDVs, where fuel consumption increases with vehicle power to a greater extent at higher vehicle powers. Discovery of this relationship is a novel with respect to transit buses.

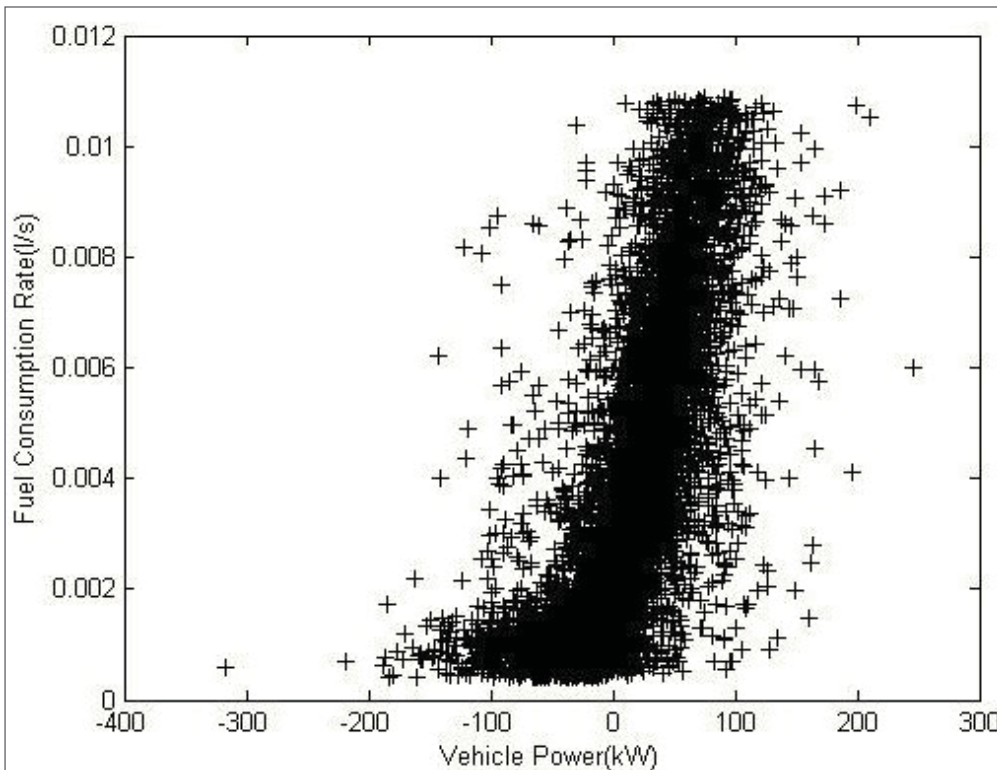


FIGURE 4-6 CONCAVE ASPECT BUS FUEL CONSUMPTION MODEL; BUS 1911 AS EXAMPLE



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Table 4-3 lists the calibration results for each bus model and series (calibrated using data from all models in the series). The fact that α_2 is smaller than zero for all models again demonstrates that the bus fuel consumption model is supralinear.

TABLE 4-3 CALIBRATION RESULTS FOR INDIVIDUAL MODEL AND SERIES MODEL

BUS NO.	α_0	α_1	α_2
1911	1.546e-03	1.139e-04	-4.498e-07
1912	1.499e-03	1.079e-04	-2.665e-07
1913	1.307e-03	1.104e-04	-3.749e-07
1919	1.599e-03	1.288e-04	-4.579e-07
1920	1.728e-03	1.128e-04	-3.206e-07
1921	1.323e-03	1.095e-04	-2.251e-07
1923	1.931e-03	1.195e-04	-3.198e-07
1900 series	1.606e-03	1.067e-04	-2.849e-07
6201	1.090e-03	7.585e-05	-3.355e-07
6203	8.516e-04	7.262e-05	-2.244e-07
6204	1.083e-03	7.881e-05	-2.110e-07
6200 series	1.076e-03	7.294e-05	-2.149e-07
6307	9.109e-04	8.319e-05	-2.489e-07
6308	1.132e-03	8.574e-05	-4.858e-07
6300 series	9.356e-04	8.323e-05	-2.694e-07
6323	1.230e-03	1.125e-04	-4.154e-07
6324	1.192e-03	1.059e-04	-1.738e-07
6320 series	1.321e-03	9.496e-05	-9.418e-08
6011 (6010 series)	1.173e-03	3.829e-05	-1.284e-08
6021 (6020 series)	1.367e-03	6.651e-05	-3.821e-08



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Model implementation, testing, and validation

The individual and series fuel-consumption models were validated by comparing their estimated fuel-consumption rates with the actual fuel-consumption rates available in the validation data set. Both data sets were smoothed before validation to reduce the effect of noise in the HEM data.

As illustrated in Figure 4-7, Figure 4-8, and Figure 4-9, the models' estimated fuel-consumption rates generally followed those of the validation data set for both individual buses and bus series. Additional graphs for the other buses can be found in Appendix C: Fuel consumption modeling. Although the models overestimated and underestimated fuel consumption for some data points, in general, the model prediction followed the real-world fuel measurements with a high coefficient of determination, as illustrated in Table 4-4. The correlation was the worst for bus 6308, because the data quality was very poor for that bus, leading to a relatively lower R-squared value, even after outliers were removed.

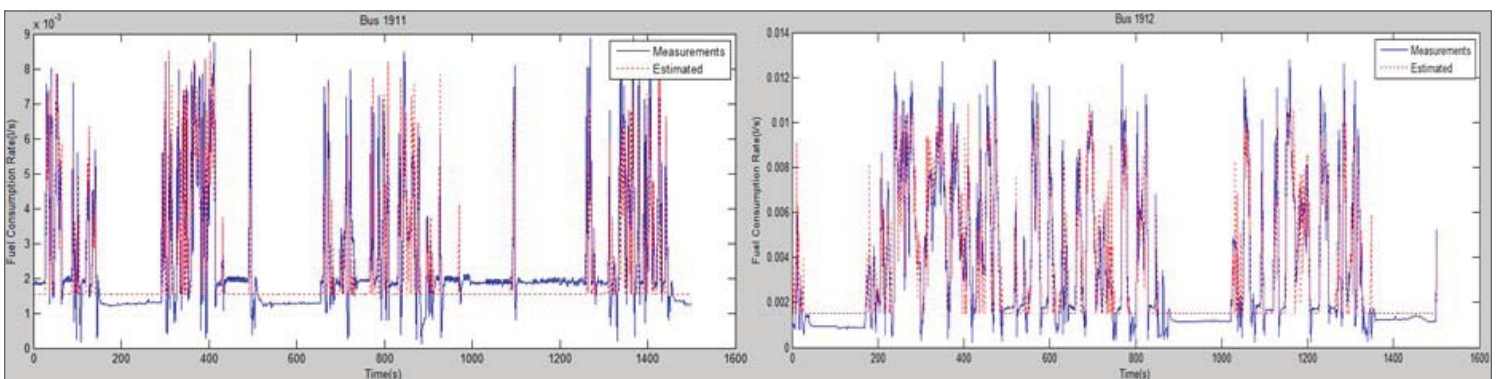


FIGURE 4-7 EXAMPLE FOR INDIVIDUAL MODEL VALIDATION FOR TWO CONVENTIONAL DIESEL BUSES

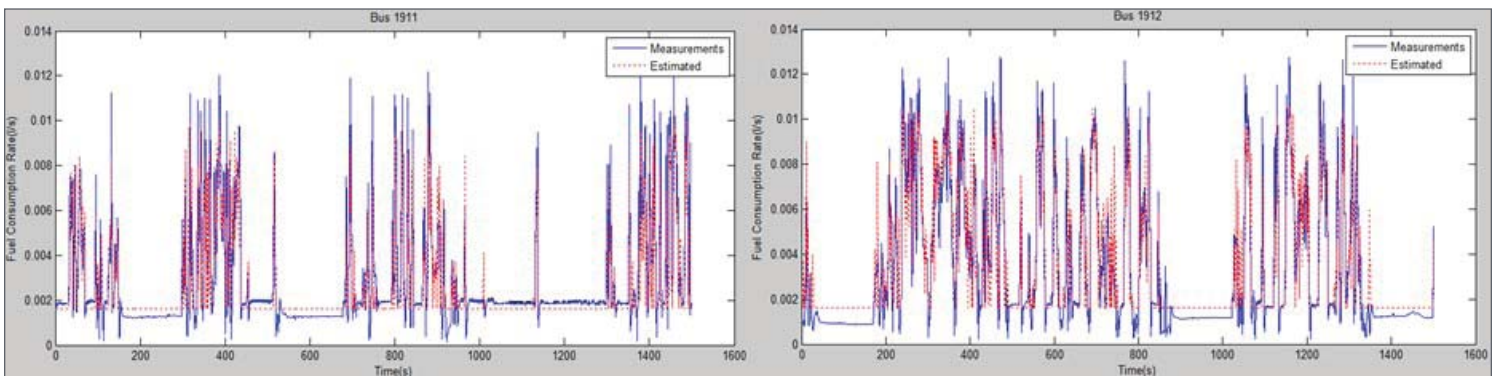


FIGURE 4-8 EXAMPLE FOR SERIES MODEL VALIDATION FOR TWO CONVENTIONAL DIESEL BUSES

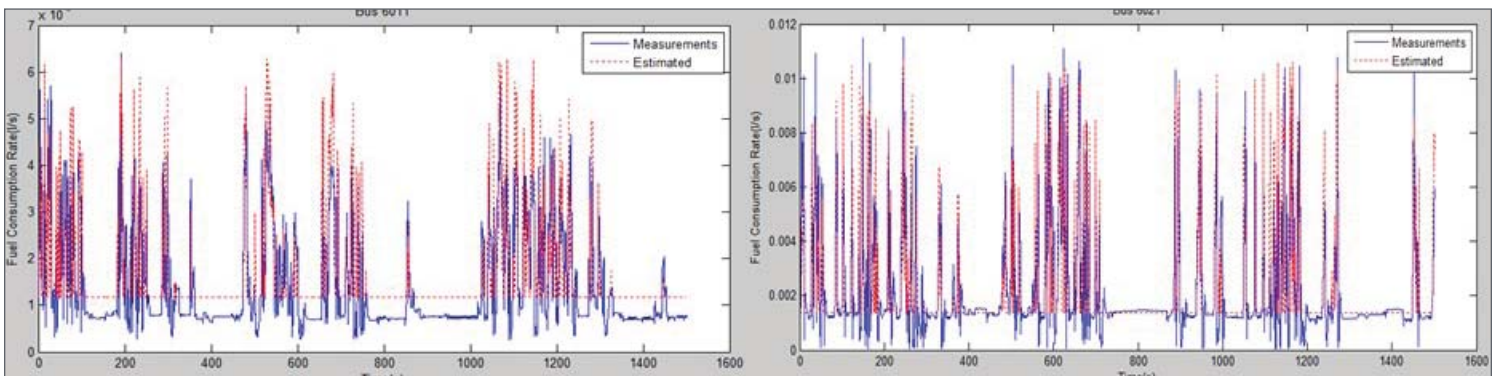


FIGURE 4-9 INDIVIDUAL MODEL VALIDATION FOR TWO HYBRID BUSES



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TABLE 4-4 COEFFICIENTS OF DETERMINATION FOR VALIDATION

BUS NO.	INDIVIDUAL MODEL VALIDATION R-SQUARED	SERIES MODEL VALIDATION R-SQUARED
1911	0.741	0.820
1912	0.813	0.812
1913	0.753	0.726
1919	0.747	0.747
1920	0.801	0.801
1921	0.856	0.853
1923	0.767	0.767
6201	0.712	0.788
6203	0.839	0.840
6204	0.798	0.798
6307	0.756	0.755
6308	0.624	0.623
6323	0.803	0.792
6324	0.793	0.796
6011	0.607	/
6021	0.694	/



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RESULTS²

Optimum cruise speed

Optimum cruise speed is the speed at which a bus' fuel consumption is minimum. Figure 4-10 is a typical example of the fuel-consumption rate as a function of cruising speed. The curve is shaped similarly to that of LDVs, which typically have minimum fuel consumption at about 40-50 km/h range (25-31 mph). For transit buses, it was in the 40-50 km/h range (25-31 mph).

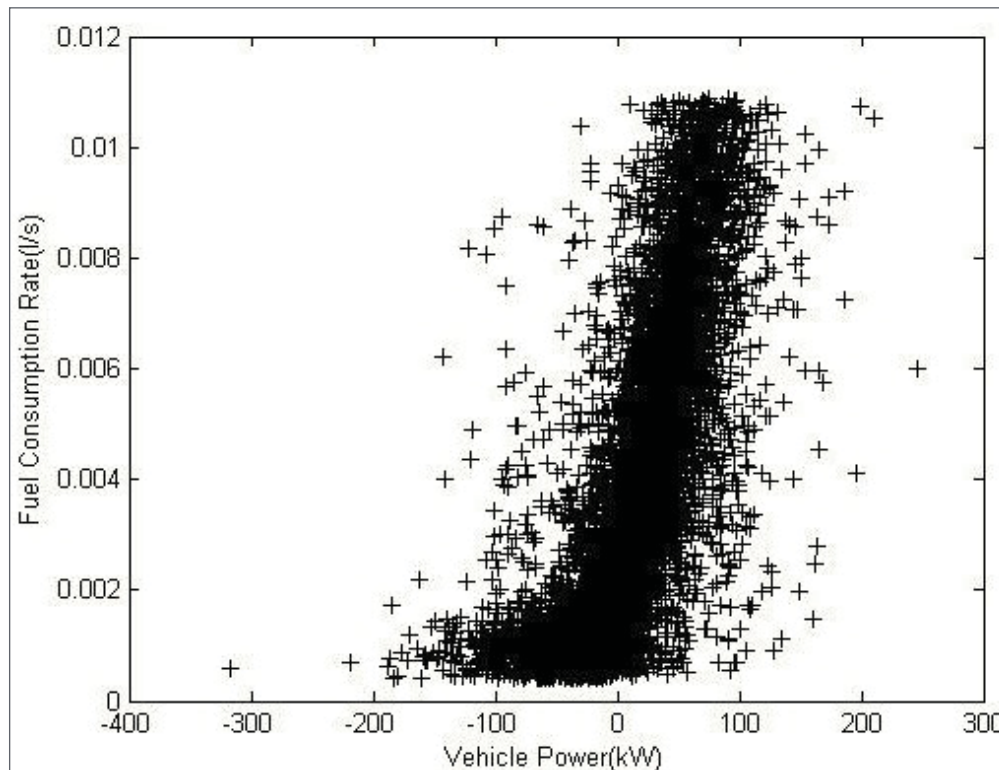


FIGURE 4-10 IMPACT OF CRUISE SPEED ON FUEL CONSUMPTION RATE

TABLE 4-5 OPTIMUM FUEL ECONOMY CRUISE SPEED FOR EACH BUS AND EACH BUS SERIES

BUS NO.	OPTIMUM SPEED (KM/H)	BUS NO.	OPTIMUM SPEED (KM/H)	BUS NO.	OPTIMUM SPEED (KM/H)
1911	46	1900 series	46	6300 series	42
1912	45	6201	48	6323	42
1913	43	6203	42	6324	40
1919	44	6204	45	6320 series	42
1920	47	6200 series	46	6011	50
1921	42	6307	41	6021	49
1923	48	6308	45		

² Modeling was performed in Matlab, with files available upon request.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Hybrid vs. conventional buses

The validated VT-CPFM model was used to compare the fuel-consumption rates of hybrid buses to those of conventional buses. Hybrid bus 6011 and the 1900 series have 80-passenger capacity and were compared. Hybrid bus 6021 and the 6320 series both have 107-passenger capacity and were compared. The fuel-consumption rates were compared for passenger loads ranging from 0 to 100 percent in 20-percent increments. In addition, the CO₂ emission rates for the buses were calculated using equation 4-8. CO₂ is positively and linearly related to fuel consumption.

$$CO_2 + FCR \times \Theta \quad (4-8)$$

Where:

CO₂ is the emission rate in the unit of g/s;

FCR represents the fuel consumption rate (l/s); and

Θ is the conversion factor between fuel consumption and CO₂ emission rate.

For this research, a value of $\Theta = 2330$, which was based on data collected in a prior study [22], because the HEM data loggers did not collect data on actual bus CO₂ emissions.

Fuel consumption, CO₂ emissions rate, and passenger load

Figure 4-11 illustrates the results of the fuel-consumption and CO₂ emission comparison. The buses with higher capacity, 6021 and the 6320 series, consumed more fuel and emitted more CO₂ than the buses with lower capacity, 6011 and the 1900 series, because they are heavier. The hybrid buses consumed less fuel and emitted less CO₂ than conventional buses with the same capacity, regardless of passenger load. Greater passenger loads correspond with higher fuel consumption levels, but not to a large extent, indicating passenger load does not heavily influence fuel consumption and CO₂ emissions.

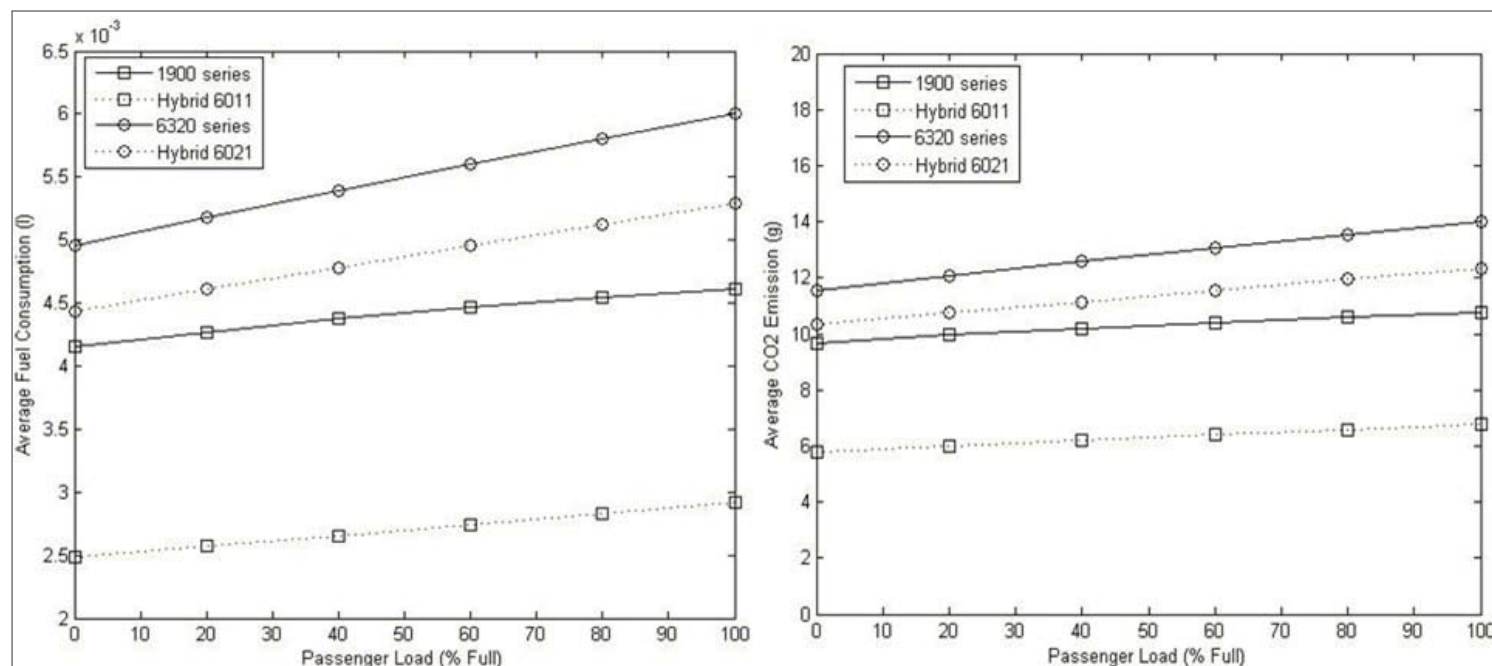


FIGURE 4-11 IMPACT OF PASSENGER LOAD ON FUEL CONSUMPTION (LEFT) AND CO₂ EMISSION (RIGHT) ON HYBRID AND CONVENTIONAL BUSES

Comparative fuel consumption and CO₂ emission

The fuel consumed and CO₂ emitted by the hybrid buses was calculated as the percent consumed/emitted less than that consumed by conventional buses. The calculation was performed for six passenger loads and four road loops – separate loops the buses traveled as collected by the HEM data logger.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

The results are illustrated in Figure 4-12 for the 80-passenger buses, and Figure 4-13 for the 107-passenger buses. For the 80-passenger buses, the hybrid consumed between 35 and 40 percent less fuel than the conventional bus. For the 107-passenger buses, the hybrid consumed between 8 and 12 percent less fuel than the conventional bus. The bus' comparative CO₂ emissions followed the same trend.

The buses relative fuel consumption was different for different road loops, but that difference was conflated with traffic conditions, bus operator behavior, and other factors. Determining the effect of road loop on comparative bus fuel consumption was beyond the scope of this research.

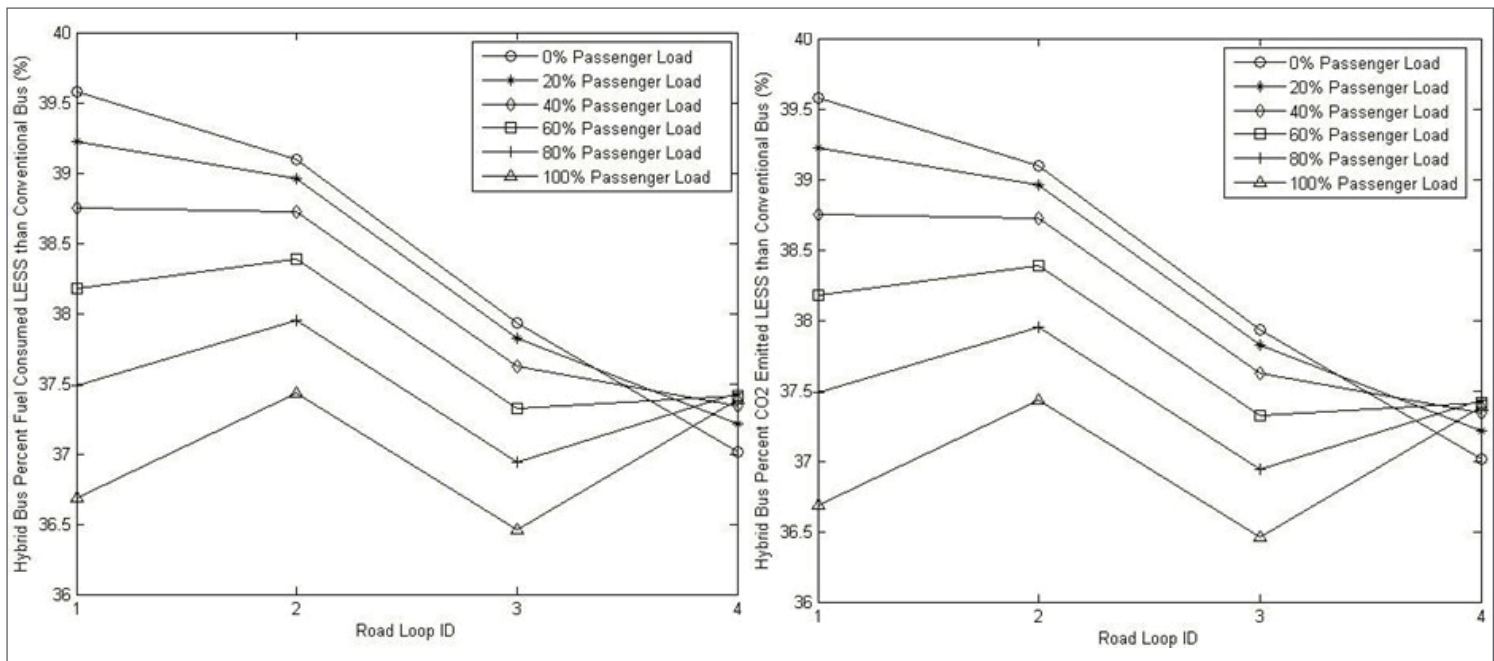


FIGURE 4-12 RELATIVE FUEL CONSUMPTION (LEFT) AND CO₂ EMISSION (RIGHT) OF 80-PASSENGER HYBRID AND CONVENTIONAL BUSES (6011 AND 1900 SERIES)

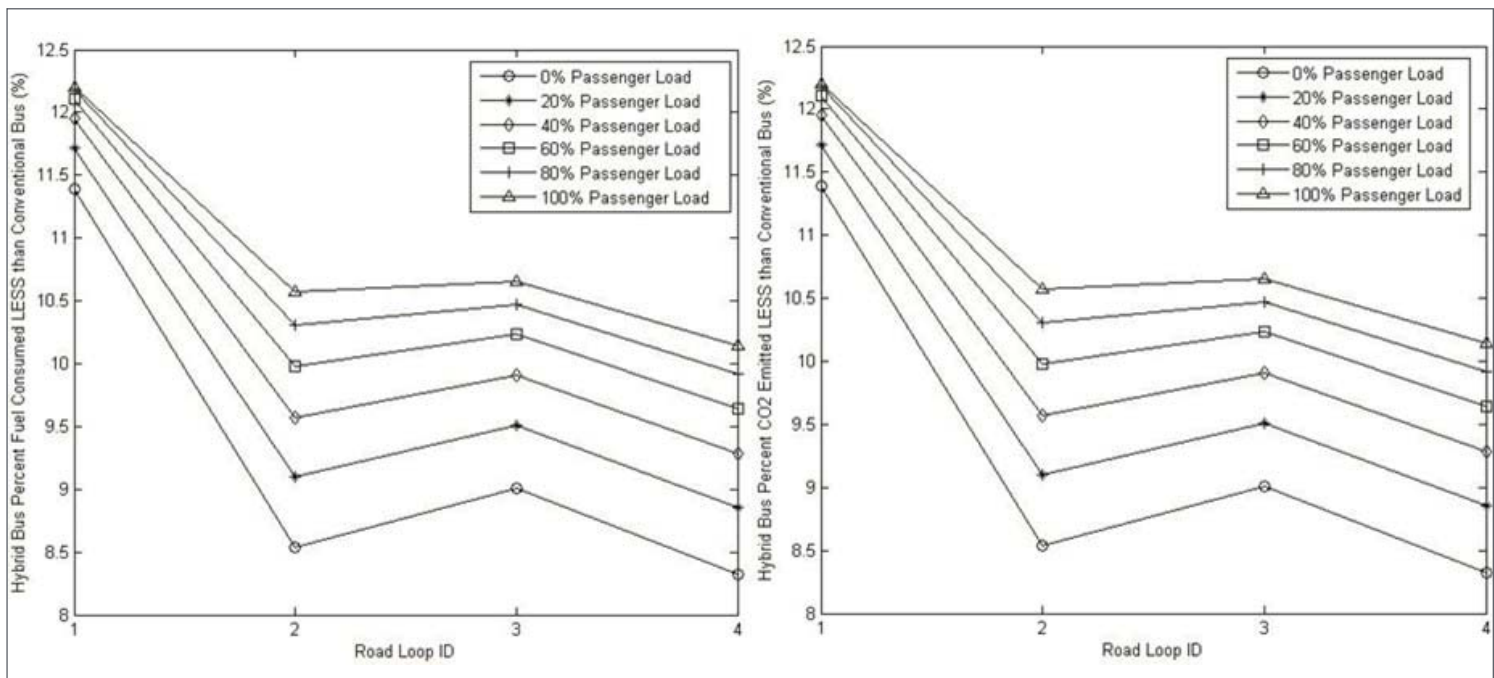


FIGURE 4-13 RELATIVE FUEL CONSUMPTION (LEFT) AND CO₂ EMISSION (RIGHT) OF 107-PASSENGER HYBRID AND CONVENTIONAL BUSES (6021 AND 6320 SERIES)



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Comparative fuel consumption and bus maneuvers

The bus trajectory data were partitioned into two maneuvers, cruising and stopped. The percent less fuel consumed and CO₂ emitted by the hybrid buses than the conventional buses was calculated for each maneuver.

Figure 4-14 and Figure 4-15 show the results. For the 80-passenger buses, the hybrid consumed 40 percent less fuel than the conventional when cruising, and 27 percent less when stopped. For the 107-person buses, the hybrid consumed about 11 percent less fuel than the conventional when cruising, and about 4 percent more fuel than the conventional when stopped. The trend for CO₂ emissions was identical. Passenger load had little impact on the relative fuel consumed by the two bus types.

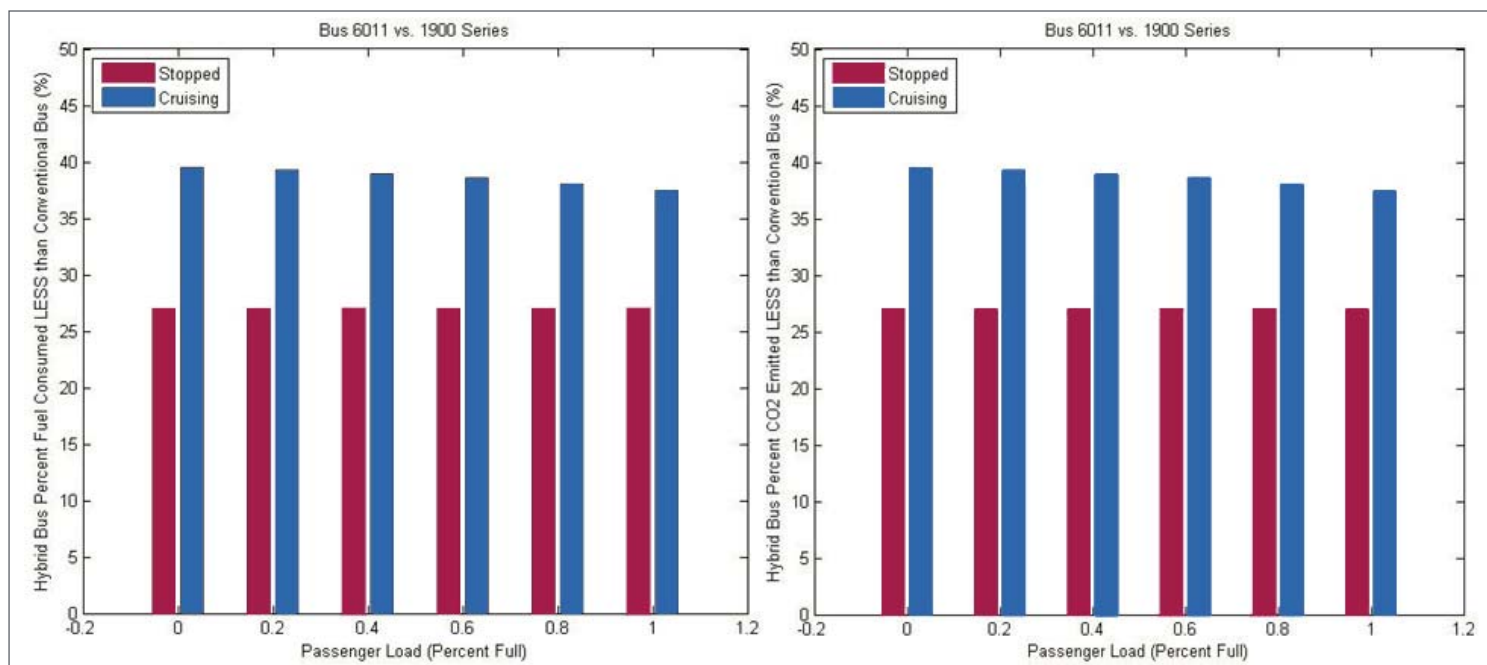


FIGURE 4-14 RELATIVE FUEL CONSUMPTION (LEFT) AND CO₂ EMISSION (RIGHT) OF 80-PASSENGER HYBRID AND CONVENTIONAL BUSES WHEN CRUISING AND WHEN STOPPED (6011 AND 1900 SERIES)

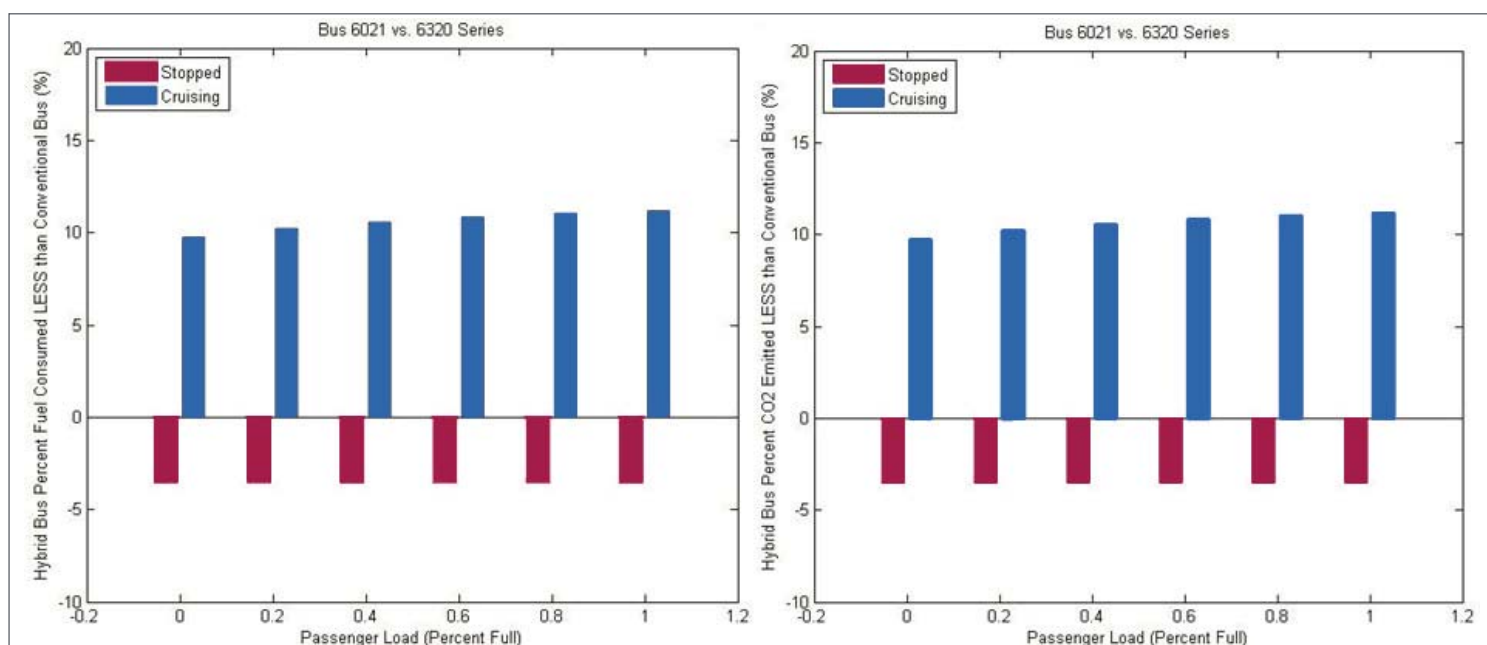


FIGURE 4-15 RELATIVE FUEL CONSUMPTION (LEFT) AND CO₂ EMISSION (RIGHT) OF 107-PASSENGER HYBRID AND CONVENTIONAL BUSES WHEN CRUISING AND WHEN STOPPED (6021 AND 6320 SERIES)



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Comparison between two small hybrid buses and one large hybrid bus

Fuel consumption and CO₂ emissions were compared between two 80-passenger hybrid buses and one 107-passenger hybrid bus. Fuel consumed and CO₂ emitted were calculated per passenger, and the buses' performance were compared as percent less fuel consumed or CO₂ emitted by the single 107-passenger hybrid bus than to that by the two 80-passenger hybrid buses. Such a calculation requires knowing a bus' passenger load, and it was repeated for four different numbers of passengers (81, 90, 100 and 107). It is possible that the same number of passengers on a 107-passenger bus are unevenly distributed between the two 80-passenger buses, so three different passenger load distributions for the two 80-passenger buses were included in the calculation: 70 and 30 percent, 60 and 40 percent, and 50 and 50 percent.

The results are shown in Figure 4-16 and demonstrate that one 107-passenger hybrid bus used between 10 and 23 percent less fuel and produced the same amount less CO₂ than two 80-passenger hybrid buses. That held true for all numbers of passengers, and the difference in fuel consumption and CO₂ emissions was greatest when ridership was poorly distributed between the two 80-passenger buses.

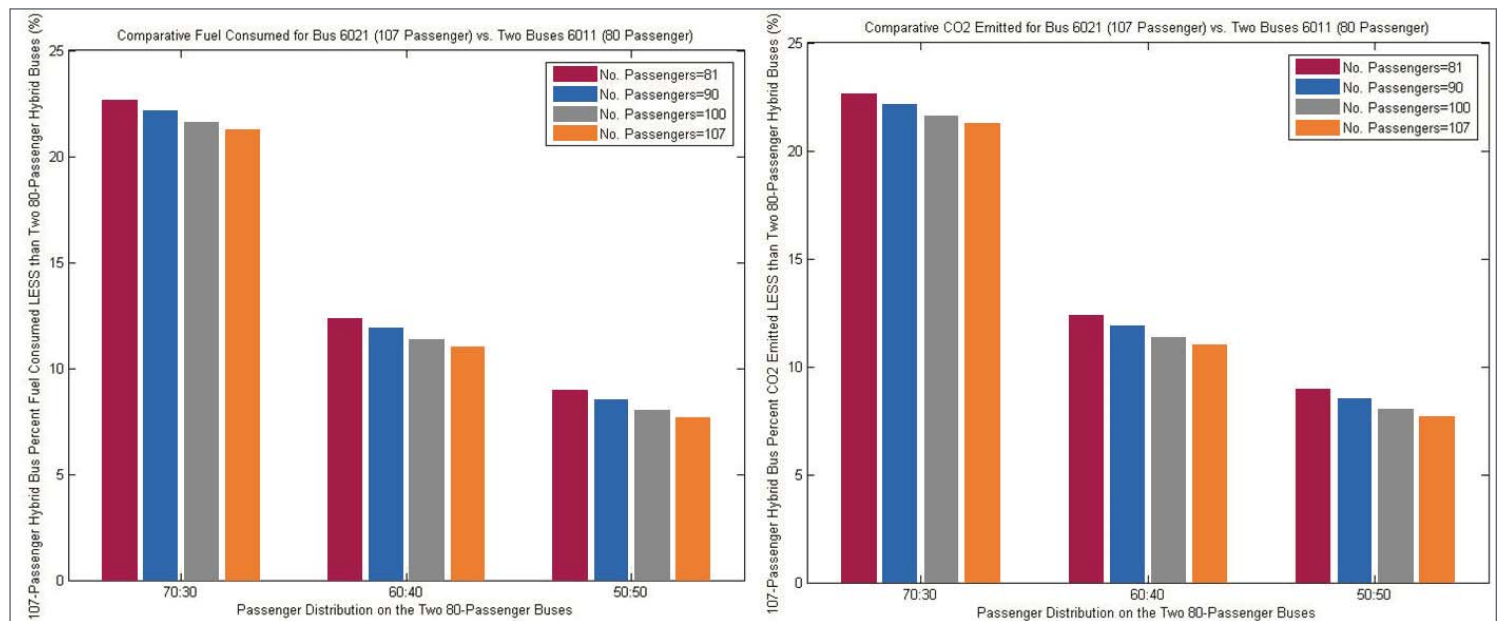


FIGURE 4-16 RELATIVE FUEL CONSUMPTION (LEFT) AND CO₂ EMISSION (RIGHT) OF ONE 107-PASSENGER HYBRID BUS AND TWO 80-PASSENGER HYBRID BUSES

CONCLUSIONS AND CONSIDERATIONS FOR OTHER TRANSIT AGENCIES

The research team extended VT-CPFM to model fuel consumption in diesel and hybrid buses. The VT-CPFM circumvents the limitation of bang-bang control inherent to the CMEM and PERE models. Regression analysis was used to calibrate the model using data from the HEM data logger, and results show that bus fuel consumption is supralinear with respect to vehicle power, different from LDVs, and a new discovery possibly warranting further investigation. Validation results demonstrate that the calibrated models have a good fit to field measurements, with an average R squared value of about 0.77. The optimum fuel economy cruising speed is in the range of 40-50 km/h (25-31 mph), lower than that of LDVs. Hybrid buses consume less fuel and produce lower emissions than conventional buses, and using a single, large hybrid bus consumes less fuel and produces lower emissions than using two smaller hybrid buses.

Route had a large effect on the relative fuel consumption of hybrid and conventional buses. More research is needed to determine what those effects are. Additionally, driver behavior affects fuel consumption, but that effect is not quantified. More research is needed to increase the accuracy of fuel-consumption models for transit buses.

The VT-CPFM can be used to accurately model transit bus fuel consumption. The model can be integrated with a micro-simulation software (e.g. INTEGRATION) to better simulate bus fuel consumption. The fuel-consumption model developed here estimates fuel-consumption rate and can be extended to CO₂ emissions. It can also be extended to estimate carbon monoxide, hydrocarbons, and nitrogen oxides emissions.

The model would be easier to implement if it input publicly available data, not data from a HEM data logger. One main recommendation is for transit bus manufacturers to make available that data.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

5. THE DYNAMIC DISPATCHING DECISION SUPPORT SYSTEM (3DSS)

OVERVIEW

This project goal was to reduce GHG emissions from transit buses by developing a dispatching system optimizing bus schedules and size selection to run buses as close to capacity as possible, reducing fuel consumption per passenger mile, while also meeting passenger expectations. The prior two report sections covered the dispatching system's main inputs – passenger demand for buses, and fuel consumed by buses (Figure 5-1). This report section discusses the dynamic dispatching algorithm's development, including inputs and outputs considered, accepted and rejected, the algorithm's framework, and its testing validation. This section concludes with recommendations regarding further testing and implementing dynamic dispatching in transit.

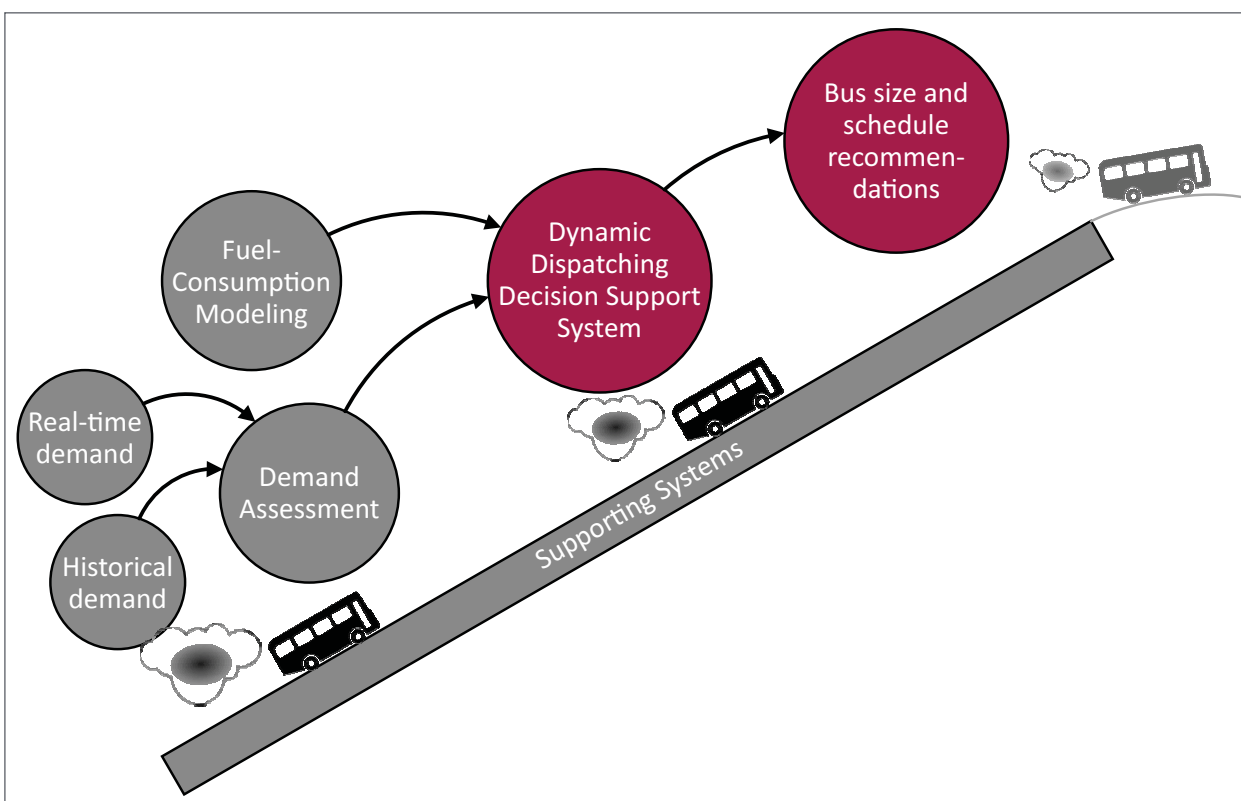


FIGURE 5-1 DOCUMENT MAP — 3DSS ALGORITHM

3DSS OUTPUTS CONSIDERED

Before the project team selected bus size and scheduling as outputs for the 3DSS algorithm, they considered a number of possible changes to bus operation that could reduce GHG emissions. Some of those changes would have been too disruptive to passenger expectations and were rejected, but might prove feasible in future implementations or for other transit agencies. This section describes possible outputs of 3DSS, and why the team chose whether or not to incorporate them into the final 3DSS product.

Dynamic routing

Dynamic routing is the re-routing of buses to meet passenger demand. It was one major category of changes the team discussed, but it was not seriously considered, because dynamic routing would have significantly disrupted the passenger experience. Below are a few examples of dynamic routing, and why they were not further investigated:

Bus stop locations

The number of stops on a route is the second-most influential factor, after differences in driving style, affecting a bus' fuel consumption. Fewer bus stops means buses are stationary for less time, consuming less fuel. Fewer stops, however, would also mean passengers, on average, would have to walk farther.



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Moving or eliminating bus stops in real time would be too disruptive to passengers, and it was not incorporated as a 3DSS output. However, the technologies used to collect ridership data, information on passenger preferences, and bus and operator behavior would inform Blacksburg Transit's decisions on whether to move or eliminate bus stops, potentially on a yearly basis. The team considered creating a separate but similar algorithm to evaluate bus stop locations, passenger service, and fuel consumption on a long-term basis, but could not do so within the constraints of this project.

Route optimization

Although dynamic routing was not possible, optimizing bus routes on a yearly or bi-yearly basis could reduce fuel consumption without greatly disrupting service. A separate algorithm from the 3DSS would analyze bus routes, topography, stop locations, and other factors to select the most fuel-efficient routes. However, doing so was not possible within the constraints of this project.

Adjusting bus stop arrival times

3DSS could collect passenger demand data from those who have requested trips, and those who are forecasted to arrive, and output optimized arrival times. The bus operators would then speed up, slow down, or stop to their buses to adjust bus arrival times. Although the team seriously considered implementing dynamic changes to bus stop arrival times, this feature was not incorporated as a 3DSS output because:

- There were serious logistical problems with determining where buses would stop and wait.
- Communicating the arrival times to bus drivers was problematic.
- Communicating the arrival times to passengers was problematic.
- Drivers would need extensive additional training to implement the idea.
- The team was concerned that changes to bus stop arrival times could not be accomplished effectively.

Bus frequency changes

Increasing the frequency (density) of buses in high-demand times would increase passenger satisfaction, and decreasing the number of buses at low-demand times would save fuel.

Transit systems already add buses in high-demand times using "tripper" buses, or spare buses staged along or near operating routes. Tripper buses wait for high demand periods, when they are dispatched to pick up riders left behind by other buses or to prevent other buses filling to capacity. Transit systems do not, however, perform the opposite – removing scheduled buses from routes. Doing so is possible, if the route is serviced by more buses than is necessary, but removing a bus would affect customer wait time. If there is only bus on the route, it cannot be removed, because doing so would cease service.

Because adding buses to routes in high-demand times is already a feature of many transit systems, and removing buses within certain constraints can be done without major disruptions to service, both were incorporated as 3DSS outputs.

Bus size selection

Matching the bus size to passenger demand would reduce fuel consumption during low-demand times, because large buses that consume more fuel would not run when few passengers needed them.

The main issue with changing bus size is how to transition from one bus to another. One option would be to have the two buses meet at a stop, and require passengers to change buses. That option was not chosen because it is logistically difficult, and because it would likely annoy passengers, reducing the LOS. The other option would be to place the replacement bus on the route in addition to the obsolete bus. The obsolete bus would stop picking up passengers and continue along the route until empty. It was decided that if a new smaller/larger bus was substituted for the current bus then That option requires two buses to run on the route for as much as an entire trip.

Implementing the second option would allow the transit system to change bus size in response to passenger demand without disrupting service, so bus size was incorporated as a 3DSS output. The fuel consumed to perform the changeover was included in the 3DSS calculation.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

3DSS ALGORITHM DEVELOPMENT

Input variables

The team had a wealth of data that could be input to the 3DSS algorithm. Those data were narrowed down into the inputs described here. The algorithms developed in 3DSS can only address a single route, so 3DSS outputs do not consider interactions between different bus routes.

The input variables for a route can be categorized into two broad groups – static and dynamic. The static variables are generally constant and include stops, travel time from tripper location, fuel consumption from tripper location, drive profile, and data from the GIS (links) database regarding the route and stops. The dynamic variables change at rates ranging from once a day to once every several seconds and include variables from the bus database, bus passenger data, and demand assessment data. The 3DSS input variables are listed in Appendix D: Dynamic demand dispatching support system (3DSS), and fall into groups depending on their source. The sources of input variables for 3DSS and a selection of variables are described here.

Bus database

The bus database includes the physical information for all the buses, such as unique bus number, bus passenger capacity and curb weight, and the fuel-consumption parameters for each specific bus, used by the VT-CPFM to calculate a bus' instantaneous fuel consumption level. It also contains route and schedule data. The route variable states the bus' route, and the bus' location on the route is dynamically updated using GPS. The schedule variable has the start stop and time for the bus.

Demand assessment

The demand assessment variables are those describing passenger demand and ridership. They are calculated by the demand-assessment algorithm using historical data collected by automatic passenger counters over the years, and using real-time data collected from the demand-assessment technologies and rider counts. Some variables are: passenger arrival, the number of passengers arriving at a stop; passengers alighting, the number of passengers alighting a bus at a stop; bus departure, the index of the bus departing from a bus stop; passengers at stop, the total passenger number at a stop; passengers left, the number of passengers cannot get on the bus at a stop; and average wait, the average wait time for each passenger in minutes.

Bus passenger data

Bus passenger data are calculated given schedule and demand-assessment data. The bus schedule is used to determine a bus' departure time for each stop. Demand assessment technologies are used to calculate the number of riders on the bus. The hold time variable is the bus' hold time at a stop, and is determined by the driver. If there are no passengers, the hold time is assumed to be zero for all stops, the initial condition for 3DSS.

Links

Links are sections of roadway along the bus routes and are extracted from the GIS map. Each link has starting coordinates, a unique identifier, a sequence number indicating its sequence along a route, the link's length, grade, speed limit, elevation and more. The expected travel time on a link is calculated using link's speed limit and length. Bus stop data and link data can be used to determine which is the next link, or stop, on a route. Other variables in the links database important for calculating drive profiles and fuel consumption are whether a link ends at a bus stop, stop sign, or traffic signal.

Stops

The variables in stops include all the static information for a specific stop – the unique stop index, the next stop's index, and the latitude and longitude of the stop. The estimated travel time between stops is calculated using the speed limit on the links between them. The variable of switchable stop indicates whether bus can be switched at this stop. The next link represents the link number of the next link from the current bus stop.

Travel time from tripper location

The travel time from the tripper location to any bus stop is calculated by using the corresponding speed limit information on the links.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Fuel consumption from tripper location

The fuel consumption for any specific bus type is calculated from the tripper location to any bus stop.

Drive profile

The drive profile contains the high-resolution data used to calculate the fuel consumption of any bus type on a specific route. A bus' speed, acceleration, distance traveled, resistance, and power are calculated using the variables in bus database, links and stops for time intervals of 0.1 min.

3DSS framework

The 3DSS algorithm uses the static and dynamic input variables to generate output recommendations regarding changing bus size and schedule. The 3DSS algorithm's framework is demonstrated in Figure 5-2. First, for every time interval, the system checks if there is a pending recommendation for an operator to approve. At the same time, the dynamic variables are updated using the GPS information from the buses. If there is a pending recommendation, then no further 3DSS recommendations are provided, because the previous action had not been completed. If there is no pending recommendation, the LOS on the route is evaluated. The LOS is calculated using the total wait time divided by the total passenger number, with lower average wait times corresponding to higher LOS. If the current LOS is less than the minimum LOS, the bus schedule does not meet passenger demand, and the 3DSS will suggest either adding an additional bus or replacing a small bus with large tripper. To determine which option is better, the 3DSS calculates if replacing the bus with a larger one increases the LOS above minimum LOS. If so, the 3DSS algorithm will recommend bus replacement. If not, the 3DSS algorithm will recommend adding an additional bus. Conversely, if the LOS is larger than the maximum LOS, the 3DSS algorithm will recommend either replacing the bus with a smaller one or removing a bus from the route. In this way, the 3DSS algorithm considers both fuel consumption and passenger needs.

Whenever a recommendation is suggested by 3DSS, a dispatch operator would decide whether or not to accept it.



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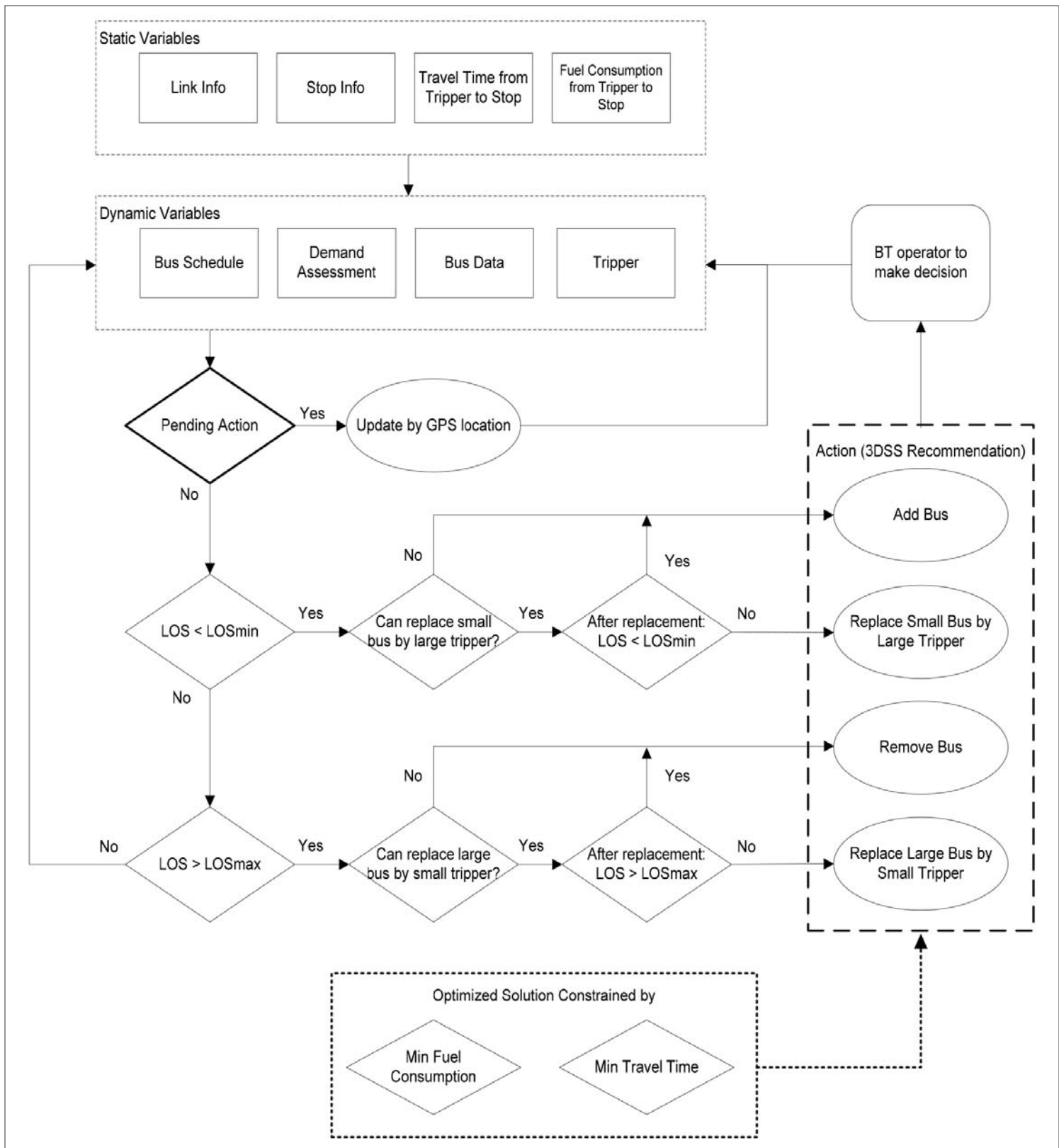


FIGURE 5-2 THE 3DSS FRAMEWORK



Transit Bus Routing On-Demand: Developing an Energy-Saving System

3DSS outputs

The 3DSS algorithm has four recommendations: adding a bus, replacing the current bus with a larger one, removing a bus, and replacing the current bus with a smaller one. 3DSS also outputs the corresponding dynamic variables for each recommended scenario.

Scenario 1: Add bus

If the LOS is very low, 3DSS will recommend adding a bus to the route. The added bus' starting time will be calculated based the current buses' headways, with the goal of minimizing changes to the current schedule. For instance, if there are three buses on the route, the additional bus will start halfway between two of them. The bus passenger data variable will be updated to reflect the change.

Scenario 2: Replace a smaller bus with larger tripper

If replacing the current bus with a larger bus will increase the LOS above the minimum, 3DSS will recommend that over adding a bus. When the smaller bus arrives at a chosen stop, it can be replaced with the larger bus. The two buses will continue along the route, but the smaller bus will not pick up any more passengers. When it is empty, it will exit the route. The smaller bus' ID will be replaced in the bus passenger data with that of the larger bus.

Scenario 3: Remove bus

If the LOS is very high, 3DSS will suggest removing a bus from the route. The bus leaving time can be estimated using bus' GPS locations, and when an empty target bus arrives at the next time check, it can exit the route. It may or may not refuse passengers to become empty. The bus passenger data and bus database can be easily updated for this scenario.

Scenario 4: Replace a larger bus with smaller tripper

If replacing a large bus with a smaller one will decrease the LOS below the maximum, 3DSS will recommend that over removing a bus. When the large bus arrives at a chosen stop, a small tripper can be added to the route. The larger bus will continue, not accepting passengers, until it is empty. The bus ID will be replaced in the bus passenger data with that of the smaller bus.

3DSS TESTING

To validate the performance of the 3DSS algorithm, it was run in a simulated environment based on historical data. Data from the Hethwood A route from in October 2014 was used, and included bus schedules, weather data, and ridership data. That data were input to the 3DSS algorithm as if it were running in real time. The algorithm then calculated fuel consumption, LOS, and GHG emissions to arrive at recommendations to add, remove, or replace buses. It also out the amount of fuel consumed, CO₂ emitted, and LOS in seconds of wait time.

Sunny days

Sunny days were used as the benchmark for testing the 3DSS algorithm, and to represent typical Blacksburg Transit operations. On a sunny day, ridership is likely lower than that on days with precipitation, because more passengers might choose to walk or bike instead of taking the bus. On those days, it was expected that the 3DSS algorithm would produce recommendations for reducing service by removing a bus or reducing bus size, resulting in less GHG emissions when compared to a standard schedule. Three sunny days in October, 2014 were chosen to run the simulation: Friday, October 17th, Monday, October 20th, and Friday, October 24th.

Rainy days

Rainy days were included in the simulation, because on rainy days, passengers who would normally walk or bike would likely choose to ride the bus, increasing ridership, and causing the 3DSS algorithm to recommend adding buses or increasing bus size, increasing GHG emissions. Four rainy days in October, 2014 were chosen to run the simulation: Friday, October 3rd, Monday, October 6th, Tuesday, October 7th (heaviest precipitation) and Friday, October 31st.

All days

In addition to a comparison between sunny and rainy days, bus fuel consumption and CO₂ emissions were calculated for every day in October 2014 to compare those values when 3DSS was run and when it was not.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Assumptions and parameters

The simulation assumed that the bus trajectories matched the bus schedule table, which differs from reality in that bus trajectories are effected by traffic conditions, weather, and other factors. The simulation also assumed that the 3DSS recommendations were all accepted by the bus dispatcher. Because, in reality, dispatchers would probably not accept all recommendations, the simulation was limited to suggest a bus schedule or size change once every four hours (which was automatically accepted), for a maximum of three changes between Blacksburg Transit's service hours of 7:00 a.m. to 6:00 p.m. These simplification were necessary, because it was not possible to implement the 3DSS algorithm in real time within the timeframe of this project to test how often a dispatched would accept them.

Key parameters for 3DSS were defined for the testing, but would also have to be defined if 3DSS were run in real time. For the testing, the minimum and maximum thresholds for LOS, or passenger wait time in seconds, were set at 350 and 600 seconds, respectively. GHG emission was calculated by a common conversion factor of 8,887 grams of CO₂ emissions per gallon of fuel consumed (Federal Register 2010).

Test Results

Sunny Days

The 3DSS recommendations for sunny days are shown in Table 5-1. In general, the LOS for those days was less than the minimum threshold; therefore 3DSS suggested either replacing a large bus with a small bus, or removing a bus entirely from the route.

The results effects of the 3DSS recommendations on fuel consumption and CO₂ emissions are listed in Table 5-2. For the three simulated days, the fuel consumption when the 3DSS recommendations were implemented was 96, 55 and 121 L less than if 3DSS was not implemented, and the corresponding CO₂ emissions were also greatly reduced. Although the average wait time for sunny days increased with implementing 3DSS recommendations, it was still below the pre-defined maximum wait time.

TABLE 5-1 3DSS RECOMMENDATIONS ON SUNNY DAYS

DATE (2014)	3DSS RECOMMENDATION 1	3DSS RECOMMENDATION 2
October 17	remove 40 ft bus (6016) at 10:40 a.m.	none
October 20	replace 60 ft bus (6022) with 40 ft tripper at 11:00 a.m.	remove 40 ft bus (1919) at 3:30 p.m.
October 24	replace 60 foot bus (1919) with 40 ft tripper at 10:30 a.m.	none

TABLE 5-2 MEASURED RESULTS ON SUNNY DAYS

DATE (2014)	MEASUREMENTS	WITHOUT 3DSS	WITH 3DSS	DIFFERENCE
October 17	Fuel Consumption (L)	438	342	-96
October 17	LOS (wait time) (s)	338	513	175
October 17	CO ₂ Emissions (g)	3892506	3039354	-853152
October 20	Fuel Consumption (L)	467	412	-55
October 20	LOS (wait time) (s)	321	497	176
October 20	CO ₂ Emissions (g)	4150229	3661444	-488785
October 24	Fuel Consumption (L)	483	362	-121
October 24	LOS (wait time) (s)	318	526	208
October 24	CO ₂ Emissions (g)	4292421	3217094	-1075327



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Rainy days

The 3DSS recommendations for rainy days are shown in Table 5 3. The recommendations were mixed and included those to increase service by adding a bus or replace a smaller bus with a larger bus, and those to decrease service by removing a bus or replace a larger bus with smaller one.

The results effects of the 3DSS recommendations on fuel consumption and CO₂ emissions are listed in Table 5 4. It was assumed that there would be more passengers on rainy days, causing the wait times to be longer than those on sunny days. The 3DSS recommendations for the mornings of October 6th and 7th were consistent with that assumption – to add a bus and to replace a smaller bus with a larger one. However, the 3DSS recommendations on October 3rd and 31st were to do nothing or to remove a bus. An error in demand assessment causing an underestimation of passengers may have caused the 3DSS to suggest removing buses.

The combined results indicate that weather might affect the accuracy of demand assessment and subsequent 3DSS recommendations. Thus, in the future efforts, weather can be incorporated in the demand-assessment algorithm to enhance the accuracy of demand assessment.

TABLE 5-3 3DSS RECOMMENDATIONS ON RAINY DAYS

DATE (2014)	3DSS RECOMMENDATION 1	3DSS RECOMMENDATION 2
October 3	None	none
October 6	add 40 ft tripper at 9:05 a.m.	remove 40 ft bus at 2:05 p.m.
October 7	replace 40 ft bus (1914) by 60 foot tripper at 7:40 a.m.	None
October 31	remove 40 ft bus (6015) at 11:40 a.m.	none

TABLE 5-4 MEASURED RESULTS ON RAINY DAYS

DATE (2014)	MEASUREMENTS	WITHOUT 3DSS	WITH 3DSS	DIFFERENCE
October 3	Fuel Consumption (L)	441	441	0
October 3	LOS (wait time) (s)	611	611	0
October 3	CO ₂ Emissions (g)	3919167	3919167	0
October 6	Fuel Consumption (L)	472	552	80
October 6	LOS (wait time) (s)	652	563	-89
October 6	CO ₂ Emissions (g)	4194664	4905624	710960
October 7	Fuel Consumption (L)	475	496	21
October 7	LOS (wait time) (s)	624	589	-35
October 7	CO ₂ Emissions (g)	4221325	4407952	186627
October 31	Fuel Consumption (L)	466	402	-64
October 31	LOS (wait time) (s)	336	578	242
October 31	CO ₂ Emissions (g)	4141342	3572574	-568768



Transit Bus Routing On-Demand: Developing an Energy-Saving System

All days

The results for fuel consumption and CO₂ emissions for every weekday during October 2014 for the Hethwood A, with and without 3DSS, are shown in Figure 5-3 and Figure 5-4. For the entire month of October, implementing 3DSS resulted in 1103 L less fuel consumed, and 9,802,361 g less CO₂ emitted, a reduction of about 10.6 percent. The test results demonstrate that 3DSS can effectively reduce fuel consumption and GHG emissions.

Figure 5-5 shows the LOS with and without 3DSS for all days in October 2014. When using 3DSS, wait times were longer, but still remained below the 600 s threshold.

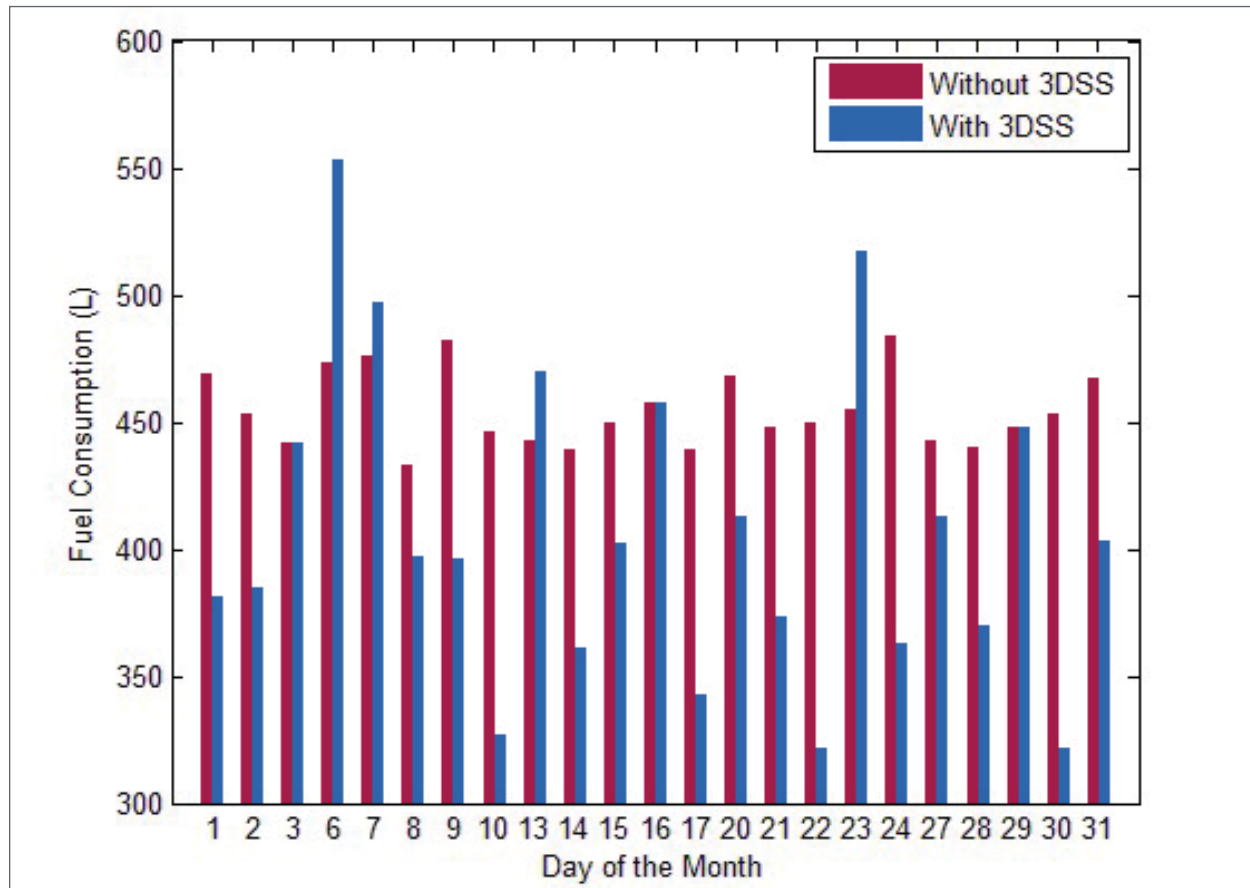


FIGURE 5-3 COMPARISON OF FUEL CONSUMPTIONS WITH AND WITHOUT 3DSS FOR OCTOBER 2014



Transit Bus Routing On-Demand: Developing an Energy-Saving System

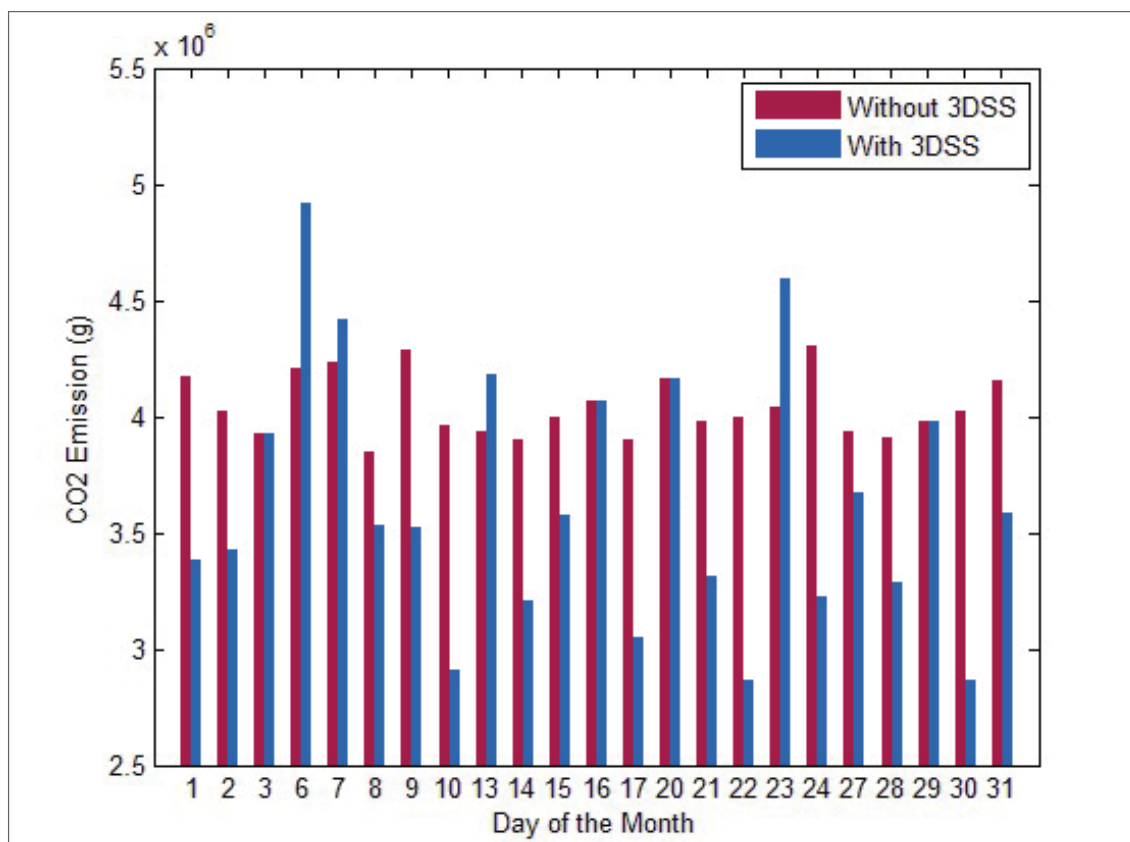


FIGURE 5-4 COMPARISON OF GREENHOUSE EMISSION OF CO₂ WITH AND WITHOUT 3DSS FOR OCTOBER 2014

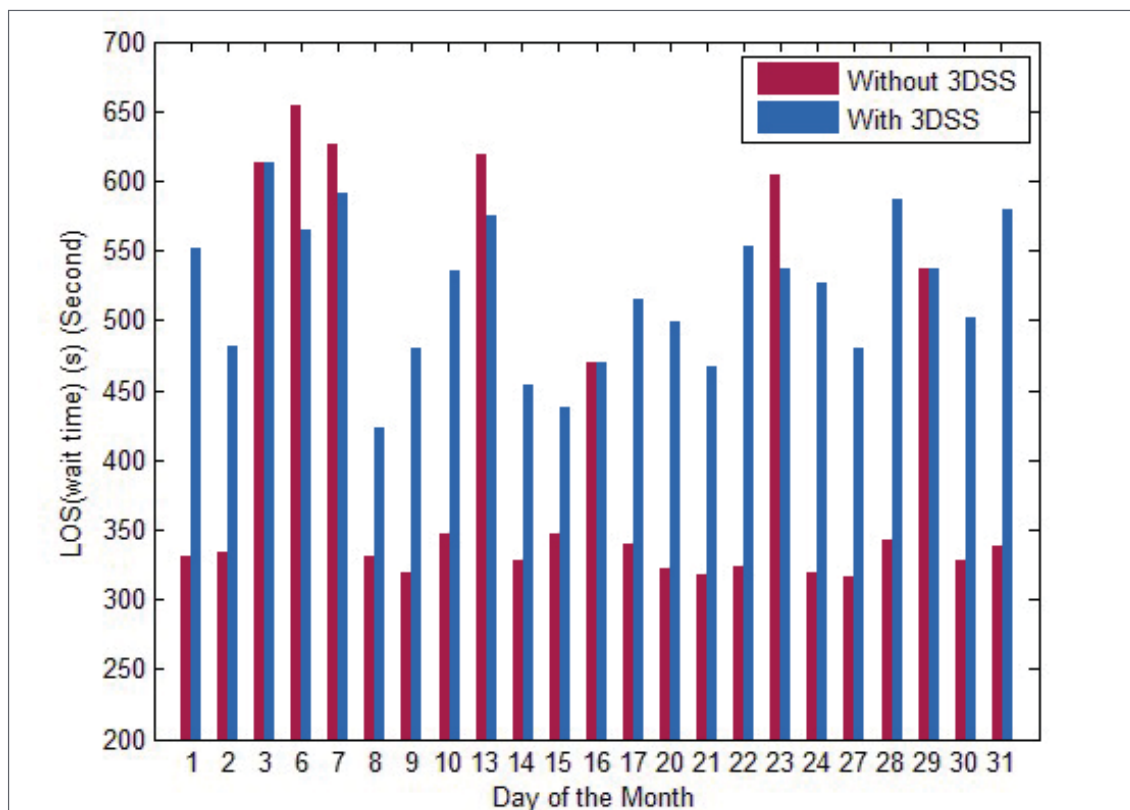


FIGURE 5-5 COMPARISON OF LOS (WAIT TIME) WITH AND WITHOUT 3DSS FOR OCTOBER 2014



Transit Bus Routing On-Demand: Developing an Energy-Saving System

FUTURE TESTING

Field operational testing

Field operational testing would be a real-time implementation of 3DSS on one or two bus routes. There are a number of reasons field operational testing was not possible within the context of this project. Blacksburg Transit typically uses the summer months, when ridership is low and there is more flexibility, to perform new-system testing or make any major changes. However, this project ended during the spring semester. Additionally, the AVL CAD system and 3DSS must be better linked before field testing can take place. Blacksburg Transit is in the process of hiring a new director, and has only had a full-time dispatcher for six months, which could also slow down field operational testing. Finally, human processes, such as driver and dispatcher training on 3DSS, need to be put in place before field operational testing is performed.

The team has identified the obstacles to overcome to perform field operational testing, and is doing everything possible to overcome them. If the project receives additional funding, the field operational tests can be run in the summer of 2015.

Operational testing

Operational testing would see full implementation of 3DSS on all routes in the Blacksburg Transit system, and would require a paradigm shift in the way the transit system operates. Transit systems use fixed schedules, so operating based on demand, not a schedule, is an alien concept. Without a comprehensive marketing and communication effort, implementing 3DSS could seriously disrupt passenger expectations.

After field operational testing takes place, research could be performed on changing attitudes and expectations regarding transit in the run up to full operational testing.

CONCLUSIONS AND CONSIDERATIONS FOR OTHER TRANSIT AGENCIES

A dynamic dispatching system could theoretically incorporate more inputs and produce more outputs than the system developed and tested for this project. For example, the team believes that driver behavior greatly affects fuel consumption, but the effect of driver behavior has yet to be quantified. Possible outputs include route changes and changes to stop locations, which have the potential to greatly reduce fuel consumption and emissions, but which would require a changes to rider attitudes and transit operations not possible within the constraints of this project.

The 3DSS testing in a simulated environment changed bus schedules and bus sizes in response to demand, and testing found that, when 3DSS was run, buses consumed 10.6 percent less fuel and produced 10.6 percent less CO₂ than when buses were scheduled normally. The LOS was still reasonable, as passengers would wait no longer than 10 min. According to the Bureau of Transportation Statistics, the total fuel consumed by transit buses in 2013 was 2117 million gallons. If 3DSS, as tested for this project, was implemented nationwide in 2013, it is possible that 224.4 million gallons of fuel would not have been consumed, and 1994.3 million kilograms of CO₂ would not have been emitted into the atmosphere.

Different transit agencies have different clienteles with different needs. Other transit agencies should consider changing the 3DSS parameters, such as LOS, to balance customer satisfaction with their fuel-savings targets.

3DSS testing was performed using historical data from a single test rout. To better understand the possible extent of fuel savings, field operational testing on more routes, and operational testing throughout the Blacksburg Transit system, should be performed. Should the project be extended, that testing can take place in the summer of 2015.



6. SUPPORTING SYSTEMS FOR DEMAND ASSESSMENT, FUEL CONSUMPTION MODELING, AND THE 3DSS

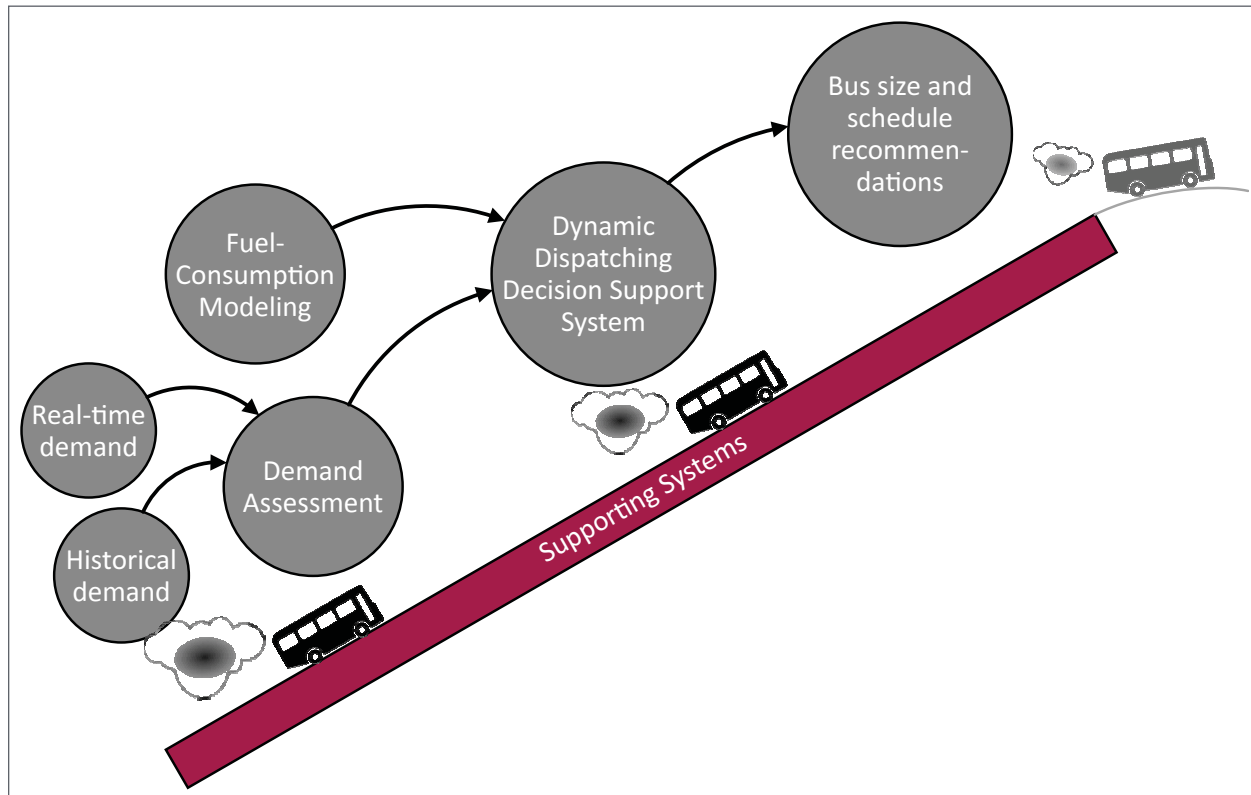


FIGURE 6-1 DOCUMENT MAP — SUPPORTING SYSTEMS

The fuel consumption model and demand-assessment algorithm leverage historical data, demand data, and fuel-consumption data. To ensure that both systems work, and can feed data to the 3DSS algorithm, a database system is necessary. The main database is housed at Blacksburg Transit and called the TIGGER database. Two other databases were leveraged by this project. The Streets database houses data from the Trapeze passenger counting system (described below) on Blacksburg Transit buses, and the BT4U backend server houses the data driving the BT4U website and mobile application. The TIGGER database imports passenger-count and bus-location information from the Streets database, and demand data gathered with the BT4U website and mobile application from the BT4U backend server. Using a single database was not possible, because each data type had different requirements that were too difficult to reconcile in a single database.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

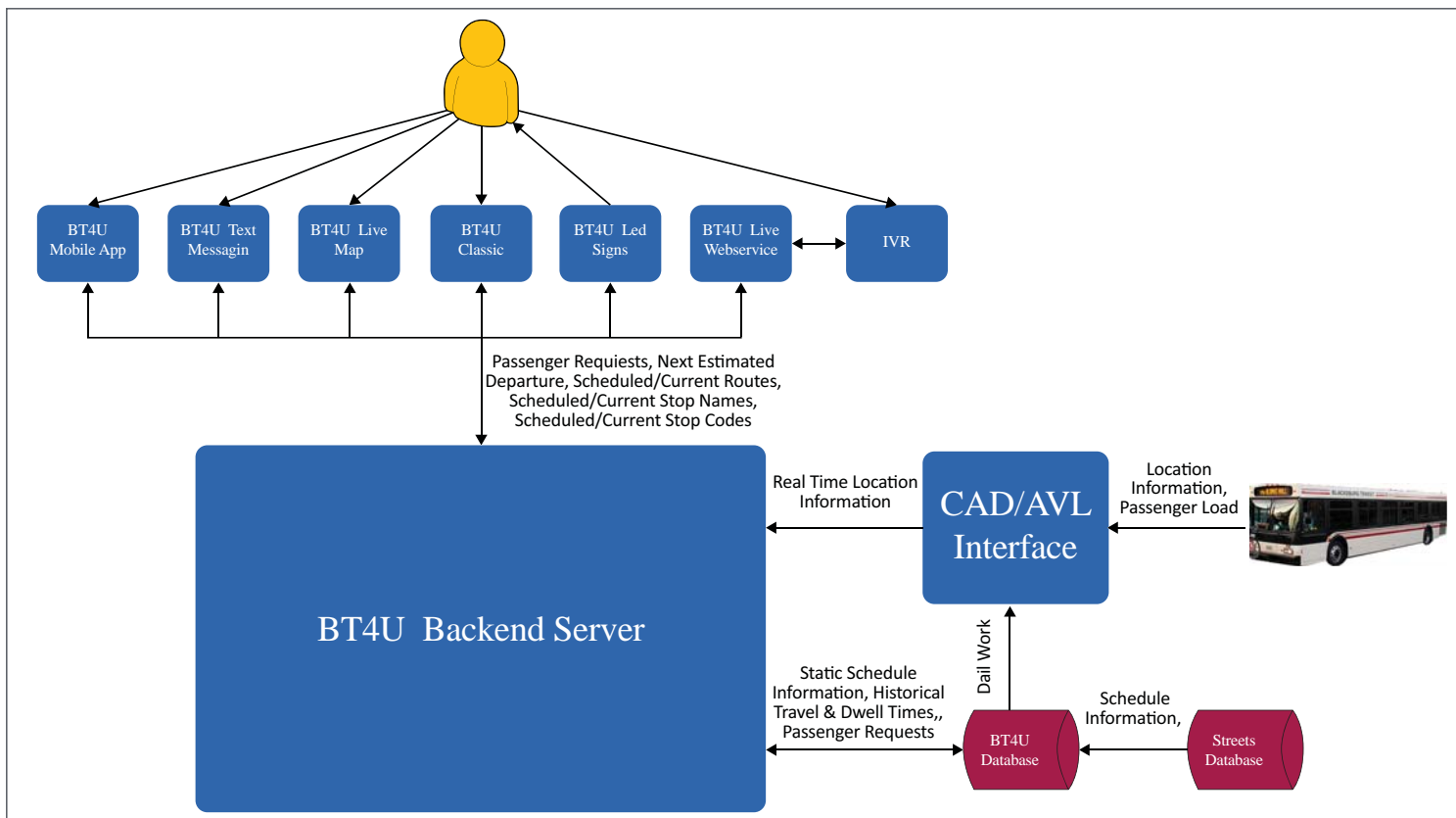


FIGURE 6-2 FRAMEWORK OF SUPPORTING SYSTEMS

DATA STORAGE

The Town of Blacksburg and Blacksburg Transit used Dell to provide computers, so the TIGGER database is housed on off-the-shelf Dell servers. The storage drives were purchased from EMC and include flash drives, 15,000 rpm hard drives, and 10,000 rpm hard drives. The system is robust, and can lose a number of drives before data are lost. The server is also backed up nightly and can be restored.

The servers are stored in a locked server room at Blacksburg Transit, so physical access is restricted. Permission to access the database is required and most users have limited access. For example, dispatchers have restricted read/write access to data relevant to bus and operator scheduling, and any Blacksburg Transit employee has read access to the dispatch information. Full read/write access is restricted to developers and administrators.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

DATA IMPORT

Data are passed from the data-collection equipment to the respective databases in the variety of manners listed in Table 6 1.

TABLE 6-1 DATA IMPORT METHODS

DATA TYPE	IMPORT METHOD
Passenger counts	Passenger counts come from the Trapeze system and includes driver-entered passenger counts using the Ranger Mobile Data Computer, and IR sensor data counting passenger entries. The data passenger counts from the Trapeze system go into the Streets database, built by Mentor Engineering and Tripspark, and is the source for bus schedule information. The data are in SQL, and is copied nightly into the TIGGER database.
Bus location	The buses send their GPS location via cellular signal when they leave a bus stop. The bus locations are transmitted to the Streets database, from which it is imported into the TIGGER database using a custom-written import function.
Actual fuel consumption and bus mileage	Bus fuel mileage data are collected by the Fuel Master system, a control unit on the fuel pumps at Blacksburg Transit. It tracks how much fuel is pumped into each bus, and the mileage the bus has travelled. The fuel data are entered into the Town of Blacksburg's financial system, which generates a report in CSV format that is imported nightly into the TIGGER database.
Weather data	Weather data are imported into the TIGGER database from an online weather data source.
Virginia Tech event data	Virginia Tech's event calendar is published years in advance, and it manually entered into the TIGGER database every few years.
Bus assignments	Bus assignments to routes, and operators to busses, are done through an intranet website at Blacksburg Transit. The data are automatically written to the TIGGER database when changes are made.
Tracking lost and found items on busses	For Blacksburg Transit employees to track lost-and-found items, they must navigate multiple spreadsheets. A program adding lost and found data was added to the dispatcher user interface, and the data added to the TIGGER database.
Vault tracking	The vaults used for cash storage on the buses are tracked on a spreadsheet, but will be consolidated, using the TIGGER database for data storage.
BT4U mobile application and website	Demand data from the mobile application is stored as MySQL by ACI/Nomad in the BT4U backend server. It is exported as a CSV, which is then imported into the TIGGER database nightly using Microsoft SQL tools.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

DATA ORGANIZATION

Many datasets have both time and GPS coordinate data, and both are used as primary data keys. GPS devices collect coordinate data more reliably than they do time data, so coordinates are the most consistent between GPS devices, like the HEM data logger and Streets data from the Trapeze passenger-counting system. Time, however, is absolute, while coordinates can be inexact and can repeat over the course of a bus' operation. Therefore, weather data, route data, bus schedule data were all related to each other using timestamps.

3DSS INTEGRATION

The 3DSS system, which inputs data on fuel consumption and real-time demand and outputs bus schedule and size-selection recommendations, will pull data from both the BT4U backend server and the TIGGER database. The 3DSS algorithm requires real-time usage data from the TIGGER database. It also requires historical demand data, bus location, and static schedule data from the BT4U backend server, which is updated nightly to the TIGGER database. It was simpler and more efficient for the 3DSS algorithm to obtain that data directly from the BT4U backend server. However, any weather, event-schedule and fuel-consumption data the 3DSS algorithm leverages is pulled from the TIGGER database.

FUTURE DATA APPLICATIONS

The TIGGER database will be used for more than bus routing and bus-size selection. Blacksburg plans on using it for the following purposes.

Bus board

The bus boards, showing which buses are assigned to which routes, are both in dispatch and in the drivers' lounge. Sometimes, the board in the drivers' lounge does not get updated. The system will be replaced with a digital system driven by TIGGER database data.

Support vehicle check in / check out

Currently, support vehicles are tracked using spreadsheets. Support vehicle check in and check out will be integrated into the dispatch user interface and driven from the TIGGER database.

CONCLUSIONS AND CONSIDERATIONS TO OTHER TRANSIT AGENCIES

A huge amount of data must be collected, sorted, and integrated into the project's components: demand assessment, fuel consumption, and 3DSS. Blacksburg Transit had already begun data collection for other projects, and integrating that system for use with this project proved challenging. A recommendation to other transit agencies would be to build a system with dynamic dispatching in mind from the beginning, creating better data linkage and relations.

The communications systems installed on Blacksburg Transit buses are some of the best commercially available, and can transfer data via cellular quickly enough to allow 3DSS to function. Other communication options are available, including dedicated short range communication (DSRC) between buses and the infrastructure, which has an even faster data transfer rate and will not experience reduced performance due to high user traffic. Much research is being performed regarding connected vehicles, and that research could be leveraged in a project attempting to use DSRC for transit bus scheduling and size optimization.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

7. ENGAGING STAKEHOLDERS

Marketing the TIGGER program to community stakeholders and sharing the results of the research with the academic community and other transit agencies was an integral part of this project. Community engagement was handled early on in the project using a number of marketing strategies, from formal meetings with stakeholders and the town council to transit staff standing at bus stops to talk about the mobile app with waiting riders.

COMMUNITY OUTREACH

Community stakeholders, including representatives from the Virginia Tech Corporate Research Center, the Virginia Tech Transportation Institute, HHHunt/Hethwood, the Roanoke Times, and the Blacksburg Planning District Commission were invited to a portion of the project kickoff meeting on April 10th, 2013. The meeting agenda included an overview of the TIGGER project and a description of its goal of using new technology to reduce GHG emissions from transit buses without sacrificing customer service.

TIGGER project staff met with Blacksburg's mayor, Ron Rordam, in November, 2013, to ensure he and the town council were engaged in the project. The mayor was a president of the Virginia

Transit Association, was very receptive to the project, understood the project's goals and technology, and understood the project team's desire to be at the forefront of transit research.

TIGGER team members met with the Blacksburg town council during a work session on June 17, 2014, to discuss launching the BT4U mobile app and the TIGGER project.

MARKETING THE SYSTEM

In the summer of 2013, a comprehensive plan was developed to market this research to the community, and is described in Appendix E: Marketing. Key messages in the marketing plan were the study's research goals, anticipated changes in service, the fact that the study is a partnership between Virginia Tech and Blacksburg Transit, and some potential benefits of the study, like shorter wait times and reduced GHG emissions. The focus groups and surveys, described in Assessing Demand for Transit Buses, were used to inform the marketing effort.

The team partnered with HHHunt and the CRC to inform passengers about the research performed on the test routes. For example, HHHunt allowed Blacksburg Transit to place signs discussing demand-assessment technologies around bus stops on the Hethwood test route. They used Facebook and email blasts to inform riders of focus groups and technology use in the neighborhood.



FIGURE 7-1 TABLETOP DISPLAY AT THE BT/TIGGER OPEN HOUSE

The team staged an open house in November 15, 2013, to share information about the project's goals and progress. The open house was held at Blacksburg Transit headquarters, had posters, demonstrations of prospective technologies, a TIGGER presentation, and allowed attendees to ask questions. The open house was held alongside VTTI's 25th anniversary event, increasing the projects' exposure.



Transit Bus Routing On-Demand: **Developing an Energy-Saving System**

The Collegiate Times, Virginia Tech's student newspaper featured two stories about the TIGGER Project. The first, published on February 5th, 2014, discussed Blacksburg Transit, ACI and Nomad Mobile Guides' efforts to develop the BT4U mobile app. The other article, published on May 28th, 2014, described the app's features and functionality, including its use as a demand-assessment tool and the TIGGER project's goal of reducing GHG emissions. Both articles are included in Appendix E: Marketing.

The TIGGER team also took a boots-on-the-ground approach, and placed staff at bus stops to discuss the mobile app with riders and encourage them to download it.

The TIGGER project website, housed under the Blacksburg Transit website, has news briefs, project updates, and frequently-asked questions and answers regarding the project.

ENGAGING THE RESEARCH COMMUNITY

This project will result in a number of academic publications and presentations. Related presentations have been made at events such as ITS World Congress, ITS Virginia, and elsewhere. Completed research will be published with the National Academies Transportation Research Board and as accepted elsewhere.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

8. TIGGER PROJECT RESULTS AND CONCLUSIONS

This project had collaborators from transit, transportation research, and industry take a novel approach to reducing GHG emissions on transit buses. It took place in an ideal test bed – a university town with a tech-savvy populace and reliable, yet innovative transit agency.

The project goal was to create a system that responded to demand for transit buses by scheduling appropriately-sized buses when needed. To do so, three major project components were integrated: assessing demand for transit buses using real-time and historical data, and creating an algorithm to forecast future demand based on those data; modeling the fuel consumption of a variety of transit bus sizes and types; and integrating the demand and fuel-consumption data into a dynamic dispatching algorithm that recommends changes to bus size and scheduling to both satisfy demand and reduce GHG emissions.

Nine technologies to measure demand for transit buses were evaluated using a number of criteria, including cost of hardware, development cost, ease of use, and rider comfort. Privacy concerns meant the thumb scan and BT4U website were not chosen to be tested. Modifying the Hokie Passport to include a RFID tag or to become a smart card was not possible, because Hokie Passports are Virginia Tech ID cards, and not controlled and distributed by Blacksburg Transit. Other smart card or RFID options were also not feasible for Blacksburg Transit, but might be for other transit agencies with the infrastructure already in place. The technology for using cameras to detect passengers at bus stops was not mature enough for this project's application, but could be an option in the future. The remaining four technologies were tested by using them to collect rider demand data, and comparing the number of demand data points with the number of riders on a route or stop corresponding with that demand-assessment technology. The BT4U Mobile App using iBeacons was the most promising technology for assessing demand, but only marginally so, and the BT4U mobile application and kiosk (running the mobile app) both have the potential to provide transit operators with advance demand information and rider origin and destination information. Any mobile app attempting to collect origin and destination information must balance ease of use with the richness of data collected. Wi-Fi also has the potential to collect demand information, but problems with range and reducing false positives make doing so challenging. More research is required before Blacksburg Transit can definitively say which demand-assessment technology best fits its needs, and the best-suited demand-assessment technology will likely differ between transit agencies. As part of demand assessment, historical ridership data were collected and correlated with months and days throughout the year. That data were incorporated into an algorithm predicting demand for transit buses, and testing proved the algorithm accurately predicted ridership to within a handful of riders. It could be even more accurate if demand-assessment technology were further refined, and if richer historical data were incorporated.

Fuel consumption had yet to be modeled for transit buses prior to this project, and the project team had to develop new methods to collect bus-performance data to incorporate into the model. Performance data were used to calibrate the models, which were then validated against actual fuel consumption. The models, based on the VT-CPFM framework, proved accurate, with an average R squared value of about 0.77. Other results included that hybrid buses consumed less fuel and produced less emissions than conventional buses, and that the optimal cruise speed for the greatest fuel economy was found to be between 40-50 km/h (25-31 mph). These findings are significant, because very little had been done on transit bus efficiency before this work, and these initial results suggest there is huge potential for research-driven fuel savings in transit bus operations. Questions remaining are how bus performance varies depending on weather conditions, route, traffic, bus fuel type, and elevation, which bus types are best suited to which applications, and the effect of driver training on fuel consumption. The fuel-consumption modeling performed for this project laid the foundation for future efforts to answer those questions.

The final major component of this project was the development of the 3DSS dynamic dispatching algorithm that incorporated fuel-consumption and demand data and produced recommendations to add or remove buses or replace buses with those larger or smaller. Although many outputs were possible, including route and stop changes, bus schedule and size were selected, because they were the least disruptive to Blacksburg Transit passengers. Inputs included data from a variety of sources, including information regarding bus size and performance, fuel consumption, passenger load, and passenger demand. 3DSS was tested using data from October, 2014, and the bus fuel consumption and CO₂ emissions were compared between when 3DSS was run and when it was not. Results indicated that when 3DSS was tested, buses consumed 10.6 percent fuel than when it was not used. Wait times increased, but they remained below the 10 minute threshold set as a testing parameter. Other transit agencies can adjust parameters according to their goals for customer satisfaction



Transit Bus Routing On-Demand: **Developing an Energy-Saving System**

and emissions reduction. The 3DSS algorithm is novel in that it produces a research-driven and actionable recommendation to a transit dispatchers, allowing them to focus on the factors directly affecting operations and budget by dispatching buses when and where they are needed.

All project components relied on database and communications systems. A large amount of disparate data had to be collected, transferred, and stored before it could be used by 3DSS, and the team devised methods to do so, largely using existing systems. Other transit agencies can benefit from the groundwork performed for this project, and should attempt to develop data systems from the ground up, enabling more efficient data linkage and relations. Vehicle-to-vehicle and vehicle-to-infrastructure technologies are maturing, and could be easily applied to transit but operations with the goal of reducing GHG emissions.

Overall, this project uniquely contributed to transit research, because it was the result of a collaboration between pure research, transit operations, and industry consultants, making it more valid and applicable than research conducted by one of those entities alone. The merging of the academic and operational was possible partly because the team hired external project managers, who were key in keeping collaborators focused on the overall project goals. The team approached the project with academic rigor, but also kept the project's applications in focus throughout, and its product, the 3DSS algorithm, was vetted by the final client – transit operators – and has the potential to reduce transit bus emissions by 10 percent.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

9. APPENDICES

APPENDIX A: PROJECT COLLABORATORS, STAKEHOLDERS, AND CONSULTANTS

Blacksburg Transit [31]

History and Background

The concept of a public transit system in Blacksburg may have first been documented in reports of a 1978 Transit Study. The report outlined a six-leg, seven-bus system of fixed routes that would service Virginia Tech and Blacksburg residents. Soon thereafter steps were taken to bring mass transit to Blacksburg.

Blacksburg Transit began running bus service in 1983 with six 30 foot buses, one van and seven full time staff. A transit management company was hired by the Town of Blacksburg to start the service and manage the operation. Shortly after beginning service, the Town of Blacksburg took over the management responsibilities and has managed the service ever since.

Service has grown to over 3.5 million riders per year serving the citizens of Blacksburg, Christiansburg, Virginia Tech, and the partnering communities within the New River Valley. The Town of Blacksburg has approximately 15,000 permanent residents and 29,000 students. We provide public transit service with 11 accessible fixed routes and BT ACCESS door-to-door service within the town limits of Blacksburg.

Blacksburg Transit now has 46 fixed-route buses: 11 x 35 (10.7 m) ft buses, 31 x 40 ft (12.2 m) buses, and 4 x 60 ft (18.3 m) articulated buses. Our BT ACCESS service currently includes 8 vehicles: 2 turtletop vans, 5 small Body-on-Chassis (BOC) and 1 large BOC.

Ninety percent of BT's ridership comes from Virginia Tech students, five percent from faculty and staff, and the remaining five percent from Blacksburg citizens.

General Information

Our mission

Blacksburg Transit provides safe, courteous, reliable, accessible and affordable public transportation to the citizens of Blacksburg, Virginia Tech, and partnering communities within the New River Valley.

Our commitment

We are committed to Safety, Courtesy, Reliability and the Environment. We are committed to seek innovative solutions to enhance or expand service to meet the needs of our communities. We are committed to see creative solutions to our current and future funding challenges.

We serve everyone

Services, programs, and employment opportunities offered by the Town of Blacksburg are available without regard to race, color, sex, age, religion, national origin, political affiliation, or disability.

Accessible transportation

Blacksburg Transit provides accessible transportation to everyone, from fixed route bus operators assisting persons on and off the bus and making bus stop announcements, to BT ACCESS service helping persons who are unable to ride the bus due to a temporary or permanent disability. BT ACCESS offers specially equipped vans and small buses along with ADA trained operators. The service is provided for all eligible persons wanting public transportation within the town limits of Blacksburg. A separate BT ACCESS brochure is available summarizing the service.

Virginia Tech Transportation Institute [32]

The Virginia Tech Transportation Institute conducts research to save lives, time, money, and protect the environment. One of the seven premier research institutes created by Virginia Tech to answer national challenges, the Virginia Tech Transportation Institute is continually advancing transportation through innovation and has impacted public policy on the national and international level.

VTTI has grown from approximately 15 faculty, staff, and students to become the second largest university-level transportation institute in the U.S. with more than 350 employees. As one of seven premier research institutes created by Virginia Tech to answer national challenges, VTTI has effected significant change in public policies for driver, passenger and pedestrian safety and is advancing the design of vehicles and infrastructure to increase safety and reduce environmental impacts.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

One of VTTI's main contributions to transportation knowledge is its naturalistic driving studies, where vehicles are instrumented with data-collecting equipment, and data regarding driver behavior and vehicle performance are collected. VTTI has designed and installed thousands of data-acquisition systems (DAS) in participant vehicles, and researchers continue to analyze the data and draw new conclusions regarding driver behavior and traffic safety. VTTI is also home to the Virginia Smart Road, a dedicated test track where experiments on new vehicle and infrastructure technology, as well as driver behavior, are conducted. Research on the Smart Road includes that on adaptive lighting systems and connected-vehicle systems, both of which have the potential to reduce energy consumption.

In all endeavors, the VTTI community is charged with finding solutions to the greatest transportation challenges facing not only the nation but the world. Those of the Institute are truly dedicating their lives to saving lives.

VTTI at a glance:

- VTTI has more than \$40 million in annual sponsored program research expenditures.
- VTTI annually supports an average of more than 100 undergraduate and graduate students and produces more than 140 publications per year.
- Most notable among VTTI endeavors are its naturalistic driving studies. Thanks to the internally developed data acquisition system, VTTI researchers are able to gather continuous video and driving performance data in real-world driving conditions. To date, these systems have been installed in nearly 4,000 vehicles deployed nationally and internationally.
- VTTI ensures its national and global success by employing a select team of multidisciplinary researchers, engineers, technicians, support staff and students.
- To accomplish its groundbreaking research, VTTI uses a range of tools, including the Virginia Smart Road and data acquisition systems. These capabilities have earned VTTI an exclusive standing in the transportation research field, making it a renowned option for transportation research, analysis and development.
- At its core, VTTI is a family; we are a community committed to conducting cutting-edge research to save lives.

Green Highway Initiative

The Virginia Green Highway Initiative (VGHI) is a partnership between VTTI, the Virginia Department of Transportation (VDOT), the Virginia Center for Transportation Innovation and Research (VCTIR), the Virginia Tech Institute for Critical Technology and Applied Science (ICTAS), the Virginia Tech College of Engineering, and the Virginia Tech Office of the Vice President for Research. VGHI is centered at VTTI with access to resources such as the Virginia Smart Road, VTTI researchers, and additional VTTI support staff.

The objectives of the VGHI include:

- Creation of innovative approaches designed to increase energy efficiency and reduce carbon emissions in the surface transportation domain
- Establishment of Virginia at the forefront of the sustainable transportation revolution
- Exploration and development of new technologies, methods, and policies that will minimize the negative impacts associated with surface transportation on Virginia ecosystems.

These goals will be achieved using the capabilities of Virginia Tech, VDOT, and other Virginia universities to pursue federal, state, and private sources of research funding and program investment. The success of VGHI will make an economic impact on Virginia, resulting in research, development, and manufacturing jobs.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Center for Sustainable Mobility

VTTI's Center for Sustainable Mobility (CSM) is conducting research relevant to society's transportation mobility, sustainability, dynamic traffic assessment, environmental modeling, and safety needs. The center translates the results of research into realistic and workable applications, creates and provides tools needed to apply developed knowledge and processes, and educates qualified engineers to meet today's transportation demands and tomorrow's transportation challenges in the areas of transportation system mobility, sustainability, and safety.

CSM comprises four focus areas:

- Traveler and Driver Behavior
- Transportation Systems and Operations
- Sustainability
- Transportation Safety Modeling

In the area of sustainability, CSM developed three internationally recognized fuel consumption and emission models, namely: VT-Micro, VT-Meso and VT-CPFM. The developed and tested eco-routing, eco-drive and eco-cooperative adaptive cruise control systems. CSM is a world-renowned center in the area of vehicle energy and emission modeling and brings high-level transportation modeling knowledge to the project.

Kimley-Horn

Kimley-Horn is a civil engineering and management company. Its description reads, "As one of the country's premier design consulting firms, Kimley-Horn applies creativity and rigor to deliver outstanding results. Whether your business is national or local, and whether your projects involve public infrastructure or private development, we seek to save you money and reduce your risk. Our engineers, planners, and environmental scientists work within your vision and your organization, bringing a sense of urgency, an above and beyond mindset, and creative yet practical solutions to help you achieve your goals" [33].

After releasing a request for proposal for project management in January 2013 and conducting interviews the following month, Kimley-Horn was selected as the project manager.

Automation Creations, Inc. and Nomad Mobile Guides, Inc.

A request for proposal was released in September, 2013, with interviews the following month. Automation Creations, Inc. and Nomad Mobile Guides were selected, and began work promptly thereafter. They fulfilled most of the requirements for the mobile application, and continued to add features and functionality throughout the project.

Automation Creations, Inc.

Automation Creations, Inc. (ACI, ACIwebs.com) is a seventeen-year-old company specializing in creating customized, data-driven, interactive, Internet and intranet information management applications. ACI has extensive commercial, education, and government project experience and is a GSA Schedule holder for information technology solutions. Located in Blacksburg, Virginia in the Corporate Research Center, we are a 'big, small company.' This means we are large enough to provide you with a deep bench of technical resources, while giving you (the customer) a personal and flexible approach to business. ACI is a small, service disabled, veteran owned, HUB Zone business, and our CAGE Code is 1SFZ9.

We create competitive advantage for our customers by combining deep industry knowledge of government, financial, and business services while leveraging technology to provide a framework for doing business more efficiently and profitably. We rely on strong core values as the building blocks for our success. Basic human values—honesty, respect, and genuine care for people are the foundation. From these values springs a culture that always places the customer first; a culture driven by commitment, dedication to excellence, and the persistence to add maximum value to all that we do.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Design and User Interface Expertise

Automation Creations has a staff of architects, graphic designers, and developers who are highly skilled in the use of Adobe products including Dreamweaver, Illustrator, Fireworks, Photoshop, Contribute, and ColdFusion. We have experience with Microsoft application architecture, design, and development as well as performance testing and tuning.

Our vivid designs grab the user's attention whether the graphics are in print format (brochures, posters, newsletters) or online within your website. Within your website, we can incorporate rich content such as audio and video elements to deliver your message in a more compelling way.

ACI's designers are equipped with the latest tools and technologies to ensure top quality graphics and animation output are available for our customers. Experience includes web graphic design, print media layout & design, and cascading style sheets to ensure consistent formatting on smartphones, tablets, and the most popular web browsers.

Web and Application Development

Automation Creations' application development team is an established developer of advanced software, including numerous analysis and design projects, developmental prototypes, and enterprise software solutions. Our niche has been to bridge the gap between the introduction of emerging information technologies and their effective, profitable use in commercial enterprises. One of this team's "value adds" is the availability of technology, often including source code, that has already been developed and can be used to accelerate the development and lower the risk on efforts performed for our customers.

Automation Creations' broad repertoire of methodologies, procedures, and technical approaches adds efficiency and control to software development projects. We are keenly aware of what is involved in the development and deployment of successful applications and, thus, the importance of thoroughly defining the objectives, features, and measurable benefits before the development process begins.

Automation Creations has established a reputation for developing practical, cost-effective systems using a variety of database, interface, and connectivity technologies that work. Our down-to-earth, problem-solving approach has received high marks from our customers. This, combined with our specific experience in designing, developing, and deploying advanced custom applications, makes Automation Creations a unique resource for any project.

We use a variety of scripting and programming languages as well as database options to make the best use of available technology. They include .NET, Java, Python, ColdFusion, PHP, VB, VB.Net, REST based Web Services, SQL Server, and MySQL.

Database Modeling and Administration

ACI's proficiency in database design and development is derived from over 50 years of cumulative developer and administrator experience. Our skill sets cover many different enterprise and freeware database platforms; these include Microsoft Access, SQL Server, Oracle, PostgreSQL and MySQL. ACI strives to achieve the Five Normal Forms of Database Development; this effort forms strong and scalable database solutions.

Our solutions are used by Fortune 500 companies, higher education institutions, and United States Government agencies and are repeatedly used by over 30,000 users daily. ACI's adeptness in the database arena leads to high customer and end user satisfaction by providing both an operationally efficient and scalable database solution.

Network Configuration & Server Administration Expertise

ACI's standard approach to server and data management include the use of various techniques ensuring no data loss, maximum server operation time, and a rapid recovery process. ACI's data backup procedure includes the use of NAS (Network Attached Storage) devices and server redundancy. This data protection procedure ensures that ACI can react quickly and efficiently to any data loss due to any catastrophic event. To further safe guard any data, ACI practices a daily data backup to a secure offsite location in case of a catastrophic event within the physical location of the data center, such as fire, flood, or terrorist action.



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Nomad Mobile Guides, Inc.

Nomad Mobile Guides, Inc (Nomad) is a subsidiary of Blacksburg based NewCity Inc, an 18-year-old interactive design firm. Nomad and NewCity occupy the same office space in the CRC. Nomad specializes in the creation of mobile applications in the travel space for both Android and iOS devices.

Nomad's customers include:

- Government and State bodies such as the American Battlefields and Monuments Commission and University of Virginia (UVA).
- Destination Marketing Organizations (DMOs) such as Black Hills, Badlands & Lakes, and Santa Cruz County Conference and Visitors Council.
- National Parks Associations such as Great Smoky Mountains Association, Yellowstone Association, and Canyonlands National Park Association
- By-ways such as the Blue Ridge Parkway, and Florida Black Bear Scenic Byway
- Media companies such as Chicago Magazine, and Emmis Communications
- Travel Publishers such as Keen Communications

Examples of Nomad's apps that regularly receive four and five star reviews can be seen at: http://www.nomadmobileguides.com/examples_of_travel_apps/

These apps are used to plan, experience and share trips to a variety of destination types. They are uniquely designed from a technical and user experience perspective to work with and without a data network connection to the mobile device.

Dynamic Data Systems

Dynamic Data Solutions handled the database management for this project. Their bid was a sole-source bid, because the Blacksburg area has few expert sources in data management. The company's agent, John Baute, is experienced in databases, manufacturing, automation, production reporting, quality, and downtime data-collection and monitoring systems.



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Project management structure

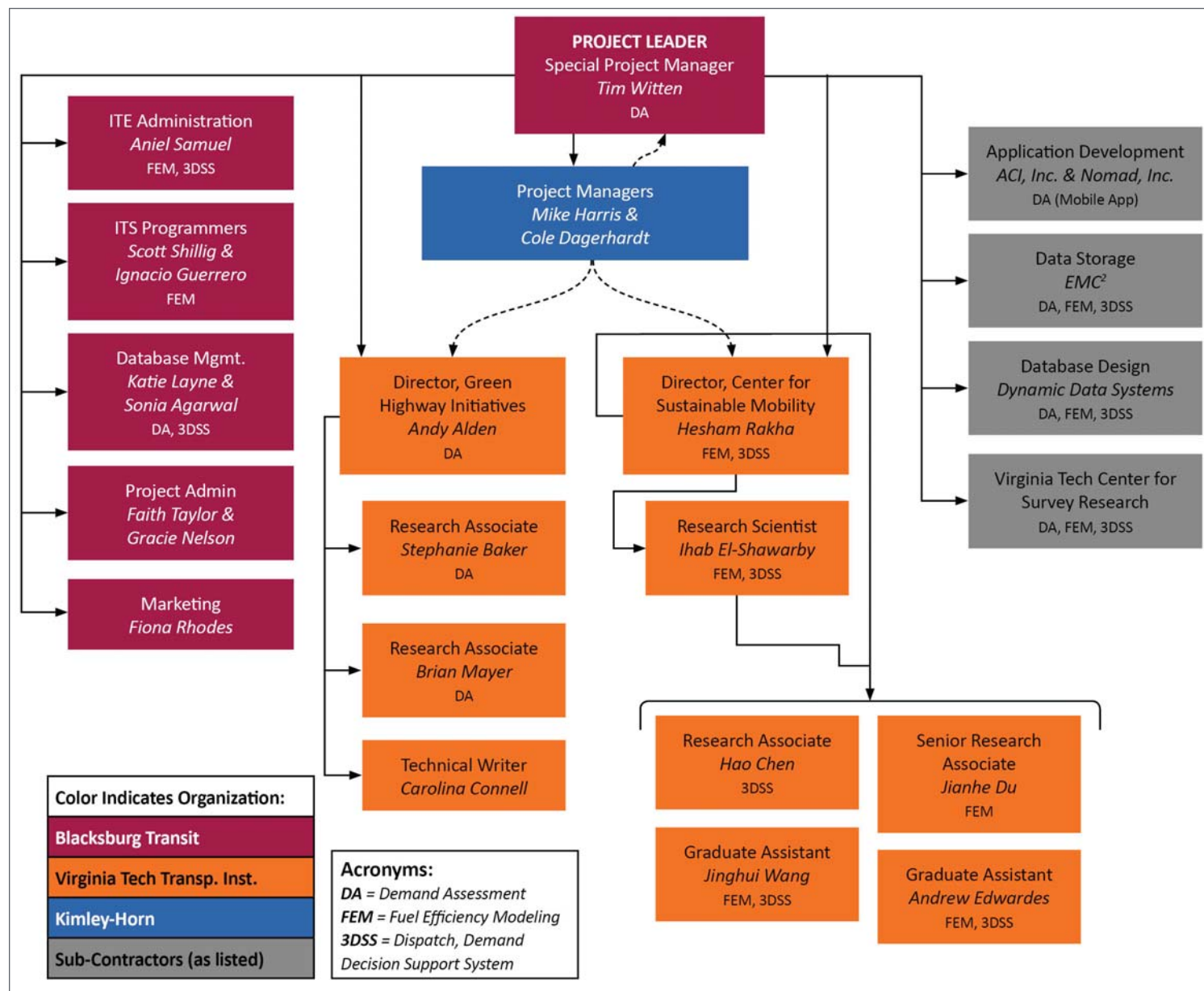


FIGURE 9-1 PROJECT MANAGEMENT STRUCTURE



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Project management plan

Scope Management

Virginia Tech Transportation Institute (VTTI)

Currently, VTTI has a research agreement with the Town of Blacksburg. The agreement was originally written with a loose scope to allow flexibility in research tasks performed as the project evolved and priorities became evident. The scope has not been modified, but VTTI's main tasks can be summarized as follows:

- Demand assessment research: analyzing multiple methodologies for demand assessment, performing a demand assessment survey, performing bus stop observations, developing the demand assessment algorithm to work in conjunction with the Dynamic Dispatcher Decision Support System (3DSS) and the Blacksburg Transit (BT) demand assessment systems.
- Data acquisition implementation: assist Blacksburg Transit in deployment of MiniDAS/DASHDAQ systems for data collection throughout the project. This data acquisition task directly supports the fuel modeling algorithms.
- Fuel model development: development of transit bus fuel model for each of Blacksburg Transit's bus types as well as calibration and validation of the fuel model. In addition, this task includes integration of the fuel model algorithm as a module in the overall 3DSS.
- 3DSS development: MATLAB development and C# coding of the 3DSS software algorithms. This task includes coordination of all input and output variables for the algorithm with multiple staff members within VTTI and BT.
- Project documentation: documentation of research efforts for all parties on this project.
- Schedule management: management of the Microsoft Project schedule for the project, specifically those tasks being performed by VTTI staff.

This will better prepare both parties to manage expectations, risks, and costs. The scope document will not be formally amended to the contract, but rather agreed upon via written email communication between Andy Alden (VTTI) and Tim Witten (BT).

The primary communication channel in regards to the existing VTTI agreement and future scoping language will occur between Tim Witten (Blacksburg Transit) and Andy Alden (VTTI). Kimley-Horn will serve as an advisor/liaison for both parties as needed and can manage coordination of changes/modifications to scoping language.

VTTI has acquired the assistance from Virginia Technical Institute Survey Research, Susan Willis, to develop a demand assessment survey. VTTI will manage the defined scope and costs for this part of the project.

Kimley-Horn

Currently, the scope and contract for project management activities to be performed by Kimley-Horn are well defined within the contract itself. If the need arises to modify Kimley-Horn's scope to change the nature of the tasks or include additional services, this will need to be performed with a formal amendment to the contract.

The primary communication channel in regards to the existing Kimley-Horn contract will occur between Tim Witten (Blacksburg Transit) and Mike Harris (Kimley-Horn).

Blacksburg Transit (BT)

Currently, Blacksburg Transit is internally managing their staff costs and needs in relation to this project.

Also Blacksburg Transit contracted Dynamic Data Systems, John Baute, to develop a database storage solution and development environment. The specifics are defined within the contract. Blacksburg Transit will manage John's scope and costs.



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Blacksburg Transit has contracted ACI-NOMAD Mobile Guides for development of a mobile application for distributing data collected. They will manage the defined scope and budget for ACI-NOMAD.

a) Additional Contractors, Consultants, Sub-contractors, and Sub-Consultants

As the project progresses, details related to scope management for additional parties will be added to this section of the project management plan.

Requirements Management

Given the highly technical nature of this project, management of project objectives as well as technical requirements for various aspects of the project will be important for development of project components and procurement documents. As such, the project team as a whole, including at least one member of Blacksburg Transit, VTTI, and Kimley-Horn, discuss the appropriate requirements for each project subtask during monthly progress meetings. Kimley-Horn documents those requirements as developed by the team. The team began this process with development of high level functional requirements in the following sections, which will be further clarified with more descriptive technical requirements as needed. The details are captured within the Concept of Operations.

a) Project Purpose and Objectives

The purpose of this project is determine through research and analysis the validity of dynamic bus routing and scheduling through the combination of existing ITS technology and new technology deployments. To address this, the team has project specific goals and objectives. The objectives will need to be SMART (Specific, Measurable, Attainable, Relevant, Time-bound).

High Level Functional Requirements for Demand Assessment Project Component

The purpose of the task is to collect bus stop demand data for use by the demand assessment and 3DSS algorithms. The algorithms will help to dynamically modify schedules, bus assignments, and possibly routes.

High Level Functional Requirements for Data Acquisition and Modeling Project Component

The purpose of the task is gathering data from the buses themselves. The data received will provide bus engine data, AVL, and passenger count data to be used as part of the modeling platform.

High Level Functional Requirements for Communication System and Power Coordination Project Component

The purpose of this task is to provide infrastructure to support communications of real-time passenger demand and on-board bus data between buses, bus stops, and Blacksburg Transit's data center.

Schedule Management

Kimley-Horn has developed and continues to maintain a draft high level schedule that includes major milestones for development of methodologies, procurement, deployment, and testing/evaluation. This schedule will serve as the primary project schedule and will be updated as requested by Kimley-Horn. Each of the project tasks and activities are included on the schedule and each team member including participants from Blacksburg Transit, VTTI, and Kimley-Horn are responsible for suggesting appropriate schedule updates for their tasks and for suggesting the addition of tasks to the schedule. In addition, VTTI has developed a Microsoft Project schedule for managing discrete research tasks and accompanying dependencies.

Kimley-Horn has developed and performs weekly update on the project Action List. This list includes all near-term and medium-term action items to be completed by each team member.

The project team discusses each item on the Action List during weekly progress calls to monitor project progress. The project team also discusses the overall schedule and potential impacts/changes at each of the monthly progress meetings. Kimley-Horn will update as required. Kimley-Horn and other project team members will provide input and clarification as to variances in the schedule to Tim Witten (Blacksburg Transit). Tim Witten will make a determination as to whether variances will be allowed when requested.



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Financial Management

a) Progress Reports

Kimley-Horn will develop project progress reports to be reviewed by the entire group following the monthly meeting in Blacksburg each month. This report will be provided to Tim Witten and Andy Alden for review prior to being released to project stakeholders.

Kimley-Horn Invoicing

Kimley-Horn will invoice on a monthly generally in the third week of each month. Tim Witten will review and provide approval for Kimley-Horn invoices. Each invoice will provide the percent complete for each major tasks within the contract.

VTTI Invoicing

Blacksburg Transit receives and manages the invoices for VTTI.

FTA and TIGGER Required Reports

Monthly progress reports are posted to the TEAM website for review and comments.

Quality Management

a) Quality Control

Kimley-Horn will assess the quality for each aspect of the project. To better prepare for review, Kimley-Horn will make note of each deliverable within the project and assign a person to review them. The same person may not be the one to review all of the deliverables as each one may have a specialty that would garner another to review.

Kimley-Horn also will note if these deliverables require a separate review or input from others. The milestones for these deliverables will help with review of the schedule, to know when the review should be done and inquire if there are any problems. If a deliverable review becomes too long, then this may need to be placed as a risk to help facilitate additional discussion to finalize the deliverable.

If there is a quality issue, this will be reported in the monthly project report. All team members should report potential quality issues to Kimley-Horn.

Resource Management

a) Staffing needs

The project core team will discuss during each weekly and monthly progress meeting the amount of action items and the availability of staff on each team to complete the tasks in a timely manner. In addition, availability of staff will be a major consideration in selection of consultants and/or contractors for completion of project components.

Communication Management

a) Project Team Meetings

The project core team will hold monthly meetings at the Blacksburg Transit office as well as weekly conference calls between these in-person meetings Kimley-Horn will provide agendas and meeting summaries for each of the monthly meetings and will update the Action List on a weekly basis following each weekly progress conference call. All agendas and summaries will be posted to the project SharePoint site for review by all team members. Action items and tasks will be documented in writing within meeting summaries for clarification.

Stakeholders

Communication with major project stakeholders such as FTA, FHWA, VDOT, Town of Blacksburg, and others will be performed through dissemination of the monthly progress report. Kimley-Horn will disseminate the progress report following review by the project core team.

Methods of communication

Email communication is the preferred method of communication between team members. Cole Dagerhardt with Kimley-Horn and Tim Witten with Blacksburg Transit should be copied on all project related emails.



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Change Management

a) Change Control Committee

The following items describe how the change control committee will function:

- Includes only core team members (Tim Witten, Andy Alden, Mike Harris, Cole Dagerhardt)
- Each request for a contractual change should be submitted formally, not through verbal communication unless stated at a meeting and the minutes is the form of documentation
- The core team members will set up a meeting to discuss any change requests.
- The requests should be distributed within the core team prior to discussion at the meeting.
- Each core team member will review any requested requirement, scope, invoicing, or other contractual changes that would require prior approval before implementation.
- All change management decisions should be documented – this can be a running list on the SharePoint site that can be easily extracted for distribution and approval/rejection

Risk Management

As the project progresses, risks or issues will be identified by project members at the weekly or monthly meetings. The risks will be consistently discussed during the project team meetings and will be added to a list of risks to be discussed at each monthly meeting. Risk descriptions will include the following information:

- Each risk will include a title, short description, and the priority level
 - High – very urgent;
 - Medium;
 - Low – not really of much concern at this time
- Each risk will be assigned to a person – this person will help to facilitate any necessary coordination to lessen the impact from the risk
- High priority risk should include a due date –Setting a due date will help to encourage any mitigation to alleviating the risk
- Risks should be discussed consistently
- Risks should be addressed at each month meeting for a status update
- Any issues relating to the risks should be addressed at each weekly call to be inquire if additional support is needed
- As the risk is dealt with, its status should be changed to reflect
- If necessary, additional comments about the status change or additional details of the risks should be noted
- Each risk should be documented within the SP site and should referenced at each monthly meeting

Procurement Management

Procurement will be managed through the Town of Blacksburg procurement department. Bidding or requirements for request for proposal documents may be developed by Blacksburg Transit, VTTI, or other project team members. Blacksburg Transit and Kimley-Horn will review procurement documents before forwarding to the Town of Blacksburg procurement department. The procurement department will place the procurement documents in the appropriate boilerplate and review for legal issues. The project team will provide 15-20 business days of notice to the procurement department before providing the procurement document, such that they can be prepared to develop, review, and release the final procurement document.



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APPENDIX B: DEMAND ASSESSMENT

Virginia Tech Institutional Review Board

The Virginia Tech Institutional Review Board (IRB) monitors and approves all research involving human participants. Its mission statement is, "Virginia Tech is committed to protecting the rights of and ensuring the safety of human subjects participating in research conducted by faculty, staff and students of the University and for research in which Virginia Tech is engaged. This commitment is vested in the Institutional Review Board for Research Involving Human Subjects (the IRB), and is guided by the ethical principles described in the "Belmont Report" and in applicable federal regulations." [34]

The Virginia Tech IRB reviewed and approved materials and procedures for the survey and focus groups run as part of this project.



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Survey summary report

Summary report



Campus Traffic Survey

Summary of Procedures and Results

Prepared by:
The Virginia Tech Center for Survey Research

April 2014





Transit Bus Routing On-Demand: Developing an Energy-Saving System

Table of Contents

Section Title	Page Number
Introduction	1
1 Methodology	2
2 Respondent Profile	3
3 BT Ridership	4
4 Technology Scenario Findings	9
5 Improvements for Local Bus Service	11
6 Data Storage	12
Appendix A	Survey Instrument
Appendix B	Email Invitation Text
Appendix C	Overall Response Frequencies
Appendix D	Response Frequencies by University Affiliation
Appendix E	Response Frequencies by BT Ridership
Appendix F	Response Frequencies by Age
Appendix G	Response Frequencies by Smartphone Ownership
Appendix H	Responses to Open-ended Survey Items



Transit Bus Routing On-Demand: Developing an Energy-Saving System



Introduction

The Virginia Tech Center for Survey Research (CSR) was retained by the Blacksburg Transit (BT), via the Virginia Tech Transportation Institute, to conduct a survey of Virginia Tech community members to learn more about BT ridership and how transit can be transformed in the Blacksburg community in the future. Specifically, a web survey was designed to gather ridership information and stakeholder opinions regarding a variety of technologies that could be utilized in the future to track rider information and improve bus service.

For the administration of the 2014 Campus Traffic Survey the CSR gathered 1,182 responses to a web-based survey. This report summarizes the data collection procedures and results of the survey. Section 1 provides an overview of the survey instrument development and data collection procedures utilized by the CSR for the collection of the data. Section 2 provides a demographic profile of the survey respondents. Section 3 provides the findings from the survey for a variety of BT ridership issues. Section 4 provides an overview of findings related to the technological scenarios presented to respondents in the survey. Section 5 includes a statement about data storage for the project.

The survey instrument is included in *Appendix A*. *Appendix B* includes the text of the electronic message invitation that was sent to the respondent pool in order to solicit response to the survey. *Appendix C* provides tables of response frequencies to all close-ended survey items. *Appendix D* provides response frequencies by the type of affiliation of the respondent to Virginia Tech. *Appendix E* provides response frequencies by BT ridership status. *Appendix F* provides



response frequencies by respondent age. *Appendix G* provides response frequencies by respondent smartphone ownership status. *Appendix H* lists all responses provided by respondents to open-ended survey questions.

1

Methodology

Sampling and Survey Instrument Design

The survey instrument was developed by representatives from the Blacksburg Transit with assistance from the CSR. The CSR gathered contact information for 7,000 randomly selected Virginia Tech faculty, staff, and students from Virginia Tech Human Resources and the University Registrar's Office for inclusion in the survey pool. The survey instrument was administered by CSR via the web using personalized web links embedded in electronic message invitations. Each member of the survey pool received an invitation message describing the purpose of the survey and instructions for completing the survey. Each invitation to participate was developed and sent by the Blacksburg Transit and the CSR and was signed by the Director of the Blacksburg Transit.

The CSR established personalized links such that sample members could be identified by CSR without necessitating that survey respondents enter a password or user identification number to complete the survey. CSR assigned each sample member a randomly generated, unique identification number that was embedded in the electronic invitation at the end of the



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sample members who had already submitted a response to the survey from subsequent electronic reminders requesting survey participation. All non-respondents to the survey were sent four reminders to complete the survey. The survey administration began in November 2013 and ended in January 2014.

2 Respondent Profile

Respondent Demographics

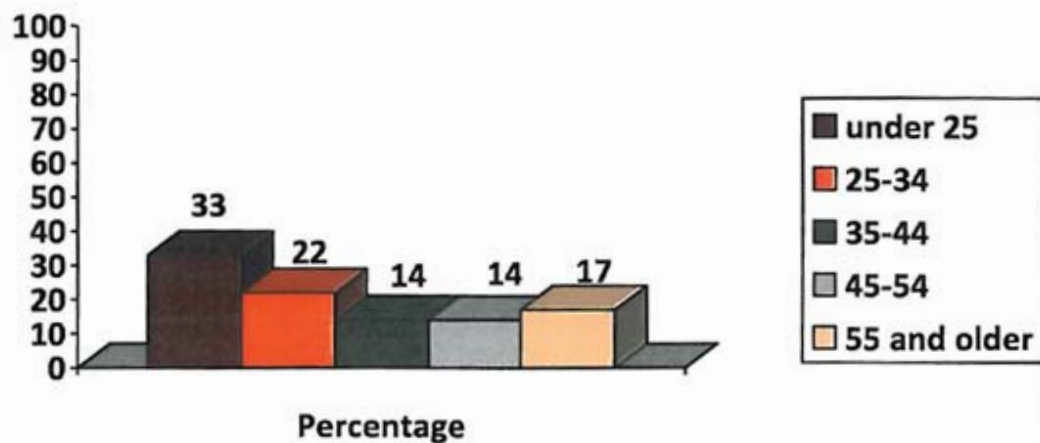
Among the 7,000 campus community members randomly selected for participation in the survey, 4,000 are students, 1,445 are staff, and 1,555 are faculty. A total of 1,182 completed surveys were submitted. There were 537 students who submitted the survey, 282 staff members, and 363 faculty. Slightly more than one third of the survey respondents (35%) reported that they ride the Blacksburg Transit (BT) bus currently in a typical week. Among the respondents who reported that they ride the BT currently during a typical week, 60 percent reported that they ride at least once per week with another 40 percent reporting that they ride the BT more than once a day. More than three fourths of survey respondents (77%) own a smartphone. Survey respondents were asked if they would be willing to participate in a focus group in the future regarding local bus transit. Almost three fourths (74%) reported that they would be willing to participate in future research. **Figure 1** depicts the age groups for the individuals who responded to the survey.



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Figure 1. Survey Respondent Age Groups



3

BT Ridership

A total of 417 survey respondents (35%) indicated on the survey that they ride the BT currently in a typical week. **Figure 2** depicts the university affiliation type of respondents who reported in the survey that they currently ride the BT in a typical week. Among the survey respondents who reported that they currently ride the BT in a typical week, 40% ride the bus more than once a day.



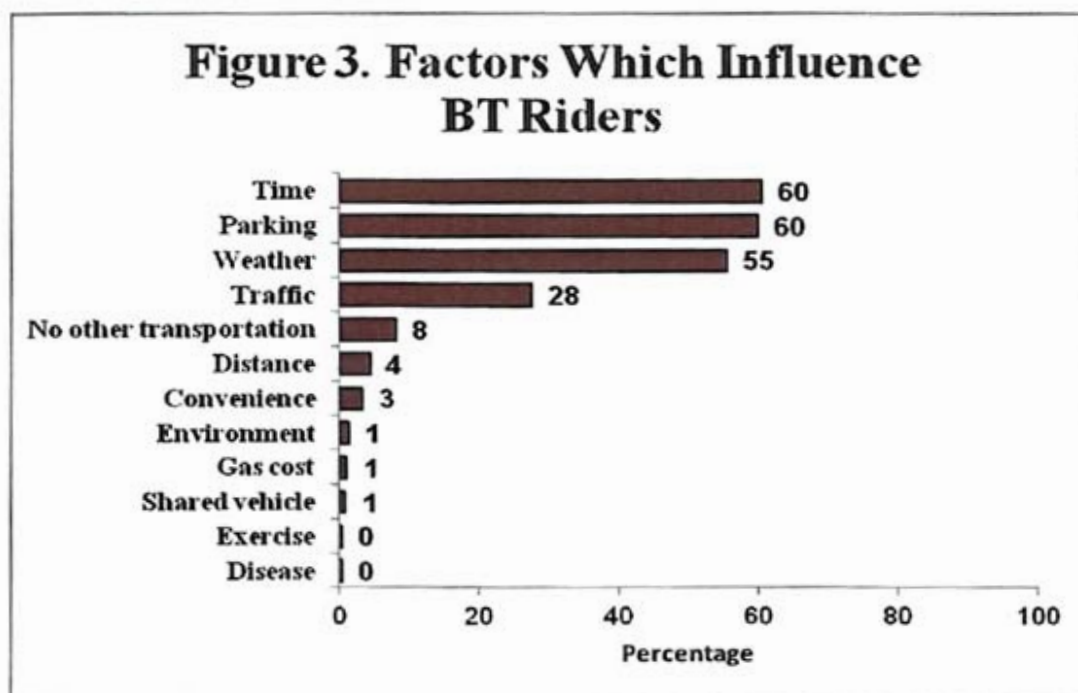
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prevalent factors reported were time, parking, and weather. **Figure 3** depicts the findings for all of the factors included on the survey.



As depicted in **Figure 4**, most BT riders are satisfied with local bus service. However, only 40 percent said they are 'very satisfied' with local bus service. Among BT riders, older riders (those age 45 or older) are slightly less satisfied (less than 90% satisfied compared to more than 90%) than younger respondents with local bus service. Faculty were less satisfied (80% satisfied) than students (92%) or staff (96%).

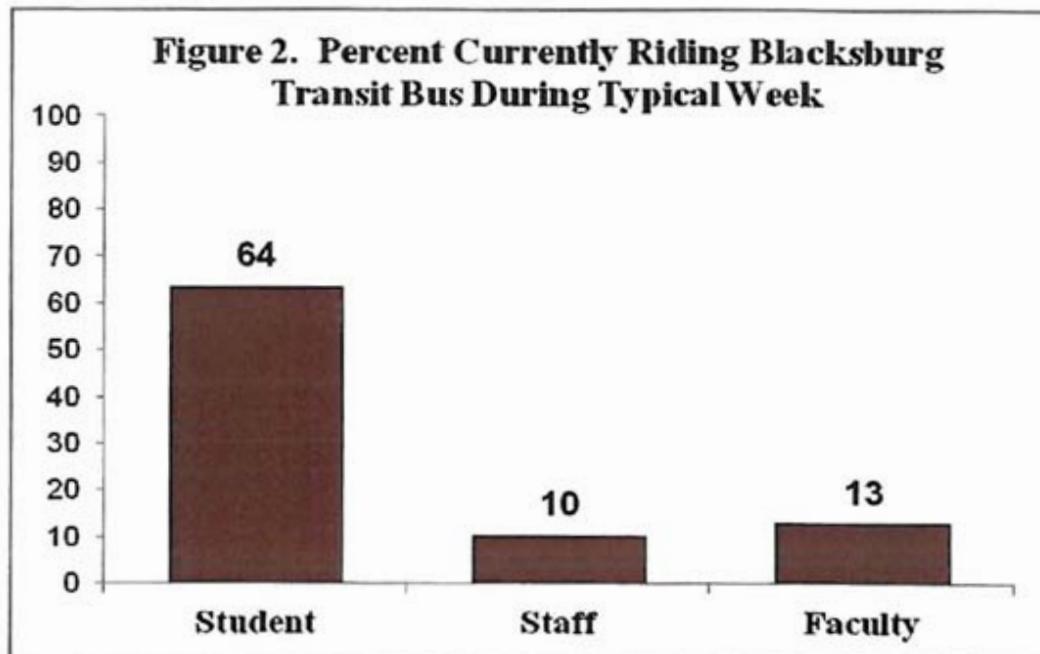


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The high percentage of student riders may indicate why more than 8 in 10 (82%) survey respondents who report riding the BT also report that they own a smartphone. This high percentage of smartphone ownership among current BT riders will allow for greater ease of use of transit technologies that require a smartphone.

The greatest number of respondents who indicated riding the BT reported that they are under the age of 25 (62%), with 22 percent in the 25-34 age group, 6 percent in the 35-44 age group, and another 6 percent in the 45-54 age group, and 4 percent in the age category of 55 and older.

The survey includes a survey item which asks respondents who reported that they ride the BT to select from a list of factors provided those factors which influence them to ride. The most



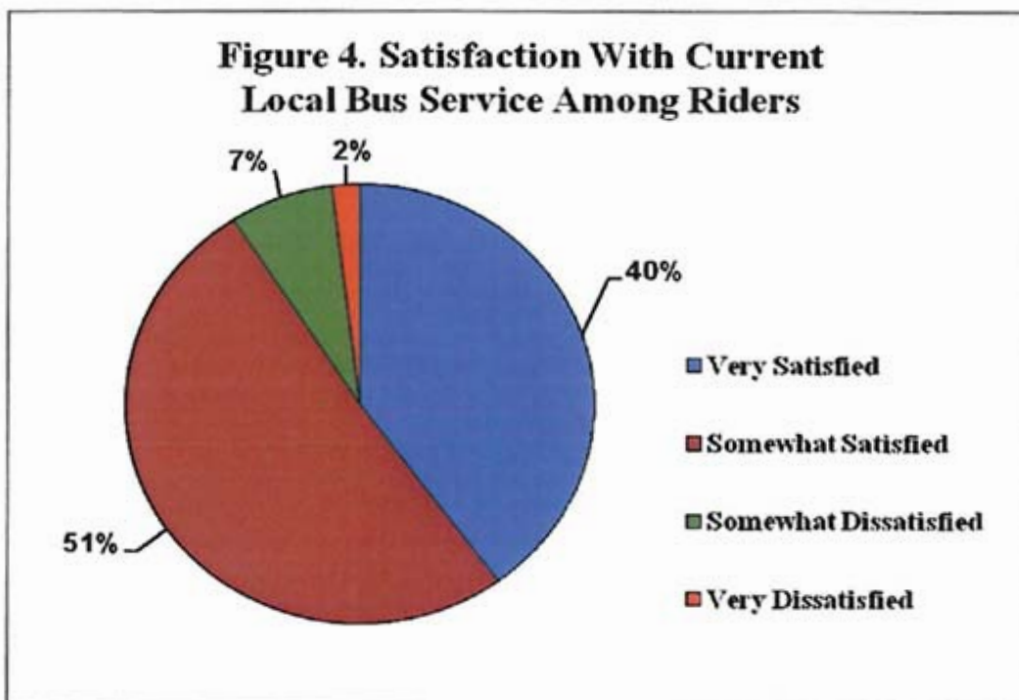
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Figure 4. Satisfaction With Current Local Bus Service Among Riders



Survey respondents were asked if they would be willing to wait a couple of minutes longer for a bus, with 43 percent responding 'yes'. Interestingly however, when asked if they would be willing to wait for a bus if it meant reducing green house gas emissions many more respondents (65%) answered 'yes' as depicted in **Figure 5**. This finding is particularly interesting given that 'time' was one of the factors reported by respondents as a primary reason for riding the BT.



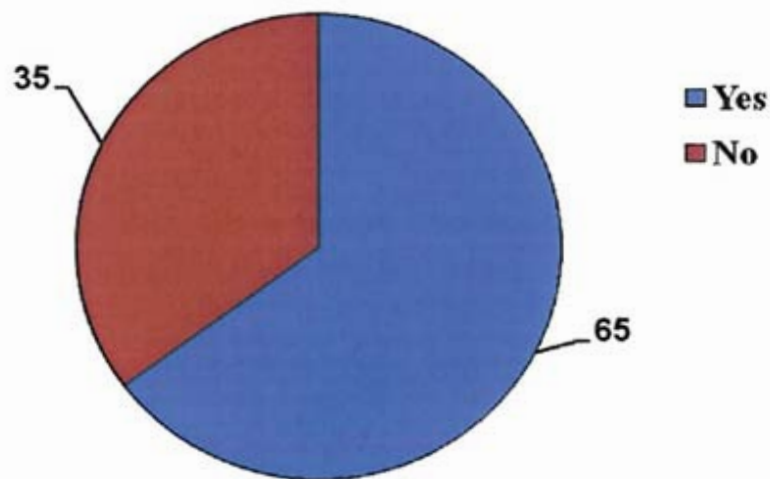
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Figure 5. Percent Willing To Wait For A Bus If It Meant Reducing Green House Gas Emissions



The University City Boulevard route was the most common route cited by BT riders as one of the routes they use most often, closely followed by the Toms Creek and Main Street routes. **Figure 6** depicts the survey findings regarding route usage by BT riders. As to be expected, some of the out of town and commuter routes were the least used among BT riders. However, some out of town routes such as the hospital route and the Two Town Trolley had higher levels of ridership among survey respondents.



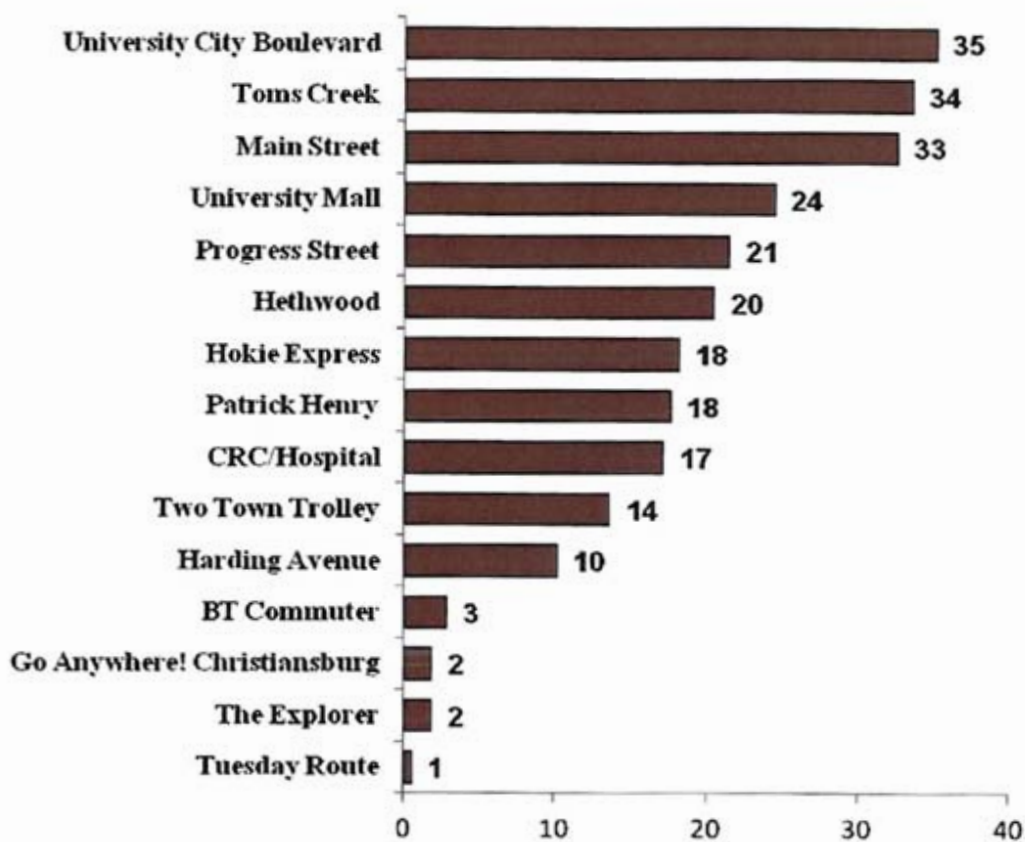
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Figure 6. Percent of BT Riders Utilizing Routes



4

Technology Scenario Findings

The survey instrument includes a number of questions related to technologies that could be used to study aspects of bus service such as levels ridership on certain routes, optimal timing for



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specific routes, and other aspects of bus service for the university community. The survey questions related to different technology scenarios are intended to assess the willingness of campus community members to use each of the technologies.

Table 1 includes the findings related to the technologies presented in the survey. The imaging system, card reader and kiosk technologies included in the survey were of most interest to survey respondents. Respondents to the survey were the least likely to use the technology scenario related to thumb scans compared to the other technology scenarios presented on the survey.

Table 1. Respondent Likelihood to Use Technology	
Scenario	Combined Valid % 'Somewhat Likely' + 'Very Likely'
You arrive at the bus stop where an imaging system is located, which will count the number of people at a stop. This will help us know how many people are waiting at the stop and assign buses accordingly.	62.0
You arrive at the bus stop and use a card reader to swipe/scan your Hokie ID to get on the bus and ride to your destination. As you exit the bus you swipe/scan your Hokie ID again to let us know that you have completed your trip.	56.1
You arrive at the bus stop and use a kiosk that we have placed at selected stops. These kiosks will allow riders to click on an interactive map to show their planned trip.	48.8
You arrive at the bus stop and use a previously downloaded mobile app that will allow you to mark where you are getting on/off the bus. Riders will also be able to report bus conditions, such as cleanliness or capacity.	43.7
You arrive at the bus stop where a reader counts the number of WiFi/Bluetooth signals at the stop, logging data points throughout your bus trip.	41.5
We will issue an RFID tag to passengers that can be attached to a backpack or elsewhere, and count the number of passengers on a bus based on RFID signals.	39.1



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Table 1 Continued. Respondent Likelihood to Use Technology

You arrive at the bus stop where you use existing BT4U avenues to tell us what bus stop you are using to get on the bus and where you are getting off. No Smartphone is necessary, information can be provided via voice or text message.	33.4
You arrive at the bus stop, scan your thumb, get on the bus, and ride to your destination. As you exit the bus you scan your thumb again to let us know that you have completed your trip.	23.2

5

Improvements for Local Bus Service

Survey respondents were asked in a final open-ended survey item what they would most like to see improved about local bus service. CSR developed a word cloud from the open-ended responses provided to this survey item by tabulating all of the responses. The size of the words in the cloud represent the relative number of times a suggestion for improvement was mentioned for the survey item. Interestingly, a technology solution emerged as one of the most prevalent responses to the survey item. Specifically, many respondents said they would like to see a web or phone application for real time arrival time information and trip information. Many respondents also asked for more service (capacity) at peak times and expanded or more efficient routes. **Figure 7** is the word cloud highlighting the responses gathered for the open-ended survey item regarding potential improvements for local bus service.



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Figure 7. Suggested Improvements for Local Bus Service



6

Data Storage

An SPSS dataset from which the data in this summary report were derived accompanies this report in electronic format. All variable and value labels are provided on the SPSS dataset. All electronic files of the survey instrument, report, tabulations and presentations related to the data are the property of the Blacksburg Transit and VTTI principals affiliated with the study. However, the Center for Survey Research will retain copies of all project materials for a period of at least one year. No information from this survey will be shared by the CSR with anyone



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other than project team members from the Blacksburg Transit without the express permission of that organization.



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Campus traffic survey

The Blacksburg Transit is conducting research with Virginia Tech community members to learn more about ridership and how transit can be transformed in the future. Technology in the area of transit is changing and we want to better understand how transit technologies may be developed to better serve customers and the environment. This survey will allow us to gather this information. Thank you for your participation in this important project.

1. Do you ride the Blacksburg Transit (BT) bus currently during a typical week?
☐ No [GO TO QUESTION 8]
☐ Yes
2. How often do you ride the BT in a typical week?
☐ About once per week
☐ 2-4 times per week
☐ About once per day
☐ More than once per day
3. Which of the following factors influence you to ride the BT? (Please Click All Response Options That Apply)
☐ Weather
☐ Parking
☐ Traffic
☐ Time
☐ Other (Please specify: _____)
4. How satisfied are you with local bus service currently?
☐ Very Satisfied
☐ Somewhat Satisfied
☐ Somewhat Dissatisfied
☐ Very Dissatisfied
☐ Don't Know
5. Would you be willing to wait a couple minutes longer for a bus?
☐ No
☐ Yes
6. Would you be willing to wait for a bus if it meant reducing green house gas emissions?
☐ No
☐ Yes
7. What BT routes do you utilize most often? (Please Click All Response Options That Apply)
☐ ROUTE LIST HERE
8. Do you own a Smartphone?
☐ No
☐ Yes



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9. Please indicate how likely you would be willing to participate in each of the technology scenarios presented below. Each of the scenarios would allow us to conduct research on technologies that could help to improve bus service for the community.

		Very Likely	Somewhat Likely	Somewhat Unlikely	Not at All Likely	Don't Know
		Please Click One Response Option				
a.	You arrive at the bus stop and use a card reader to swipe/scan your Hokie ID to get on the bus and ride to your destination. As you exit the bus you swipe/scan your Hokie ID again to let us know that you have completed your trip.	1	2	3	4	5
b.	You arrive at the bus stop where an imaging system is located, which will count the number of people at a stop. This will help us know how many people are waiting at the stop and assign buses accordingly.	1	2	3	4	5
c.	You arrive at the bus stop where a reader counts the number of Wi-Fi/Bluetooth signals at the stop, logging datapoints throughout your bus trip.	1	2	3	4	5
d.	We will issue an RFID tag to passengers that can be attached to a backpack or elsewhere, and count the number of passengers on a bus based on RFID signals.	1	2	3	4	5
e.	You arrive at the bus stop where you use existing BT4U avenues to tell us what bus stop you are using to get on the bus and where you are getting off. Smartphone is necessary, information can be provided via voice or text message.	1	2	3	4	5
f.	You arrive at the bus stop and use a previously downloaded mobile app that will allow you to mark where you get on/off the bus. Riders will also be able to report bus conditions, such as cleanliness or capacity.	1	2	3	4	5
g.	You arrive at the bus stop and use a kiosk that we have placed at selected stops. These kiosks will allow riders to click on an interactive map to show their planned trip.	1	2	3	4	5
h.	You arrive at the bus stop, scan your thumb, get on the bus, and ride to your destination. As you exit the bus you scan your thumb again to let us know that you have completed your trip.	1	2	3	4	5

10. Would you be willing to participate in a focus group in the future regarding local bus transit?

- ☐ No
☐ Yes

11. In what year were you born?

12. What would you most like to see improved about local bus service?

Thank you for your help with our study. Please click "submit" to end the survey.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Focus group summary report

Focus Groups

The VTTI research team conducted focus groups to gauge customer perception of the technologies under consideration for collecting real-time demand data for the BT. The focus groups were designed to collect the thoughts and opinions of Blacksburg Transit users regarding the proposed technologies. The Blacksburg Transit user input helped inform decision-making about which technologies should be pursued for full implementation.

Participants

Three focus groups were held near Blacksburg Transit stops accessible to Blacksburg Transit riders that may use the Blacksburg Transit to get to work (i.e., Virginia Tech Corporate Research Center) and/or home (i.e., Hethwood Residential Area). Seventeen Blacksburg Transit users took part in the focus groups. Each focus group lasted 90 minutes. To participate, individuals had to be at least 18 years old, users of the Blacksburg Transit, and able to attend a focus group at the times and locations where they were being held. Recruitment was conducted in a variety of ways including handing out flyers at Blacksburg Transit stops and putting recruitment information on e-mail list serves likely to reach people who use the Blacksburg Transit.

Participant Protection

Several steps were taken to protect participant privacy. The recruitment approach and associated materials and protocols were reviewed and approved by the Virginia Tech Institutional Review Board (IRB). The research team did not collect participant names on surveys or transcribe participant names from focus group audio files. Participant contact information was stored on password-protected computers that were only accessible to researchers.

Potential participants were given informed consent information via email during recruitment so that it could be reviewed prior to the focus group. Participants were also reminded prior to data collection (i.e., focus group, survey) that they were free to stop their participation at any time, that their names would not be transcribed, and that they did not have to answer any questions they were uncomfortable answering. Hard copies of the consent forms were distributed and signed before the start of each focus group.

Qualitative Approach

A tape-based approach was used to analyze the focus groups. This methodology is described by Richard A. Kruger as one where a “moderator prepares a written report based on an abridged transcript after listening to tapes plus field notes and moderator debriefing.”² For this analysis, the focus group facilitator listened to the audio files, reviewed work products (i.e., Post-It Notes, flip chart paper) and created a summary report for each focus group. Though no transcripts were created, the focus group facilitator captured key points directly from audio files and work products and shared them with another member of the research team that had been present at the focus groups to ensure no major points had been missed.

After the individual focus group reports were completed, the focus group facilitator consolidated the technology summaries from each individual focus group report. The facilitator reviewed the consolidated findings for each technology and identified common themes. Table 1 is a listing of each technology and the themes that arose about that technology in at least two of the three focus groups. For instance, in regards to the App, at least two of the three focus groups discussed accessibility, privacy/security, and accuracy. Though issues mentioned in at least one focus group are not listed in Table 1, they are presented in the findings.

Findings

Table 9-1 lists each technology and the themes that were mentioned in at least two of the three focus groups. The themes are listed in the table in order of frequency. For instance, Accessibility and Technical Issues were themes that arose under five of the eight technologies. A description of the themes under each technology is provided below the table.

2 Kruger, R. A. Focus Group Interviewing. Retrieved May 9, 2014, from http://www.tc.umn.edu/~rkrueger/focus_analysis.html



Transit Bus Routing On-Demand: Developing an Energy-Saving System

TABLE 9-1 TECHNOLOGY THEMES

	APP	BT4U	CAMERA	HOKIE PASSPORT	KIOSK	RFID	THUMB SCANNER	WI-FI/ BLUETOOTH
ACCESSIBILITY	✓	✓	✓	✓				✓
TECHNICAL ISSUES		✓	✓		✓		✓	✓
PRIVACY/SECURITY	✓		✓				✓	✓
COST			✓		✓			✓
SPEED		✓		✓			✓	
LIKELIHOOD OF USAGE					✓	✓		
MISUSE					✓		✓	
VANDALISM			✓		✓			
ACCURACY	✓							
CONVENIENCE				✓				
EDUCATION			✓					
HYGIENE							✓	
LOGISTICAL ISSUES						✓		

**Themes are noted in this table if they arose in at least two focus groups.*

App

When discussing the App, the themes of accessibility, accuracy, and privacy/security arose in at least two of the three focus groups. In terms of accessibility, participants discussed how the App needs to be multi-platform and compatible with various smartphones. Another accessibility issue raised was the need for alternatives to the App (such as BT4U) for people without a smartphone. Accuracy was also discussed; participants said the App should be as accurate and updated/real-time as possible. Participants said they want a simple App that tells them which bus is coming and when it will arrive. Finally, privacy/security was mentioned; participants want a check-in feature on the App because they would prefer checking-in to being tracked. At least one participant mentioned liking the App because users can have their own private access versus needing to share with others.

There were several other themes raised about the App in at least one focus group including education, cost, advertising, technical issues, and usefulness. Participants mentioned that education would be required because they were unsure how the app works and wondered if it is quicker than current technologies such as text. Costs were described by participants in terms of cost in time to understand how to use the technology and cost in upgrading a phone service to use the App. Advertising was seen as important so users don't confuse a 3rd party App with the Blacksburg Transit App. Technically, the issue was raised that the App might not help with counting riders. Finally, it was mentioned that the App would be useful if people had a smartphone.

BT4U

Several themes about BT4U arose in at least two focus groups including technical issues, speed, and accessibility. Participants raised a variety of technical issues including BT4U sometimes has glitches and bugs, it freezes up, it can stop working at night, it may be off a few minutes on arrival time, and users have to listen to the BT4U message each time even if they know the number they want to punch. In terms of speed, it



Transit Bus Routing On-Demand: Developing an Energy-Saving System

was mentioned that BT4U is easy and quick to read and that it is immediate when a user texts during low traffic times but can be slow during high traffic times. Participants also discussed how BT4U is accessible. They like that it is multi-platform (i.e., access by text or phone), that it is already available, and that it is a nice option as opposed to having to call someone to get a schedule. Another issue raised about accessibility is that using BT4U can be a problem if you don't know the stops.

Other themes mentioned in at least one focus group included helpfulness, efficiency, cost, and suggested upgrades. Participants mentioned that BT4U provides helpful information on routes and bus locations and is efficient if you know your stops. In terms of cost, at least one participant thought BT4U was more practical and cheaper than other technologies discussed. Several upgrades to BT4U were suggested including having a text alert system to alert people when a schedule changes due to holidays, weekends, or weather and the ability to allow people to opt for alerts based on routes/times.

Camera

Regarding the cameras, many themes arose in the focus groups including accessibility, technical issues, education, vandalism, privacy/security, and cost. In terms of accessibility, the participants discussed how users do not need to do anything or have anything to be counted by the camera; they just need to show up. Technically, participants were unsure how the camera worked and wondered if it would count people accurately. For instance, participants asked if the camera would count people walking or jogging by the bus stop. In a related way, the theme of education was discussed. Participants said that Blacksburg Transit would need to explain how the cameras work and clarify their purpose because people would wonder why a camera is at the bus stop. At least one participant commented that the camera might be confused as something that is adding security, which could be problematic if that is not the intent of the camera system. Concerns over vandalism were raised during the focus groups. Participants thought the cameras might be vandalized and that such damage could affect service reliability and thus create uncertainty for users. Another concern was privacy/security. Participants commented that the camera could be hacked and that they don't like being watched. At least one participant commented that cameras at the Blacksburg Transit stops would be "creepy." Other participants liked the idea of cameras for security reasons and researchers had to point out that security was not an intended purpose of the potential camera system. The issue of cost was raised by participants though there was some disagreement on whether or not the cameras would be more or less expensive than other technologies. They also wondered if technologies such as the cameras would raise their tuition/fees. At least one participant indicated that s/he would be against the implementation of technology that notably raised costs for users.

In at least one focus group, the theme of feedback was mentioned. Feedback was described as providing users with some indication that the camera had registered their presence at the bus stop.

Hokie Passport

Several themes about the Hokie Passport were raised in at least two focus groups including accessibility, convenience, and speed. In terms of accessibility, participants said that if Hokie Passports were used to count riders that there would need to be something for non-Virginia Tech users who didn't have a passport. Participants also discussed several issues regarding the convenience of the Hokie Passport. Users don't have to do anything (i.e., searching, reading) to use it. It would be easy and time efficient to use because riders already have it on hand. The Hokie Passport was described as fast and easy to use, you "just swipe." A related issue was speed. Participants stated a preference to scan a Hokie Passport at the bus stop instead of inside the bus so riders don't have to wait to board. A related comment from at least one participant was that scanning a Hokie Passport would be faster and preferable to sliding it.

Other themes raised in at least one focus group include education, technical issues, and privacy/security. It was mentioned that education will be needed to help people understand that scanning their Hokie Passport will make the bus come quicker, otherwise people will assume someone else already scanned a passport and the bus is coming. The related technical issue of how to ensure that people are using the technology was mentioned. In terms of privacy/security, participants discussed how they like that the Hokie Passport is an impersonal and non-invasive way to count users at a bus stop.

Kiosk

In at least two focus groups the themes of cost, technical issues, misuse, vandalism, and likelihood of usage were raised during the discussion of kiosks. In terms of cost, a few participants said kiosks seemed expensive and users wouldn't want bus fees to go up. Another participant thought software, internet connections, and electricity would all be expensive for kiosks. Technically, users said kiosks seemed like outdated



Transit Bus Routing On-Demand: Developing an Energy-Saving System

technology that could be damaged (e.g., weather, vandalism). It was suggested that there are smarter ways to implement the same type of system (i.e., Smartphone). Participants discussed the need to prevent misuse and vandalism of the kiosks. Misuse was described as people not checking-in or checking-in multiple times to speed up the bus. Vandalism was mentioned as a potential threat to the kiosks and participants thought vandalism could affect service reliability. Finally, participants discussed the likelihood of usage of kiosks. Some said they would give it a shot if it were there, in particular on campus. Other participants said they would not use it because they wouldn't want to wait in line, they don't need it off campus, and/or because it might harbor germs.

Other themes that arose in at least one focus group included accessibility and ease of use. It was mentioned that kiosks are easy to read and that users could access the kiosk if they forgot or didn't want to bring other technology.

RFID

When discussing RFID, the themes likelihood of usage and logistical issues came up in at least two focus groups. Participants indicated that they were unlikely to carry another card and would not keep up with a keychain. Participants also raised logistical concerns wondering how the RFID tags would be distributed to everyone (i.e., Virginia Tech and non-Virginia Tech users). RFID was thought by at least one participant to be an inefficient idea due to the logistical challenge of telling a large number of people to do it.

Other themes mentioned in at least one focus group included feedback, technical issues, education, convenience, and privacy/security. Participants said feedback would be necessary to let users know that they had been counted at a bus top. The related technical issue of how to ensure everyone is being counted was also mentioned. In addition, because some participants were unsure how RFID technology works and if it would replace Hokie Passport, Blacksburg Transit would likely need to conduct education/outreach when implementing RFID technology. Though some participants said they'd be unlikely to use the RFID, at least one participant said it would be easy to use RFID if it was on a keychain. A few participants raised the issue of privacy/security and said they didn't like the idea of being tracked and would want the RFID minimally linked with identity information.

Thumb Scanner

Several themes emerged in at least two focus groups for the thumb scanner including hygiene, speed, technical issues, security, and misuse. In terms of hygiene, some participants didn't like the idea of touching the thumb scanner as it could harbor germs. Participants also raised the issue of speed, saying they didn't want to wait in line to scan their thumb. Technically, some participants had used thumb scanners before and said they didn't always work or didn't work well. In terms of security, participants were concerned about security breaches, hackers, and identity theft. Finally, participants thought that some people might misuse the thumb scanner by scanning their finger repetitively. For example, at least one participant suggested that users might try to scan multiple fingers to speed up the bus.

In at least one focus group, participants raised the themes of education, feedback, convenience, and likelihood of usage. In terms of education, participants said Blacksburg Transit would need to explain how the scanner works and assure people that it is non-invasive. Participants also raised the issue of feedback, saying that Blacksburg Transit will need to assure people that they are aware that someone is waiting at the stop after checking-in at the thumb scanner. In at least one focus group, participants said they wouldn't use it and thought it was creepy.

Wi-Fi/Bluetooth

During at least two of the three focus groups, the themes of cost, security/privacy, accessibility, and technical issues were raised for the Wi-Fi/Bluetooth. Participants were concerned about a variety of cost related issues including the cost in time to understand how to use the technology, the cost of upgrading current service, the cost of the reader/software itself, and potential costs to implement the technology. Participants also discussed privacy/security issues related to the Wi-Fi/Bluetooth. Some participants felt it was non-invasive; a technology that is just counting users, while some participants thought it was a security concern due to potential hacking. In terms of accessibility, some participants raised the issue that not all Blacksburg Transit riders have a smart phone/Wi-Fi/Bluetooth so even if it is a good idea not everyone would be counted. Finally, several technical issues were raised for the Wi-Fi/Bluetooth reader including the ability of users to decline tracking, the ability of users to turn it off, and the technical concern that leaving the Wi-Fi/Bluetooth on can cause battery drain. At least one participant also mentioned that s/he would rather have an active check-in system rather than just having something that draws information from users, an issue that could also fall under security/privacy.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Bus stop observation

TABLE 9-2 BUS STOP OBSERVATION — STOPS AND OBSERVATION TIMES

STOP #	STOP NAME	ROUTE	HEADWAY (MIN)	TIME CHECK STOP*	ARRIVAL TIME STANDARD DEV. (MIN)	DAYS	TIMES	HOURS/ DAY	HOURS WATCHED	BUS ARRIVALS	DATES (DEC 2013- JUNE 2014)
1707	Pratt/Kraft Wbnd	CRC	15	Yes	01:48.5	M-F	7:15am-6:30pm	11.5	40.25	161	4/22-4/25
1707	Pratt/Kraft Wbnd	CRC	30	Yes	01:48.5	M-F	7:30pm-9:30pm	2.5	2	4	4/22-4/23
1715	Kraft/Moss Bldg Sbnd	CRC/Hospital	60	No		M-F	7:20am-6:20pm	11	57	57	5/28-5/30, 6/13, 6/16-6/18
1211	Tall Oaks/ Copper Croft Nbnd	Hethwood	30	Yes	01:30.3	M-F	7am-6:30pm	11.5	36	72	6/18-6/20, 6/23
1216	Prices Fork/ Plantation Ebnd	Hethwood	30	No	01:40.6	F-Sat	10pm-2:30am	5	10	20	5/9-5/10
1211	Tall Oaks/ Copper Croft Nbnd	Hethwood	60	Yes	01:30.3	M-Th	10:30pm-12:30am	3		45.5	
						Sat	9:30am-9:30pm	13	11.5		4/19
						Sun	11:30am-10:30pm	12	19		4/20, 5/4
						M-F	6:30pm-9:30pm	3	6		6/19, 6/20
						Sat	9:30am-6:30pm	9	9		6/21
1216	Prices Fork/ Plantation Ebnd	Hethwood	60	No	01:40.6	M-Th	10:30pm-12:30am	3		12	
						Sun	11:30am-10:30pm	12	12		5/11
1208	Tall Oaks/ Foxtrail Sbnd	Hethwood A	10	No	02:50.4	M-F	7:30am-6:10pm	10.8	10.5	63	12/17-12/19, 3/6,3/7
1210	Tall Oaks/ Foxridge Nbnd	Hethwood A	10	Yes	01:58.2	M-F	7am-6:10pm	11.3	10.75	64.5	12/17-12/19, 3/6,3/7
1211	Tall Oaks/ Copper Croft Nbnd	Hethwood A	10	Yes	01:58.8	M-F	7am-6:10pm	11.3	35	210	4/18, 4/21, 5/2, 5/5, 5/6
1211	Tall Oaks/ Copper Croft Nbnd	Hethwood A	30	Yes	01:58.8	M-F	7:30pm-9:30pm	3	3.5	7	4/18, 5/2
1206	Tall Oaks/ Foxhunt Ebnd	Hethwood B	15	Yes	01:49.8	M-F	7am-6:30pm	12	22.5	90	12/10-12/11, 12/13, 5/14-5/15
1206	Tall Oaks/ Foxhunt Ebnd	Hethwood B	30	Yes	01:49.8	M-F	6:30pm-9:30pm	3	2.5	5	5/14
1216	Prices Fork/ Plantation Ebnd	Hethwood A, B	0-10			M-F	7am-6:15pm	11.5	14.67	146.7	5/6, 5/9, 5/12
1216	Prices Fork/ Plantation Ebnd	Hethwood A, B	30 (x2)	No		M-F	7:30pm-9:30pm	2.5	5	10	5/9, 5/12

*Time check stops are those at or immediately following time checks, where the standard deviation of bus arrivals is very small.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Passenger Arrival vs. Time to Average Bus Arrival and Headway

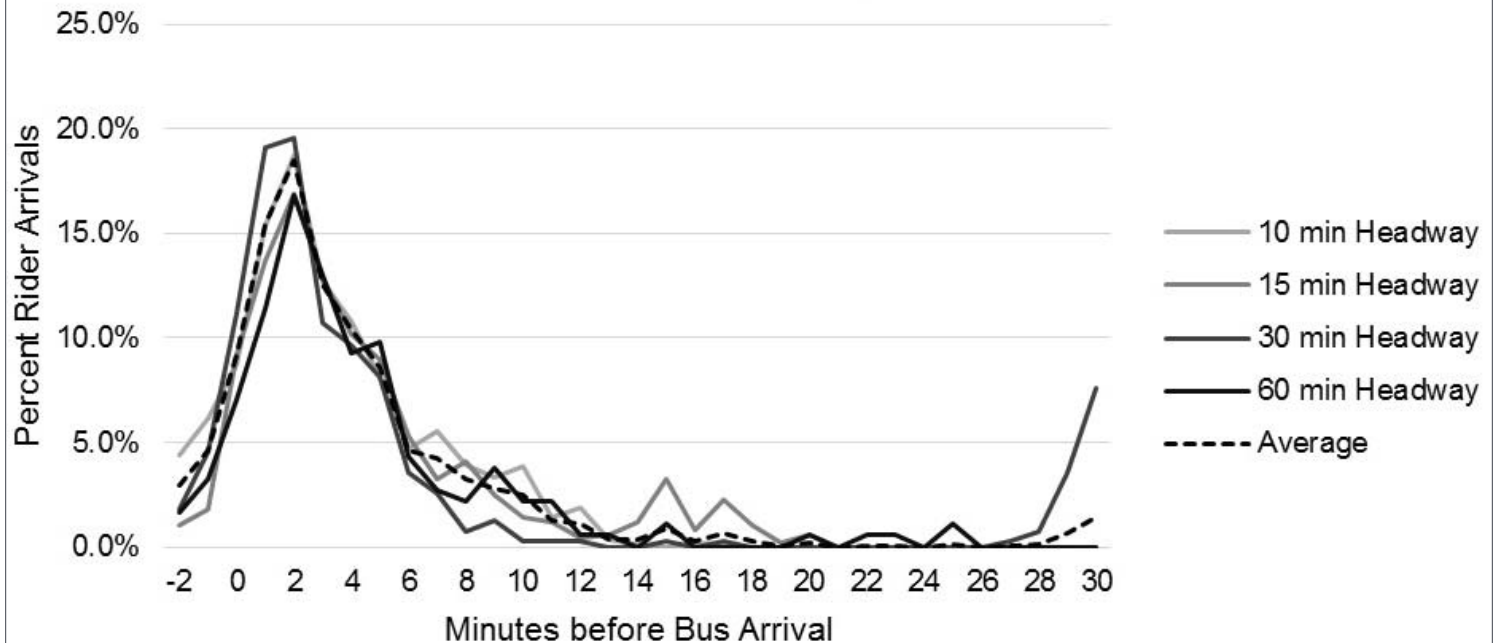


FIGURE 9-2 PASSENGER ARRIVAL RATE COMPARISON BY HEADWAY

Passenger Arrival vs. Time to Average Bus Arrival and Route for Stops with 15 min Headway

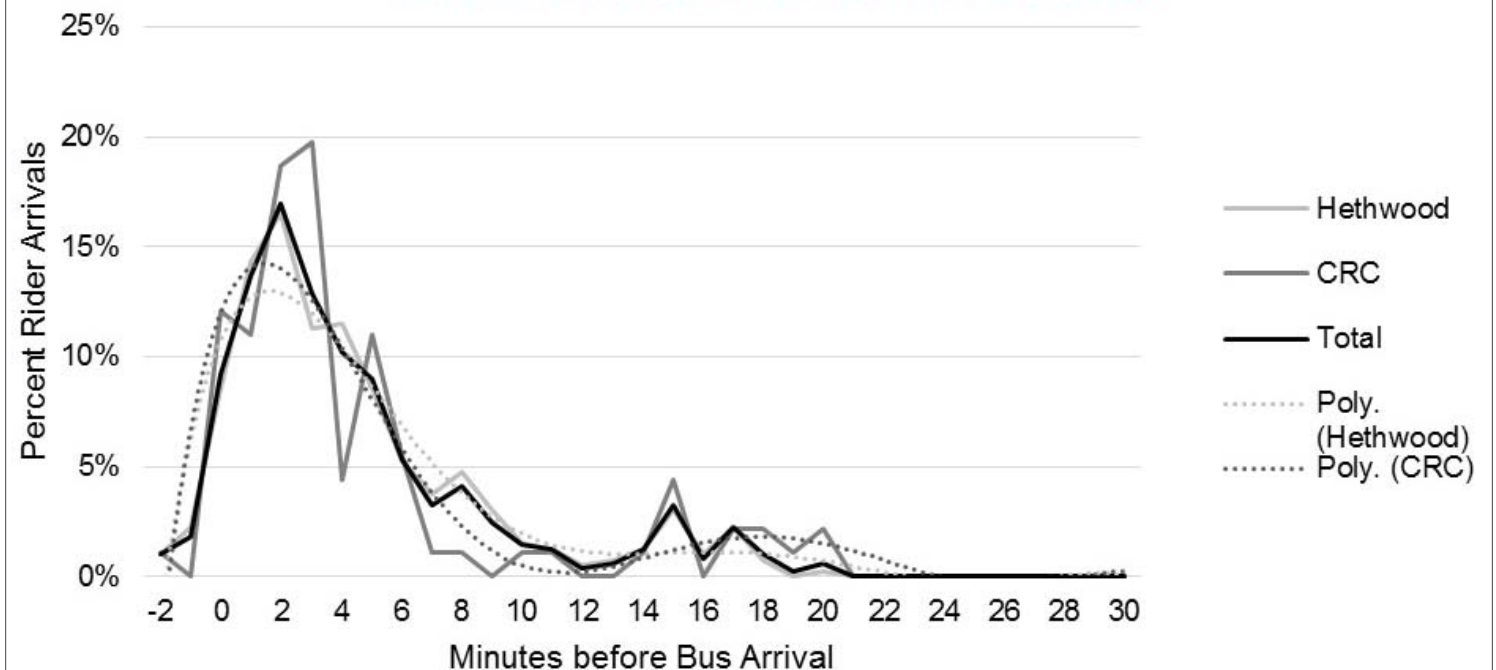


FIGURE 9-3 PASSENGER ARRIVAL RATE COMPARISON BY ROUTE FOR STOPS WITH 15 MIN HEADWAY



Transit Bus Routing On-Demand: Developing an Energy-Saving System

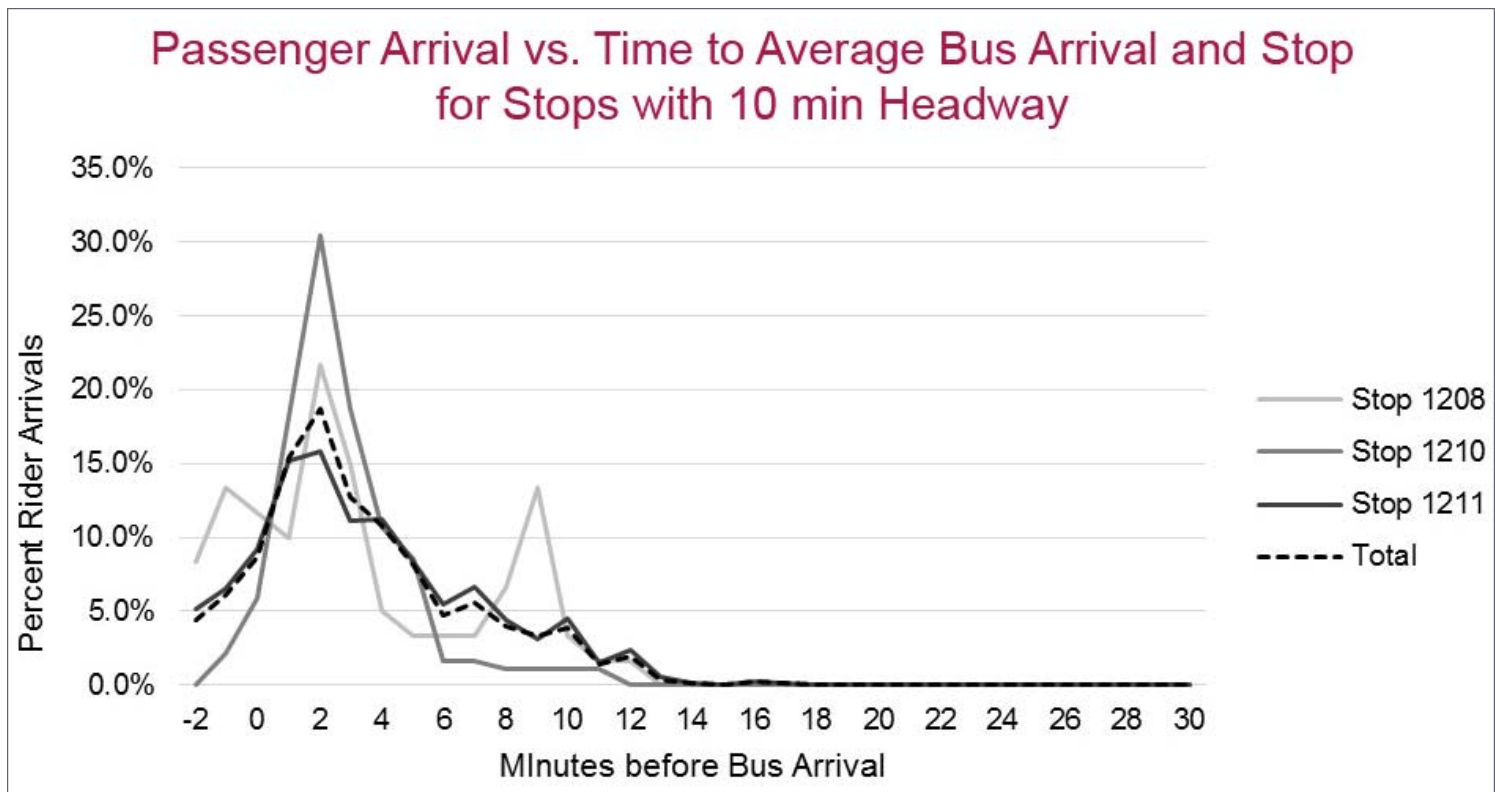


FIGURE 9-4 PASSENGER ARRIVAL RATE COMPARISON BY STOP FOR STOPS WITH 10 MIN HEADWAY



Transit Bus Routing On-Demand: Developing an Energy-Saving System

BT4U website description of technology

History of BT4U

In the mid-1990s, Blacksburg Transit received funding to develop AVLGPS systems on vehicles. The goal then was to have information for dispatching and reporting, and ultimately to share the information with riders. Virginia Tech’s Student Government Association later asked for a bus tracking system, and Blacksburg Transit introduced BT4U in February of 2011 as a website and texting engine. The webmap was added later, in May 2013. The current system has three channels, interactive voice, text and web.

BT4U Classic, web version description and functionality

Select the route name and stop code from the drop down menus.

Click “Submit” and the next three stop times are displayed.

The screenshot shows the BT4U website interface. At the top is the BT4U logo. Below it, the text reads: "To find the departure time of the next bus enter in:". There are two dropdown menus: "Route Name:" with "--Select-" and "Stop Code:". Below these is a "Submit" button. At the bottom, there are links: "BT4U Live Map | BT4U Help | BT4U FAQ | How to Find a Stop Code" and a footer: "Blacksburg Transit All Rights Reserved..."

FIGURE 9-5 BT4U WEBSITE SCREENSHOT, SETTING ROUTE NAME AND STOP CODE

This screenshot shows the BT4U website after the "Submit" button was clicked. The "Route Name:" dropdown now shows "HWD - Hethw" and the "Stop Code:" dropdown shows "1206 - Tall O". The "Submit" button is still present. Below the input fields, three rows of information are displayed, each containing: "Pattern Name: Hethwood", "Stop Name: Tall Oaks/Foxhunt Ebnd", and "Estimated Departure Time: 4:26 PM", "4:56 PM", and "5:27 PM" respectively. At the bottom, the same links and footer as in Figure 9-5 are visible.

FIGURE 9-6 BT4U WEBSITE SCREENSHOT, STOP TIMES DISPLAYED



Transit Bus Routing On-Demand: Developing an Energy-Saving System

BT4U LiveMap, Web Version

Select the route using the check box.

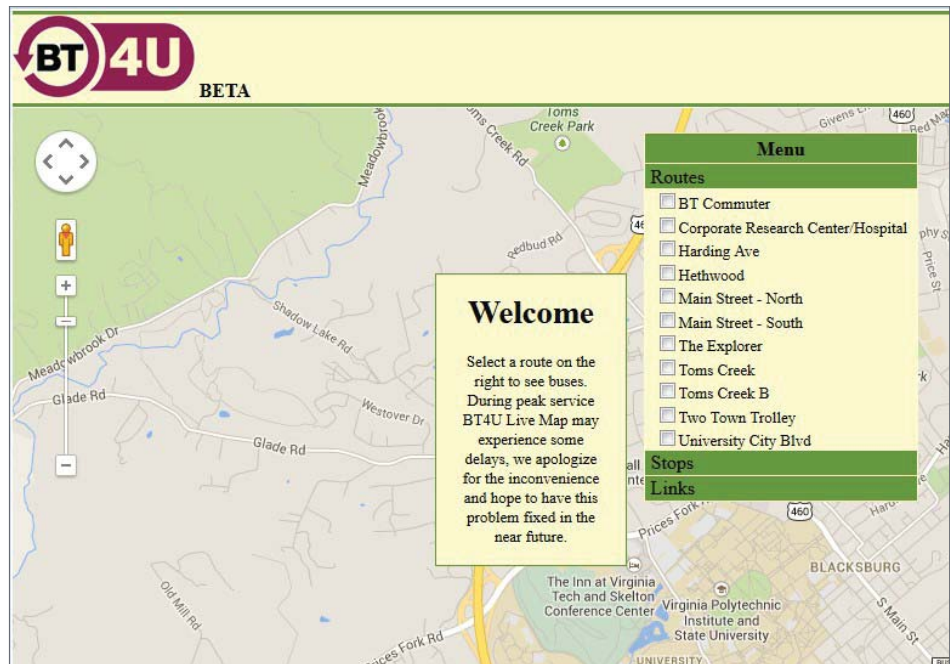


FIGURE 9-7 BT4U WEBSITE LIVEMap, WELCOME PAGE

Then select the stop using either the check boxes, or by clicking the bus image on the map.

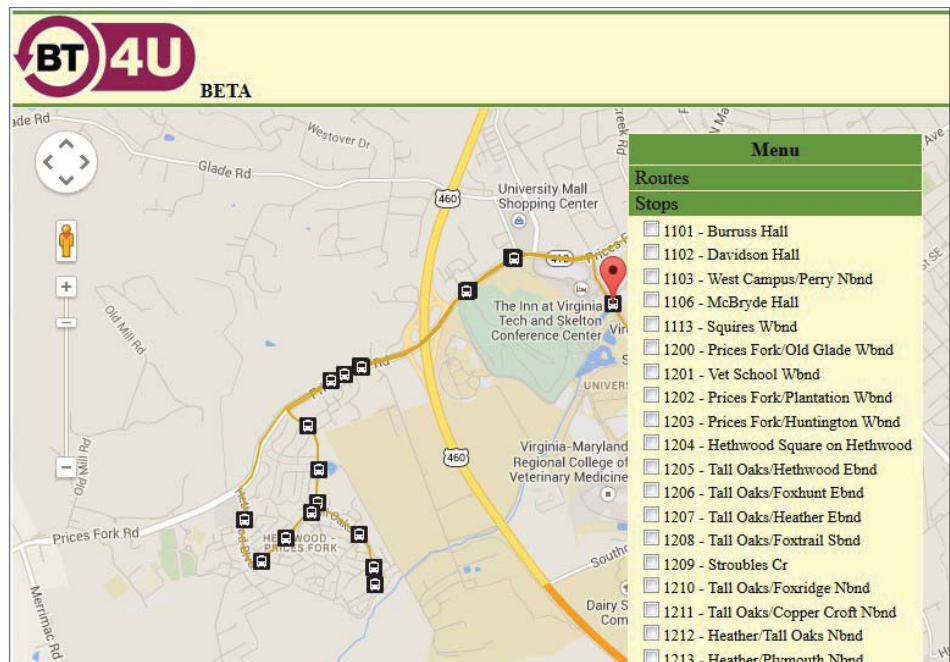


FIGURE 9-8 BT4U WEBSITE LIVEMap, BUS STOP DISPLAY



Transit Bus Routing On-Demand: Developing an Energy-Saving System

The next three bus departure times will be shown in a pop-up window pointing to the bus stop.

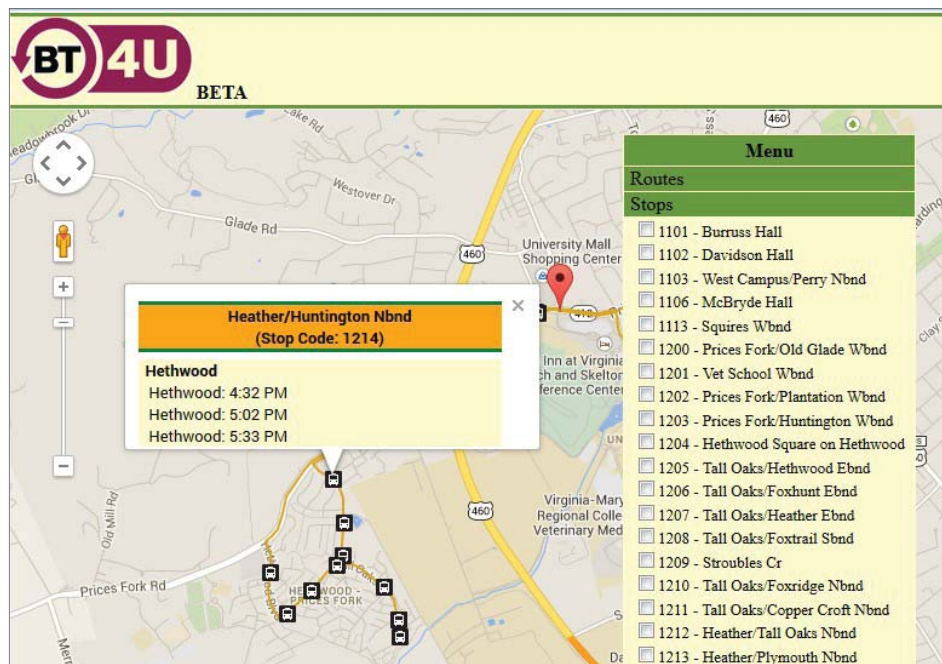


FIGURE 9-9 BT4U WEBSITE LIVEMAP, BUS STOP DETAILS POPUP

BT4U mobile application

BT4U mobile app RFP

1. Scope of work

This RFP is seeking qualified bidders for the development of a mobile application for Blacksburg Transit. The mobile application shall be an extension of the existing BT4U (<http://bt4u.org/>) service and is intended to serve as an additional source of transit traveler information.

The developer shall design a mobile application that provides transit riders with a simple, easy to use interface. At its core the mobile application shall be able to inform riders: where the nearest bus stops are to their current location, route information, schedule information, additional bus passenger capacity, when the next bus(es) will be arriving and allow riders to plan trips. The mobile application shall utilize Google's existing Directions API for trip planning. The mobile application shall feature an adaptive learning module which is integrated with the trip planning module which will identify an individual's trip patterns and make trip recommendations for the most optimal route and schedule.

In addition to the core functionality the mobile application shall feature the ability to collect information on ridership data to satisfy TIGGER grant research. The mobile application shall feature the ability of riders to report on the status of buses, how full they are, if something is broken and will also allow riders to submit photos of problems. The mobile application shall feature the ability to tie static advertisements on the bus, area wide advertising campaigns, locations along the bus route and locations at the destination to mobile application advertisements. The mobile application shall feature gamification, the ability of the rider to earn badges, points, and/or credits for accomplishing tasks. I.e. a rider would receive a badge if they rode the bus every day for a month.

An Android and iOS mobile application shall be developed for the latest version of each mobile operating system. The mobile application shall also be backwards compatible with Android and iOS operating systems going back two years. The mobile application shall be developed, tested, listed on mobile market places and hosted by the developer. The developer shall list the mobile application on the Google Play and Apple App store.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

2. Requirements

Types of Requirements;

B = Basic Requirement

E = Enhanced Requirement

REQUIREMENT	TYPE OF REQUIREMENT
The developer shall create a real-time transit information and interactive mobile application.	B
<p>The developer shall create a version of the application for Android and iOS compatible mobile devices. The application shall be compatible with the following Android versions:</p> <ul style="list-style-type: none"> • 4.3 • 4.2.x • 4.1.x • 4.0.3-4.0.4 • 3.2 • 3.1 • 2.3.3-2.3.7 <p>The application shall be compatible with the following iOS versions:</p> <ul style="list-style-type: none"> • 7.0 • 6.1.4 • 6.1.3 • 4.2.1 • 3.1.3 	B
The developer shall provide a non-exclusive perpetual license to Blacksburg Transit for all software. All third party software shall be purchased in such a way that Blacksburg Transit is the original registered owner and licensee.	B
The developer shall arrange a source code escrow agreement with a certified escrow agent located in the United States and approved by Blacksburg Transit. The escrow agreement shall allow Blacksburg Transit to have access to the software held in escrow if the developer becomes insolvent, ends support for the application or fails to remedy application failures required under the contract, including warranty or under any subsequent application maintenance agreement. The developer shall pay all initial and on-going fees associated with the escrow account until termination of the contractor.	B
The developer shall host the service off site and shall provide three (3) years of technical support, hosting, and updates.	B
The vendor shall provide help desk support for Blacksburg Transit staff with help desk staff available from 9:00 AM EST to 5:00 PM EST Monday through Friday excluding Blacksburg Transit observed holidays.	B
The developer shall provide remote support capabilities and shall support software updates.	B
The developer shall include a minimum of three mobile application updates (three updates for iOS and three updates for Android) to make the mobile application compatible with new versions of the iOS and Android platforms.	B



Transit Bus Routing On-Demand: Developing an Energy-Saving System

REQUIREMENT	TYPE OF REQUIREMENT
The mobile application and the off site hosting service shall feature 99.99 percent availability.	B
The developer shall be responsible to make the mobile application available for download from the Apple App store and the Google Play store. The iOS and Android application must be accepted and approved by the Apple App and Google Play stores. The project shall not be considered complete until both applications are available for download on the Google Play and Apple App Store.	B
The developer shall be responsible for maintaining access to the mobile application in the Google Play and Apple App stores during the three (3) years of technical support.	
The developer shall work with the Blacksburg Transit web developer to make the app available for download from www.btransit.org/ and www.bt4u.org/	B
The mobile application shall pull bus location, route, alerts and schedule information from the Blacksburg Transit servers.	B
The mobile application shall pull bus location data once per 10 seconds and show the moving location of the bus on a map interface. The application shall add no more than 1 second of delay for processing and posting of the real-time data received from BT4U.	B
The mobile application shall check the BT4U system for schedule changes and alerts once per 10 seconds for updates to scheduled arrival times, departure times, and alerts on the mobile application.	B
The mobile application shall be capable of processing General Transit Feed Specification (GTFS) feeds from the 4 regional transit partners. These include Valley Metro, Radford Transit, Polaski Area Transit, and Megabus. The mobile application shall be capable of posting partner agency GTFS data to the user interface in a manner consistent with BT data processing. The mobile application shall be capable of supporting the above listed transit partners as well as 6 additional transit partners in the future.	
The mobile application shall follow the same color scheme as BT4U.	B
The mobile application shall have a trip planner that utilizes the Google Directions API that allows users to plan transit trips.	B
The mobile application shall be capable of collecting the user device location information and transmitting to the BT4U system on a time basis that conserves data transmission and mobile device battery usage as much as possible yet allows for accurate data collection for Blacksburg Transit.	B
The mobile application shall intuitively display the following static information: <ul style="list-style-type: none"> • Fares and pass information • Customer service information and contact information • Static schedules • Tips for riding the bus 	B
The mobile application shall show departure times from transit stops specified by the user and from the nearest stop to the user's current location.	B



Transit Bus Routing On-Demand: Developing an Energy-Saving System

REQUIREMENT	TYPE OF REQUIREMENT
The mobile application shall show bus location and bus routes on a map	B
The mobile application shall show the bus route on a map interface simultaneously with the bus location.	B
The mobile application shall show bus departure times on the map interface when the user selects a stop location on the map.	B
The mobile application shall show arrival times with countdown clocks on when the bus will arrive.	B
The mobile application shall show real-time information on capacity of vehicles and the available capacity of vehicles.	B
The mobile application shall display Blacksburg Transit customizable alerts	B
The mobile application shall allow the user to save a list of favorite stops and routes. The lists shall be easily accessible.	B
The mobile application shall allow Blacksburg Transit to post information related to inclement weather, detours, or special events along with schedule and route information. Blacksburg Transit shall be capable of pushing these updates to the mobile application through BT4U and shall be capable of manually posting information through the mobile application back-end access portal.	
The mobile application shall feature a user configurable audible announcement or alert for the next stop and/or the user's destination stop.	B
The mobile application shall allow the user to earn badges, credits or points and a status based on ride statistics.	E
The mobile application shall recognize bus statistics and correlate that to specific users to automatically log badges, credits or points.	E
The mobile application shall allow the user to share announcements about badges credits or points using social media integration in the mobile application. At a minimum the mobile application shall be integrated with the following social medial platforms: <ul style="list-style-type: none"> • Facebook • Twitter • Google+ 	E
The mobile application shall remember route patterns without user interaction and shall make recommendations based on travel patterns for optimal routes.	E
The mobile application shall allow the user to input their class schedule for the trip planner to optimize route selection and customize alerts.	E
The mobile application shall allow the user to save a list of favorite locations, stops and buildings and the application shall utilize these locations to better manage trip planning and route selection.	E



Transit Bus Routing On-Demand: Developing an Energy-Saving System

REQUIREMENT	TYPE OF REQUIREMENT
The mobile application shall recognize when and where a user gets on and off a bus based on user GPS location data and bus GPS location data.	E
The mobile application shall feature an anonymous tracker that shall be optimized to use minimal battery power. The tracking information shall be sent to the back-end application for query by administrators for planning purposes and to be inputted into the adaptive learning module.	E
The mobile application shall allow users to turn on Bluetooth to be discoverable to facilitate data collection.	E
The mobile application shall be able to recognize when users are on vehicles with specific advertising.	E
The back-end system shall feature a web based interface that allows Blacksburg Transit staff to specify which type of advertising is on vehicles and link that advertising to mobile application advertising campaigns.	E
The mobile application shall allow users to scan QR codes on vehicles and tie that with coupons.	E
All advertising revenue shall be for Blacksburg Transit. The developer is not entitled to any advertising revenue.	E
<p>The mobile application shall allow the user to report with buttons, messages and/or a photo:</p> <ul style="list-style-type: none"> • Late buses • Early buses • Crowded buses • Empty buses • Vandalism • Graffiti • Dangerous or unsafe driving • Cleanliness <p>The hosted application would process this information and send as an email to a Blacksburg Transit representative. The application should have the capability of sending the email notifications to up to 20 different users and the types of emails sent to each user should be customizable based upon responsibilities.</p>	E
The mobile application shall allow users the ability to provide recommendations for the system.	E
The mobile application shall allow users to share information with other users in real-time about status of buses, stops and specific routes.	E
The application shall feature a back-end password protected, browser based interface for administrative purposes and mobile application usage statistics and queries.	B
The application shall collect mobile application usage statistics that are location based. The data shall be stored on a password protected server in CSV format. The data shall be accessed through a password protected browser based interface that allows administrators to run queries on the data. Individual user information shall be scrubbed of any traceable information and made anonymous prior to being stored on the server.	B
The back-end of the application shall allow Blacksburg Transit staff to run reports on how many mobile users are using the application on a particular bus, stop or route.	B



Transit Bus Routing On-Demand: Developing an Energy-Saving System

3. Mobile Application Use Case Scenario

The following narrative illustrates the desired functionality of the mobile application through a use case scenario. The proposer shall review the narrative and answer the questions below.

Meredith is a 3rd year VT student living in Foxridge apartments serviced by the Hethwood route. This Tuesday she is up and watching the Today Show when her phone dings and she receives a notification that she has 10 minutes to get to the bus stop to catch the 8:40 Hethwood A bus to campus. The notification tells her that the bus is running on time and currently has 18 passengers with an expected passenger load of 65 percent when she boards at stop 1609. She gathers her belongings and heads to the bus stop, when she gets within 30 meters of the bus stop the applications checks the arrival times and dings to let her know that the bus is now 2 minutes late and the expected passenger load is 85 percent of capacity. Since Meredith is one of 5 passengers at the stop using the application the backend systems at BT predicts that Meredith is one of 18 passengers waiting at this stop. Since 18 additional passengers will place the bus over capacity, the BT dispatcher is notified to send a tripper to pick up the passengers missed by the route bus.

Meredith is in luck since she is near the front of the line and is able to get on the bus. Once the bus starts moving the application dings and asks if she is willing to turn on the anonymous tracking part of the application to provide information for the TIGGER project. She clicks the yes button and is surprised when the phone dings again and tells her that she just received a badge for tracking her 50th trip, and asks her if would she like to share that on Facebook.

After her day has finished, Meredith is ready to head home. She turns on the application, and receives a notification that her typical bus is running late. The application tells her that due to low passenger demand in Foxridge, the bus will pause momentarily to wait for an increase in passenger demand before beginning to circulate again. The application also tells her this is saving CO2 emissions.

Meredith's bus arrives at her stop; the bus is wrapped with a Hardee's advertisement. Once Meredith is on the bus a message pops up alerting her to a coupon offer from Hardee's. As Meredith is getting off the bus, she notices trash left under the seats and sends a report with the app.

Once Meredith is off the bus she switches off the app, and her trips and experiences are recorded:

- 3.1. Provide an explanation of how you would incorporate gamification into the mobile application and how the user would interact with the system.
- 3.2. Provide an explanation of how you would provide CO2 reduction notifications to mobile users based on schedule or route changes.
- 3.3. Provide an explanation on how you would incorporate on-bus static advertising and location based advertising with the mobile application.
- 3.4. Provide examples of how you have incorporated gamification into other mobile applications.
- 3.5. Provide an explanation of how you would collect crowd sourced information and how you would utilize that information for a better ride experience.
- 3.6. Provide an explanation on how you would incorporate a user's class schedule into the learning algorithm.
- 3.7. Provide an explanation on how you would encourage mobile users to activate Bluetooth/GPS/WI-FI on their mobile device so that Blacksburg Transit can better track ridership.
- 3.8. Describe how the mobile application would handle an appropriate amount of alerts so as to not overwhelm the user.
- 3.9. Provide visual examples of the main components/pages/menus in the mobile application.
- 3.10. Provide ideas on how the Developer would make this mobile application appealing to users.
- 3.11. Provide a description of your plan for a convenient interface with the BT4U system. What are the most efficient method(s) of integration between the hosted solution and the BT4U system?
- 3.12. Provide an explanation of your expectations Blacksburg Transit staff. How often do you anticipate Blacksburg Transit staff to assist with technical troubleshooting or configuration?
- 3.13. Provide a description of how your plan will minimize battery and CPU usage.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

4. Developer Information

The developer shall provide information for the following questions:

- 4.1. Describe any past experience the developer has with transit and mapping mobile application development.
- 4.2. Describe your project team and provide resumes for key team members.
- 4.3. Where is your project team/company located?
- 4.4. Describe your technical support environment and staff.

5. Cost Proposal

The developer offers to furnish to Blacksburg Transit all goods and/or services at the prices as proposed below, pursuant to all requirements, terms, and conditions as stated in the RFP and response. Support Services shall include three (3) years of technical support, mobile application and back-end application updates support and hosting.

Alternative pricing schemes may be proposed provided that they are in addition to a base proposal.

Provide firm-fixed price proposals for each of the following:

REQUIREMENT	COST
Base Requirements	
Feature Set 1 — Gamification	
Feature Set 2 — Adaptive Learning	
Feature Set 3 — Advertising	
Feature Set 4 — Crowd Sourced Information	
Support Services	

6. Schedule

The developer shall complete the scope of based on the following schedule:

MILESTONE	DATE
Beta version delivered and available on Google Play and Apple App Store	01/06/2014
Final mobile application delivered and available on Google Play and Apple App store	03/10/2014



Transit Bus Routing On-Demand: Developing an Energy-Saving System

BT4U mobile app description and functionality

The BT4U mobile app can be installed for free on iOS and Android devices. When a user opens the app, the home screen has a section for the user to **Plan a Trip** by entering a start and end location. It also displays the nearest bus stop (if the location detection is enabled) and that stop's next few bus arrival times. The home screen is shown in Figure 9-10. Four options appear at the bottom of the home screen: **Routes & Schedules** (Figure 9-11), which where users can select a route to display its stops and bus arrival times; **Go Home!** (Figure 9-11), where users enter their home address, and the app will detect their current position and present them with transit options to get home; **Visitors** (Figure 9-11), which displays Blacksburg Transit's fare information; and **Using BT & the App**, which provides information about Blacksburg Transit's mission and services.

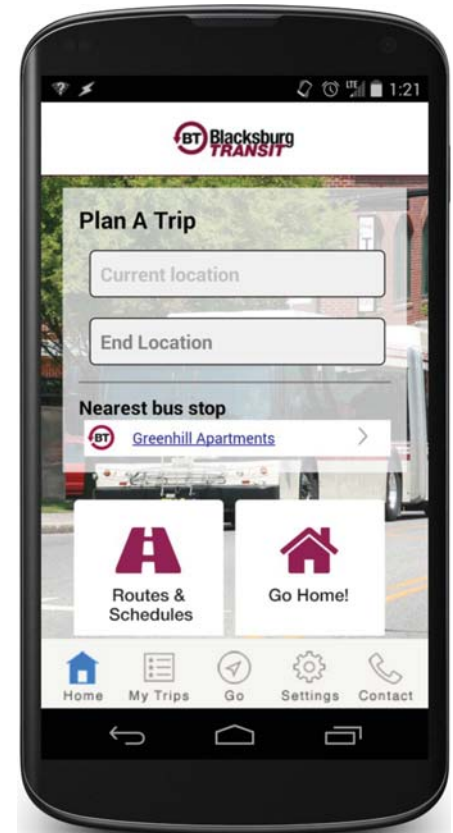


FIGURE 9-10 BT4U MOBILE APP HOME SCREEN (APPENDIX)

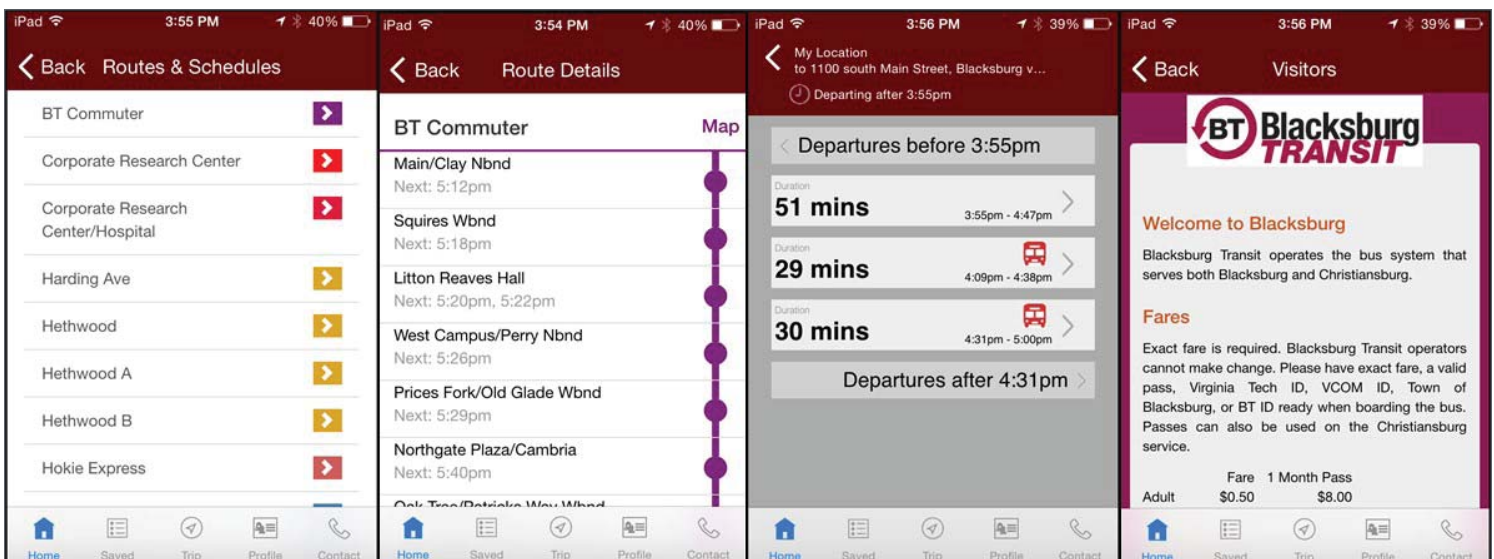


FIGURE 9-11 BT4U MOBILE APP SCREENS, FROM LEFT TO RIGHT: ROUTES AND SCHEDULES, ROUTE DETAILS, GO HOME!, AND VISITORS

When planning a trip, users click in the "Current location" and "End location" boxes, and are brought to a screen where they can either enter an address, select from recent locations, or select from a list of known locations in the Blacksburg area. When both current and destination locations are chosen, users can show bus schedules for if they "Go Now," or they can enter a departure or arrival time. Once timing option is selected, the app displays the next three bus arrival times based on that timing. The screens used for trip planning are shown in Figure 9-12.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

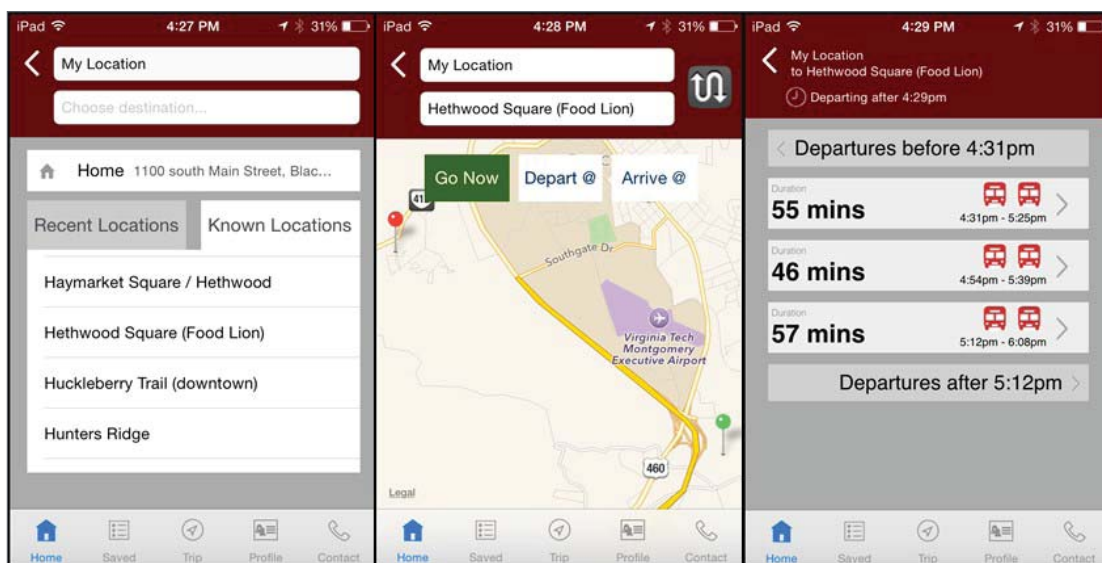


FIGURE 9-12 BT4U MOBILE APP SCREENS, FROM LEFT TO RIGHT: ENTERING LOCATION AND DESTINATION, SELECTING TIMING OPTION, AND BUS ARRIVAL TIMES

At the bottom of the app, users can access additional features from a menu. Choosing Saved brings users to the My Trips screen, where they can select from a list of prior destinations and trips, and which will take them to the screen where they select timing options before being shown bus departure times, as in the right screenshot of Figure 9-12. Choosing Trip brings users to the trip planning screen shown on the left of Figure 9-12. Selecting Profile brings users to a screen where they can enter and update their home address, used by the Go Home! function. Choosing Contact shows users Blacksburg Transit's phone number, email address and business address to allow users to easily give feedback regarding the mobile app and transit service (Figure 9-13).

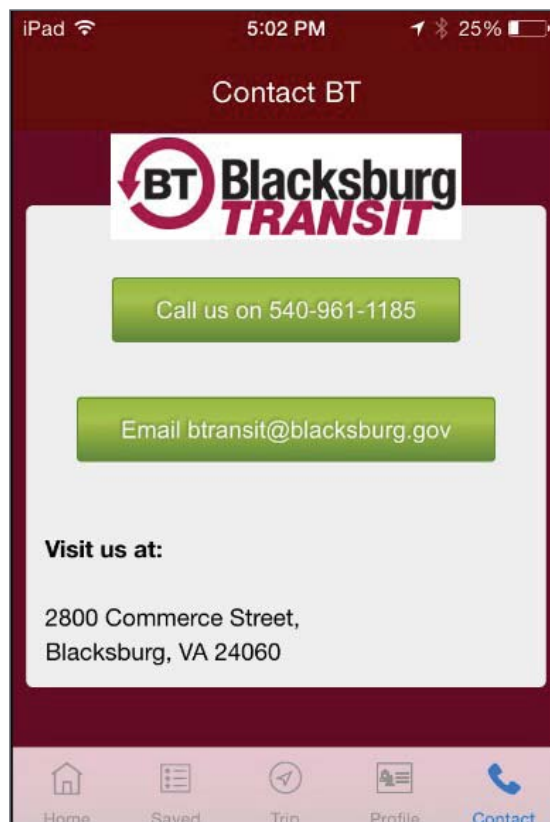


FIGURE 9-13 BT4U MOBILE APP SCREENS: CONTACT BT



Transit Bus Routing On-Demand: Developing an Energy-Saving System

iBeacons

Notes regarding iBeacons

For iBeacons at bus stops, if only a percentage of mobile apps detect iBeacons, the system could be calibrated with the passenger counts of riders alighting at that stop, the data from iBeacons could be used to estimate the demand at the stop.

For iBeacons on buses, distance traveled could also have been used to weed out non-passengers, but the team determined that a time period was sufficient.

Like smartphones, iBeacons have UUIDs, but they are grouped into families sharing a UUID number. iBeacon families typically have a hierarchy of major and minor numbers. For example, the UUID may be shared by all stores in a chain, with the major number identifying the store, and the minor identifying the department. Apps can register to detect all iBeacon devices in one or more UUID families, and potentially for major numbers within those UUID families. Apple iOS devices limit all apps on the device to a maximum of ten registered UUID families, so the UUID identifier design must use as few UUID families as possible. Another Apple limitation is that it will only report the loss of an iBeacon when it has lost all iBeacons sharing the same UUID. Android devices have no such limitations and build their own detection/loss logic; however, for this project, Apple limitations drove the mobile app design.

Each iBeacon in the system has a configuration for recognition time. The app will only report iBeacon events for an iBeacon if it is listed in the set of configured iBeacons. The iBeacon configuration is maintained centrally and downloaded to each device if and when it changes using our general purpose caching mechanism. Thus the apps can act autonomously even offline and report the iBeacon events when the device is next online and the app is still running. It is also possible for us to experiment with iBeacon configuration without app updates. As each iBeacon has a separate configuration, it is possible to conduct A/B differential type experiments.

Each event is recorded with the following data: the smart phone's anonymous and unique UUID, the device's session UUID, the event type, the iBeacon's UUID (major and minor), the smart phone's GPS position (if known), the time, the iBeacon type (bus stop or bus), and use of the iBeacon (bus stop or bus number).

The typical sequence of events for a rider boarding a bus at one stop and getting off another stop is:

1. Detect bus stop iBeacon
2. Recognize bus stop iBeacon after user has waited long enough
3. Detect a bus iBeacon when boarding the bus
4. Recognize bus iBeacon after user has ridden the bus long enough
5. Loss of bus stop iBeacon as bus moves away from the bus stop
6. Detect bus stop iBeacon at the destination bus stop when rider gets off the bus
7. Loss of bus iBeacon as bus moves away from the bus stop and rider
8. Loss of bus stop iBeacon when rider walks away from the bus stop



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Demand-assessment algorithm

Clean data

- 1) Filter Data by Week, DOW, Route, Stop, & TripName.
 - a) There may be correlation between Routes, Stops, and TripNames but not Weeks.
 - b) Total Fare, Alight Count, or Board Count
 - c) Consider excluding route dependent on: stop & potential destination
- 2) Make adjustments to Week #'s, Full/Reduced Service, Gamedays (add field), and Graduation (add field), as necessary.

Account for trippers that don't have a TripName

- 3) Find Average Arrival time for each TripName (by Stop, Route, DOW, & Week).
- 4) Make time bands for each TripName, Stop, Route, DOW, & Week.
 - a) There should be no gaps between timebands.
 - i) Example:
 - (1) TripName 1, Stop 3 average is 9:01
 - (2) TripName 2, Stop 3 average is 9:07
 - (3) TripName 3, Stop 3 average is 9:15
 - (4) THEN TripName 2, Stop 3 Time band is 9:04-9:11
- 5) Filter Data by Week, DOW, Route, Stop, & Time Band.

Determine yearly trend and weekly seasonality factors

- 6) Find Total Yearly Riders by DOW, Route, Stop, Time Band.
- 7) Determine trend in yearly riders
 - a) Biggest jump (trend) in riders should occur at the beginning of the VT school year in August
- 8) Find Average Riders per week by DOW, Route, Stop, Time Band.
- 9) Determine Weekly Seasonality Factors for each year of data
- 10) Average Weekly Seasonality Factors from year to year to come up with final Weekly Seasonality Factors

Create forecast for the next year

- 11) Apply Trend to most recent year to find Riders by Week, DOW, Route, Stop, & TripName.
- 12) Apply Weekly Seasonality Factors to find Riders by Week, DOW, Route, Stop, & TripName.

Determine arrival time

- 13) Determine standard arrival distribution type and parameters
 - a) May vary dependent on:
 - i) Campus/DT vs not
 - ii) Time of Day
 - iii) Headway
- 14) Take the forecasted riders by TripName, Stop, Route, DOW, and Week and apply the arrival distribution using the average arrival time to come up with an arrival time for each forecasted rider.
- 15) Import these arrivals and times into DDDSS
- 16) Import average bus arrival into DDDSS
 - a) Necessary if they are what we use to determine arrival times otherwise arrival times need to be in reference to the arrival time



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Demand assessment flow chart

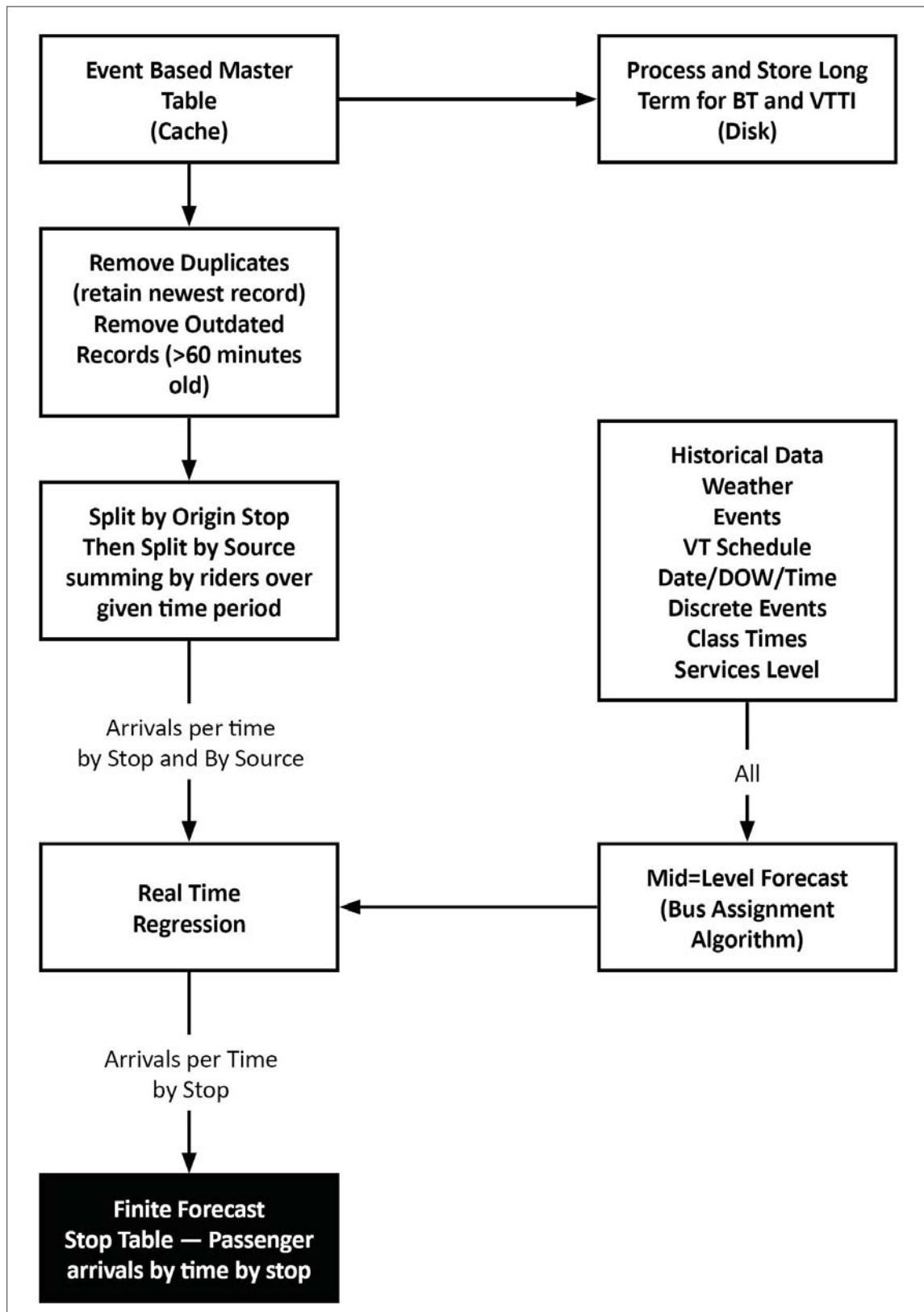


FIGURE 9-14 DEMAND ASSESSMENT ALGORITHM FLOW CHART



Transit Bus Routing On-Demand: Developing an Energy-Saving System

APPENDIX C: FUEL CONSUMPTION MODELING

Details of Problems and Solutions with the HEM Data Logger

1. Some of the loggers could not upload data to the server, because they could not establish a good Wi-Fi connection. The access points in the parking garage were installed too close to the ceiling, and experienced interference from the metallic ceiling and its supporting beams. To solve the problem, those access points were moved to vertical columns about one to two meters below the ceiling. Also, new access points were installed to ensure full Wi-Fi coverage, and the access point channels and power levels were adjusted. After those changes were made, the Hem data loggers connected to the network and uploaded data regularly.
2. The data loggers would delete files independently of data-transfer success. When, for whatever reason, the Apache server issued an http error 500, the loggers deleted files that had not been uploaded, resulting in data loss. A firmware update fixed the problem, but about a quarter of the data loggers had to be sent to the manufacturer to be re-flashed.
3. The data upload from the logger failed and gave a maximum time exceeded PHP error message. Changing the max_execution_time variable to 0 and the max_input_time to -1 solved the problem.
4. The mini loggers do not have a battery or a capacitor to power them to finish the data upload after the master switch is turn off. Also, they were designed for trucks and off-road-vehicles, not for city buses. City buses, like the ones at BT, have a master switch to cut all electrical power and preserve the battery from multiple drains. Therefore, the standard operating procedure of turning the buses off often resulted in lost data. To remedy that problem, the team developed a custom direct current (DC) uninterruptible power supply (UPS) system to power the mini loggers after the bus' master switch has been turned off.
5. Power cycling the data loggers rendered the SD cards unusable. Installing and using the DC UPSs greatly increased the SD cards' life expectancy.
6. When the real time clock (RTC) battery failed, the logger used the wrong timestamp for the data filenames. That happened in at least two data loggers. The DC UPSs also helped reduce the frequency of failed batteries.
7. The Wi-Fi signal on the data loggers was underpowered and required a long time to transmit a few megabytes to the server. Because power was limited to keep the logger from overheating, the upload speed could not be increased. To mitigate the problem, the data loggers were set to collect data at 2 Hz instead of 10 Hz, reducing file size.
8. Sometimes the logger did not generate a .GPS data file, but that problem did not occur frequently enough to diagnose and solve.
9. The data loggers could collect a large number of variables. The team had to decide which variables to prioritize and collect.



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Bus Fuel Consumption Model – additional graphs

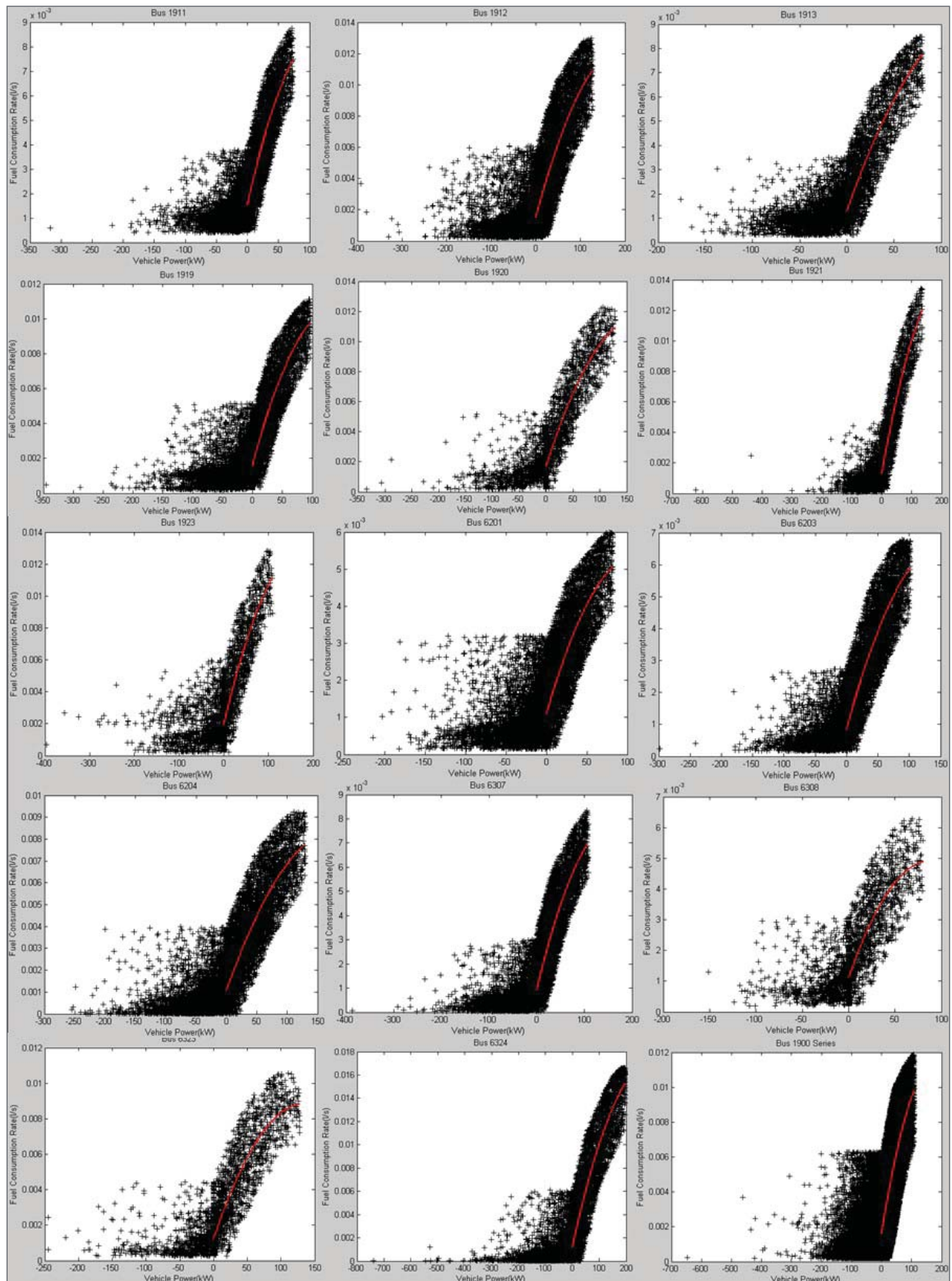


FIGURE 9-15 FUEL CONSUMPTION MODEL, ADDITIONAL GRAPHS 1



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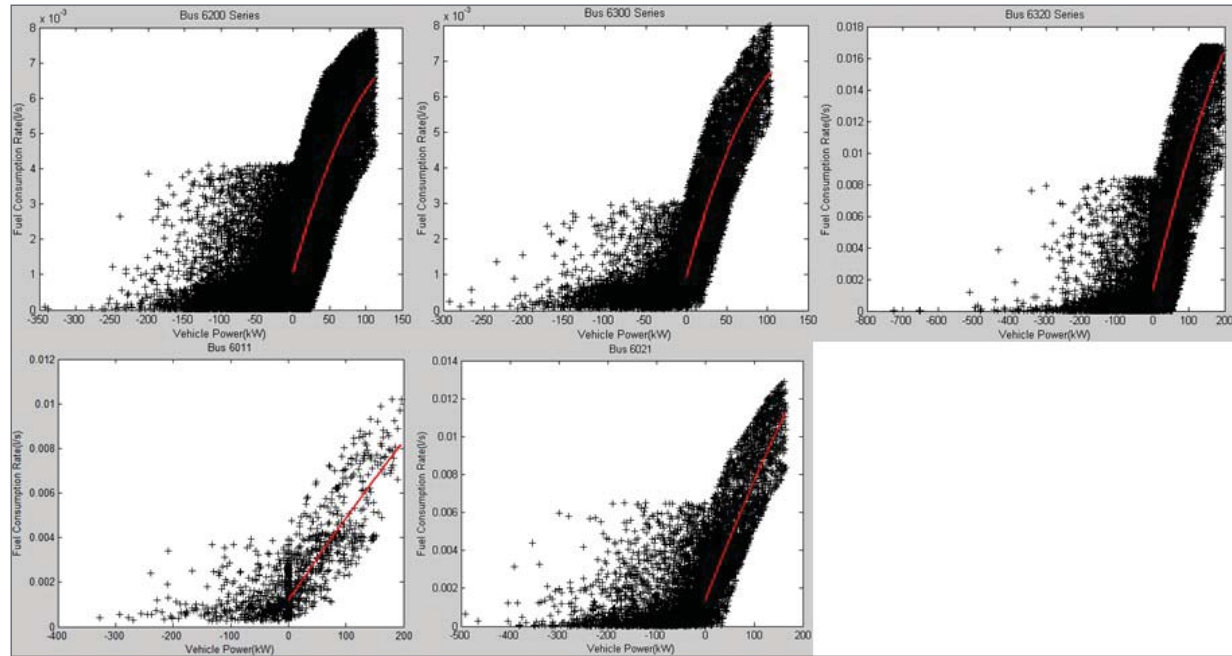
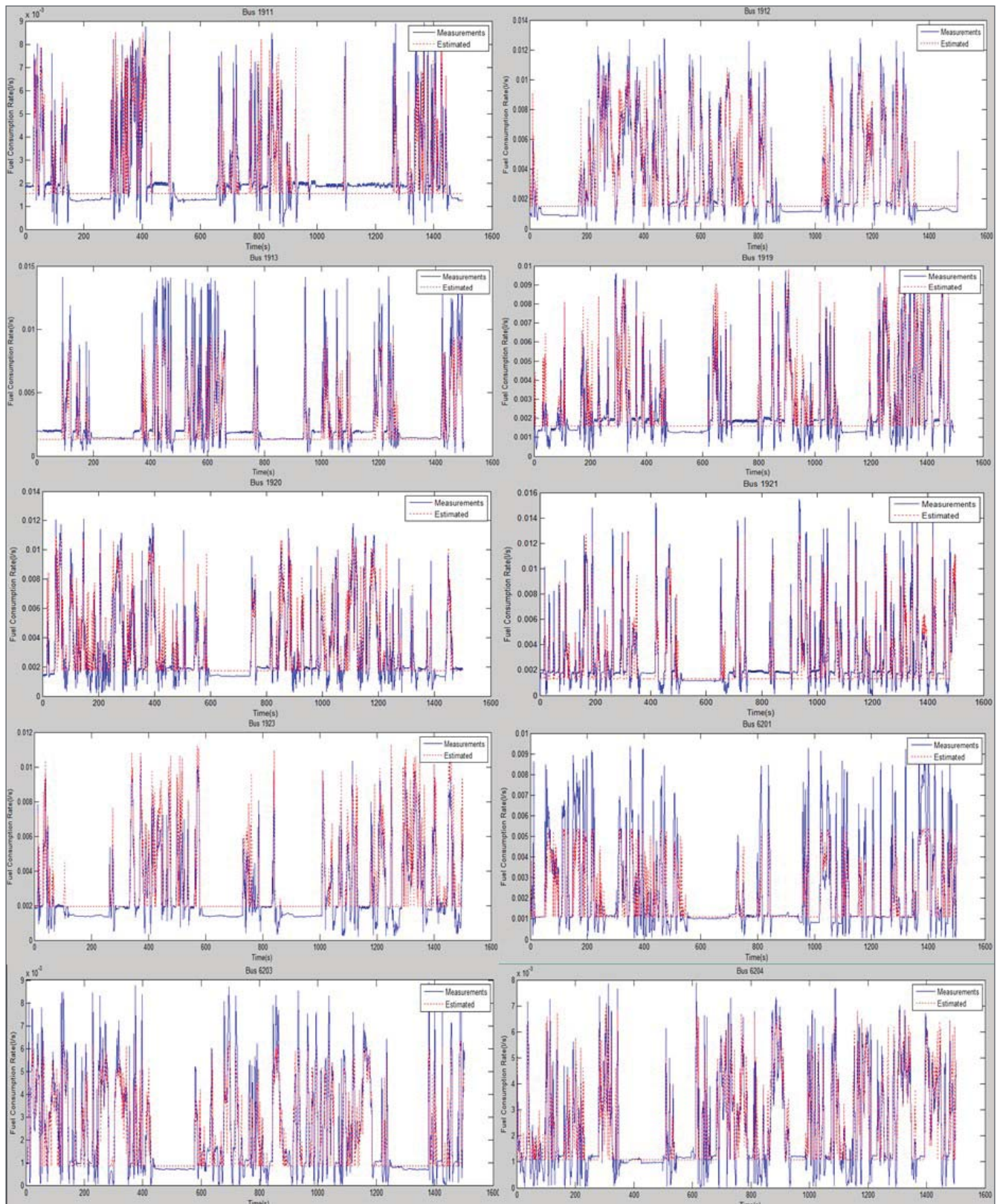


FIGURE 9-16 FUEL CONSUMPTION MODEL, ADDITIONAL GRAPHS 2



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Fuel Consumption Model Validation – additional graphs

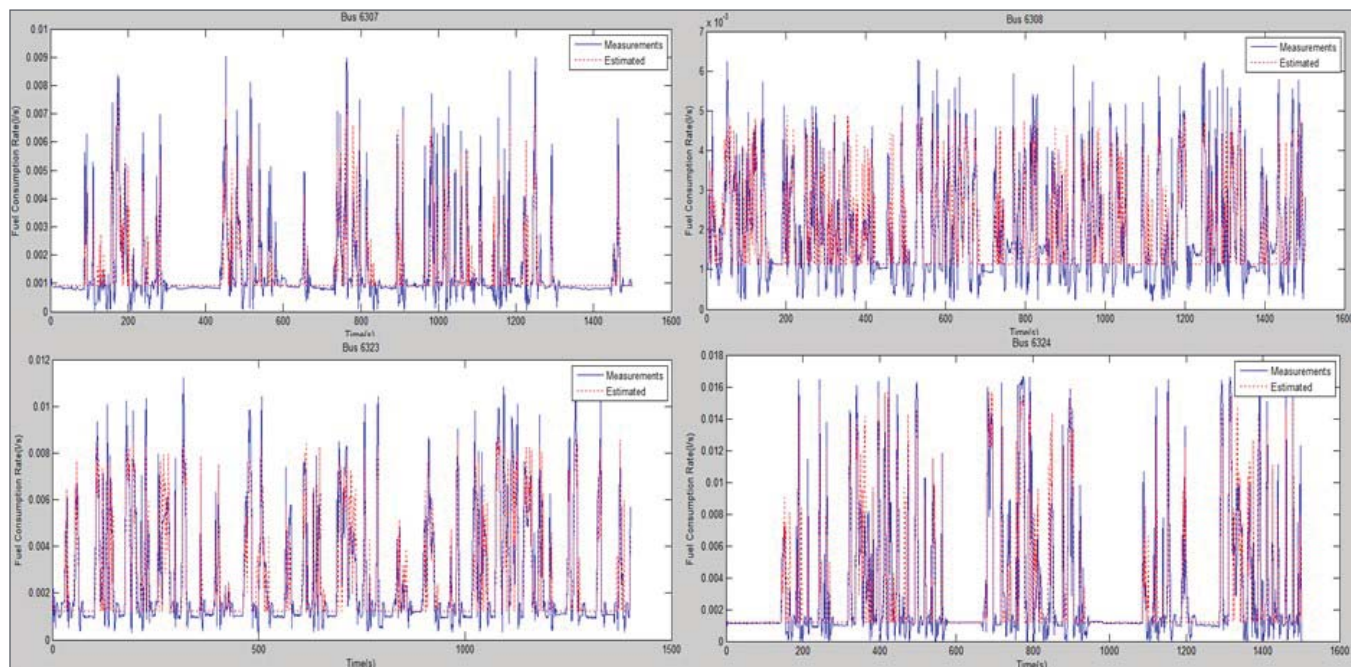


Individual model validation for conventional diesel buses (1)

FIGURE 9-17 FUEL CONSUMPTION MODEL VALIDATION FOR CONVENTIONAL DIESEL BUSES, ADDITIONAL GRAPHS 1



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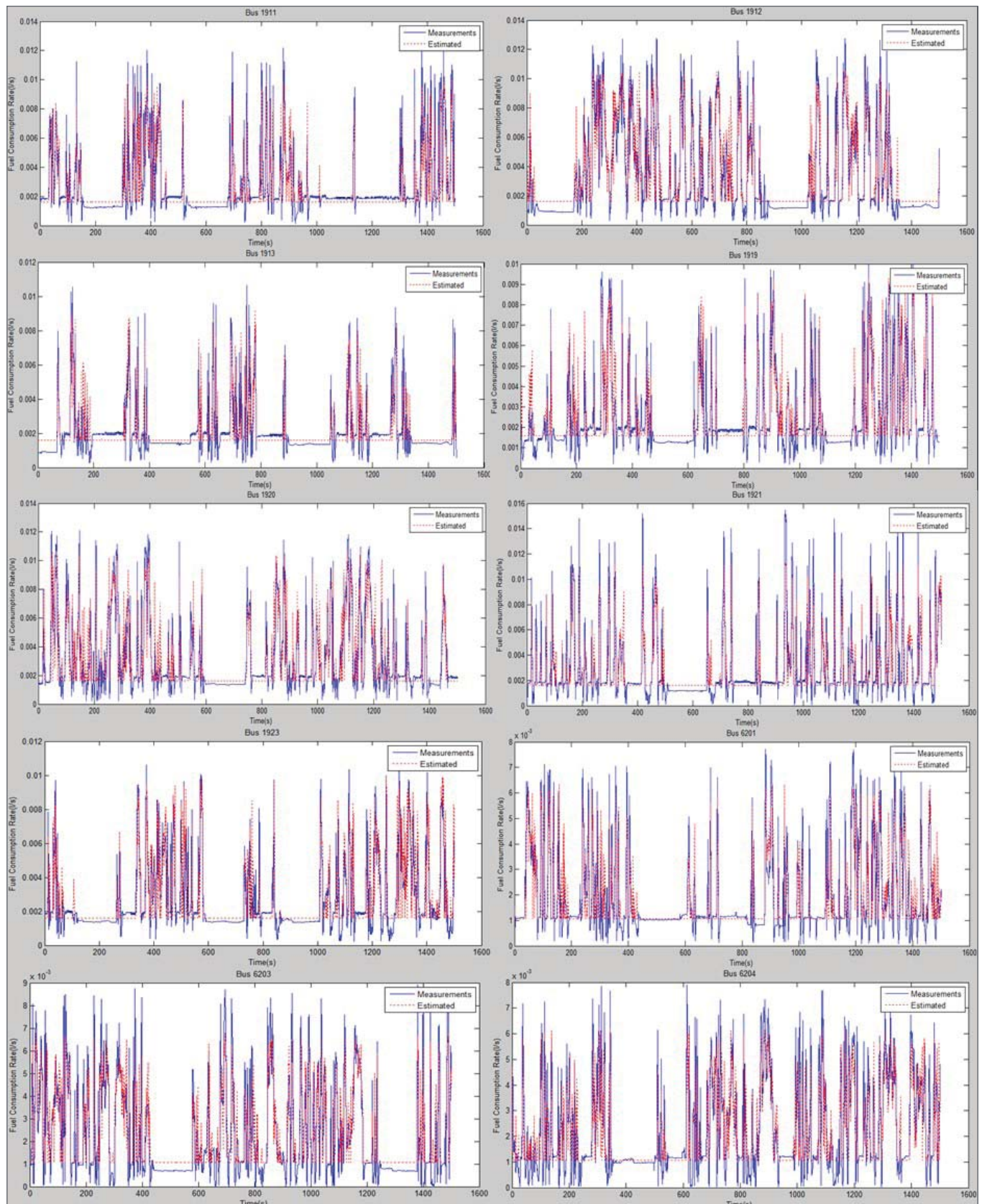


Individual model validation for conventional diesel buses (2)

FIGURE 9-18 FUEL CONSUMPTION MODEL VALIDATION FOR CONVENTIONAL DIESEL BUSES, ADDITIONAL GRAPHS 2



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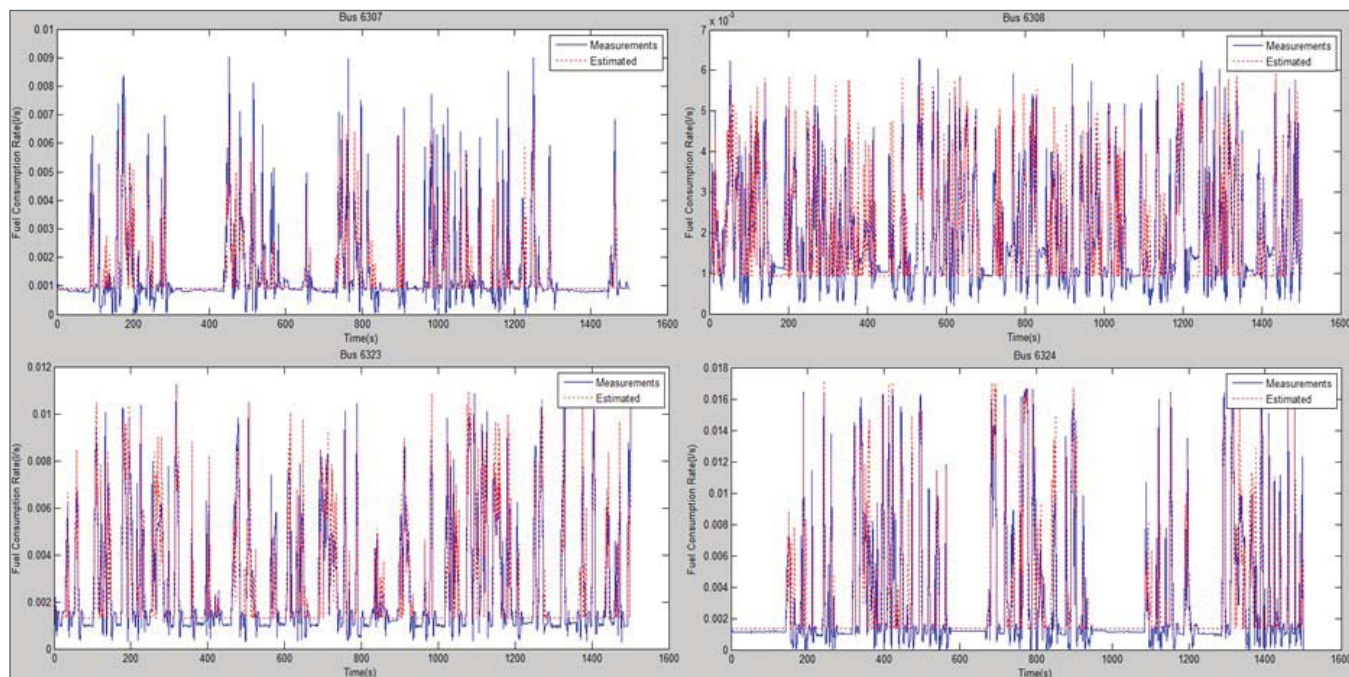


Series model validation for conventional diesel buses (1)

FIGURE 9-19 FUEL CONSUMPTION VALIDATION FOR CONVENTIONAL DIESEL BUS SERIES, ADDITIONAL GRAPHS 1

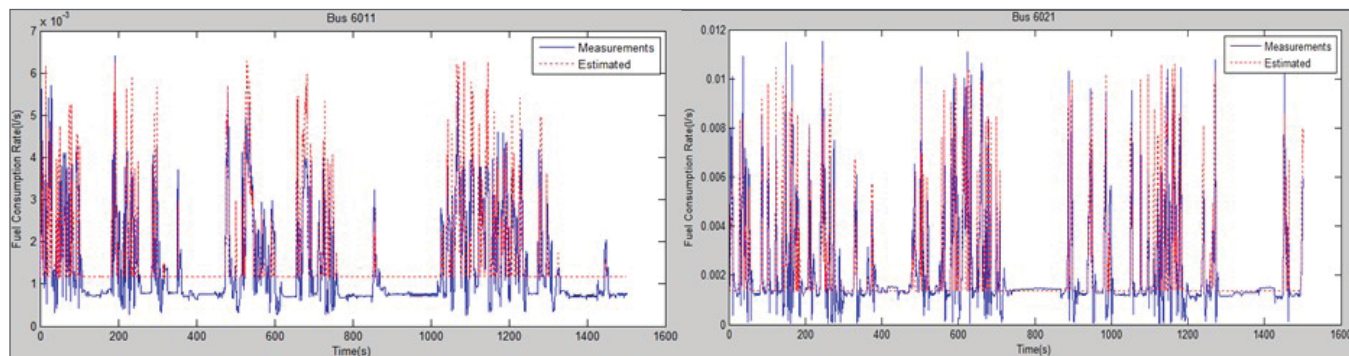


Transit Bus Routing On-Demand: Developing an Energy-Saving System



Series model validation for conventional diesel buses (2)

FIGURE 9-20 FUEL CONSUMPTION VALIDATION FOR CONVENTIONAL DIESEL BUS SERIES, ADDITIONAL GRAPHS 2



Individual model validation for hybrid buses

FIGURE 9-21 FUEL CONSUMPTION VALIDATION FOR HYBRID BUSES, ADDITIONAL GRAPHS



Transit Bus Routing On-Demand: Developing an Energy-Saving System

APPENDIX D: DYNAMIC DEMAND DISPATCHING SUPPORT SYSTEM (3DSS)

Dynamic Routing Implementations and Issues

- Bypassing or rerouting around stops where no passengers intend to board or exit the bus. That would require each passenger's destination be known ahead of time, not possible without enforcing passenger tracking.
- Merging nearby routes in real time so a nearly-empty bus could pick up passengers on a nearby route that is overcrowded. This would also require passenger destinations be known, and that passengers and potential passengers be notified of routing changes.
- Requiring riders move to alternate bus stops. This would inconvenience riders, and require Blacksburg Transit notify them in real time where they need to be.
- Using an active transit signal priority system that gives buses priority at traffic lights. The significant infrastructure changes required to implement it were outside the scope of this project.
- Reducing the time buses spend idling. Potential maintenance and bus performance issues caused the team to reject this option.
- Having buses with insufficient passenger demand park along the route, and be powered with shore power for longer shut-downs. The infrastructure modifications required to implement this option were outside the project scope.
- Creating virtual stops, where the bus would pick up and drop off passengers at alternate locations. This would also require passenger and potential-passenger destinations be known, and that passengers and potential passengers be notified of routing changes.

3DSS Input Variables

TABLE 9-3 INPUT VARIABLES FOR 3DSS

DATABASE	VARIABLE	DESCRIPTION	DATA ORIGIN
Bus DataBase	Bus (b)	unique bus number, starting at 1	TIGGER DB
Bus DataBase	BT Bus Number	unique 4-digit index number for each bus	TIGGER DB
Bus DataBase	Max Capacity	maximum number of passengers allowed on the bus	TIGGER DB
Bus DataBase	Curb Weight (lbs)	bus weight	TIGGER DB
Bus DataBase	α_0	fuel consumption model parameter	Fuel Consumption Model/ TIGGER DB
Bus DataBase	α_1	fuel consumption model parameter	Fuel Consumption Model/ TIGGER DB
Bus DataBase	α_2	fuel consumption model parameter	Fuel Consumption Model/ TIGGER DB
Bus DataBase	Route	the route of this bus	TIGGER DB
Bus DataBase	Location on Route	which link or stop is the bus at	TIGGER DB
Bus DataBase	Start Stop	the bus' first stop	TIGGER DB



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DATABASE	VARIABLE	DESCRIPTION	DATA ORIGIN
Bus DataBase	Start Time	the bus' start time	TIGGER DB
Bus DataBase	Trip#/loop	the number of times bus has passed the start stop	TIGGER DB
Bus DataBase	Leaving Route	true if the bus leaves the current route	TIGGER DB
Bus DataBase	Beta	fuel consumption model parameter	fuel consumption model/TIGGER DB
BusPassengerData	Stop	stop code in sequence	BT4U DB
BusPassengerData	Next Expected/ Projected Departure Time for Each Bus	departure time from current stop	BT4U DB
BusPassengerData	# Riders on bus before stop n for Each Bus	number of riders on bus before arriving current stop	calculated based on demand and schedule
DemandAssessment	Time	time of day in 1-minute intervals	DA algorithm
DemandAssessment	Minutes	minutes starting at 1 when first passenger is detected at a stop	DA algorithm
DemandAssessment	Expected Passengers Arrival (DA)	expected passenger arrival number to stop from demand assessment	DA algorithm/TIGGER DB
DemandAssessment	Expected Alighting (DA)	expected passenger alighting number to stop from demand assessment	DA algorithm/TIGGER DB
DemandAssessment	Expected Passengers Arrival (APP)	expected passenger arrival number to stop from app data	DA algorithm/Mobile App DB
DemandAssessment	Expected Alighting (APP)	expected passenger alighting number to stop from app data	DA algorithm/Mobile App DB
DemandAssessment	Estimated Passengers Arrival	estimated passenger arrival number to stop by demand assessment and app	DA algorithm
DemandAssessment	Estimated Alighting	estimated passenger alighting number to stop by demand assessment and app	DA algorithm



Transit Bus Routing On-Demand: Developing an Energy-Saving System

DATABASE	VARIABLE	DESCRIPTION	DATA ORIGIN
DemandAssessment	Bus Departure	number of buses departing from stop at that time, if no bus is departing it is 0	calculated from BusPassengerData
DemandAssessment	Passengers at stop	total passenger number at this stop	calculated based on demand and schedule
DemandAssessment	Passengers Left	number of passengers who cannot board at this stop	calculated based on demand and schedule
DemandAssessment	Real time passengers Left	real time data for number of passengers left behind at this stop	calculated based on demand and schedule
DemandAssessment	Average Wait (min)	average wait time for each passenger at this stop	calculated based on demand and schedule
Links	Link Number	unique link index number	route-specific, contained in route input file
Links	FID	unique identifying number for each link	route-specific, contained in route input file
Links	Link Name	link name	route-specific, contained in route input file
Links	Distance (m)	link length	route-specific, contained in route input file
Links	Grade (percent)	link grade	route-specific, contained in route input file
Links	Speed Limit (mph)	link speed limit	route-specific, contained in route input file
Links	End In Stop	whether this link ends in a stop sign, stop light, or bus stop	route-specific, contained in route input file
Links	Next bus stop	stop code for next stop	route-specific, contained in route input file
Links	Next Link/Stop	next link or bus stop	route-specific, contained in route input file
Links	Expected Travel Time (sec)	average travel time to travel across link	route-specific, contained in route input file



Transit Bus Routing On-Demand: Developing an Energy-Saving System

DATABASE	VARIABLE	DESCRIPTION	DATA ORIGIN
Links	Xcoord (deg)	latitude of link start point	route-specific, contained in route input file
Links	Ycoord (deg)	longitude of link start point	route-specific, contained in route input file
Links	Rank	ordinal number of the link	route-specific, contained in route input file
Links	Bus Stop	whether this link ends with a bus stop	route-specific, contained in route input file
Links	Notes	additional info to estimate travel time	route-specific, contained in route input file
Links	Elevation (m)	road elevation	route-specific, contained in route input file
Stops	Stop	stop index in sequence	BT4U DB
Stops	Next Stop	index (unique identifier) of next stop	BT4U DB
Stops	Lat (deg)	latitude of the stop	BT4U DB
Stops	Long (deg)	longitude of the stop	BT4U DB
Stops	Travel Time (sec) To next stop	travel time to the next stop	BT4U DB
Stops	Switchable stop	whether a bus can be switched at this stop (only at time check point)	BT4U DB
Stops	Time Check	whether the stop is a time check	BT4U DB
Stops	Next Link	link number of the next link	BT4U DB
Stops	Name	stop name	BT4U DB
Stops	Stop Code	stop code	BT4U DB
TravelTimeFromTripperLocation	Travel Time from Each Waiting Location to Each Stop	travel time from each tripper bus waiting location to each stop	route-specific, contained in route input file
FuelConsumptionFromTripper Location	Fuel Consumption from Each Waiting Location to Each Stop	fuel consumption from each waiting location to each stop	route-specific, contained in route input file



Transit Bus Routing On-Demand: Developing an Energy-Saving System

DATABASE	VARIABLE	DESCRIPTION	DATA ORIGIN
Driver Profile	Time (sec)	time stamp for the interval of 0.1 min	route-specific, contained in route input file
Driver Profile	Velocity (mph)	speed over link	route-specific, contained in route input file
Driver Profile	Acceleration (mph^2)	acceleration over link	route-specific, contained in route input file
Driver Profile	Distance (m)	travel distance over link	route-specific, contained in route input file
Driver Profile	Resistance (N)	resistance over link	route-specific, contained in route input file
Driver Profile	Power (N)	engine power over link	route-specific, contained in route input file
Driver Profile	Power^2 (N^2)	squared engine power over link	route-specific, contained in route input file



Transit Bus Routing On-Demand: Developing an Energy-Saving System

APPENDIX E: MARKETING

TIGGER Marketing Plan

Objective: Create a sense of community and involvement in the TIGGER project through education and two-way communication so that all stakeholders are aware of its benefits, effect on their commute, and other facets of the project.

Project Summary

The Blacksburg Transit service goes through several peak periods in the day. For example, after every class change there are numerous people trying to exit campus. However, sometimes demand shifts, and Blacksburg Transit currently has no way of knowing how many people will be at a stop (aside from historical data). The shift could be because of exams, or because of a football game. We want to be able to tell when the demand has changed from what we expect it to be, so that we can route the buses more efficiently. We hope to engage in a proactive versus reactive method of dealing with passenger demand, which will promote a better passenger experience with BT.

Jimmy and John Take a Ride

Jimmy rides Blacksburg Transit every day, like he has since freshmen year. The bus system works for him, most of the time. He usually enjoys his commute to and from campus, but today while standing at his Hethwood stop, he sees two buses with “Bus Full” flashing across the front of them drive right past him. Seeing the bus drive away creates a feeling of irritation in Jimmy, especially since his class takes attendance at the beginning of each class. Luckily, a tripper has been waiting and will get him to campus. Jimmy is happy to finally be on a bus, but agitated that he is going to be late for class.

John, Jimmy’s friend, had a completely different experience. He went to his stop on campus at an “off-time” while classes were in session. The bus came to his stop exactly on time, and he boarded the bus. After showing his passport, John looked up and noticed that he was the only one on the bus. While, it was nice to have a private bus trip, John felt like it was a waste of resources. On his ride home from Burruss to Hethwood, only two more people got on. John thought, “There has to be a better way.”

The goal of TIGGER is to find out if Jimmy’s and John’s situations are preventable. BT wants to find out if it is possible to gauge passenger demand by using various technologies. The TIGGER project hopes to use technology such as thumbprint scanners, cameras, apps, and other consumer-input to know which buses need to be where, and at what time. BT envisions Jimmy having the ability to let us know he is at a stop, either through active or passive measures. That way Jimmy makes it to class on time, and the John doesn’t ride on an empty bus. Along with knowing where passengers are boarding, BT wants to know where passengers are going. If their destination is known, BT can better determine the demand for other parts of the system. TIGGER hopes to produce a notification system where we can alert passengers to changes in service level for unforeseen circumstances (e.g. inclement weather). As part of the application, Blacksburg Transit also wants passengers to let us know if the bus is to their expectations (clean, courteous operator, etc.).

Having the ability to change how buses run could result in lower GHG emissions and increased efficiency. It is our goal with TIGGER to discover if the consumer experience can be enhanced by engaging them, having them tell us what it is like to ride the buses every day, and how we can make it better.

Primary Target Audience

1. Residents of Hethwood Apartment Complex
2. Riders located in the Corporate Research Center
3. Virginia Tech
4. BT Employees
5. Town Employees



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Secondary Target Audience

1. Elected Officials
2. Town Council
3. General Public
4. MPO
5. DRPT
6. FTA

Key Messages (for Primary and Secondary Audience)

1. The Dynamic Routing and Scheduling Study aims to find out if dynamic schedules are viable. We don't know what the outcomes will be. This is a learning process for all.
2. During the study, a service change might be noticed. We may decide to hold a bus at a stop for few minutes longer, or have a bus show up unscheduled (if the demand is present).
3. This project is a partnership between VTTI and Blacksburg Transit. We are working together to find out if changing buses to fit demand is a feasible option.
4. We want passengers to give their opinions and feedback. Knowing how the changes are affecting passengers is part of the study.

Potential Benefits (for Primary Audience)

1. Passengers may arrive at their location sooner, or know if they are going to arrive later.
2. There will be a potential reduction in GHGs, which provides for a cleaner community (both locally and globally).
3. The resources saved through this project can be reallocated to other areas (e.g. if we spend less time driving buses that are not being used to capacity the buses may need to be replaced less often).

Potential Benefits (for Secondary Audience)

1. Increased customer service for those using our service
2. Saved resources (i.e. fuel use reduction and fewer unnecessary miles on the buses)

Strategies (for Primary Audience)

- Create awareness of the project, primarily in Hethwood neighborhood.
 - Work with HHHunt to contact residents and spread awareness.
- Create awareness for the service, secondarily in CRC market.
- Educate those involved and affected by the study.
- Communicate throughout the process to make sure we keep everyone on the same page.

Strategies (for Secondary Audience)

- Conduct quarterly meetings to provide project update.
- Provide handouts on project
- Create a dialogue where the secondary audience can communicate thoughts about the TIGGER project.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Tactics

Prior to Technology Deployment April 2013-August 2013:

- Use various media to educate and engage stakeholders to create awareness about the project
 - BT4U- Use the service to disseminate information. Provide links to various resources (i.e. website,
 - BT Website- Much like the BT4U service, this will work to provide schedule information
 - E-mail
 - Interior bus cards
 - Exterior ads
 - Collegiate Times Article
 - Dining Hall cards
 - Utilize Assets of Community Relations Office
- Conduct a public meeting to collect opinions and concerns prior to deployment
- Conduct Focus groups to engage existing participants, and also attract/educate new passengers
- Work with CSR to engage consumers with a survey asking opinions on potential technologies.
 - How the study works, what it entails, benefits/drawbacks of project.
 - Follow up with riders via focus groups

During Technology Deployment September 2013-May 2014

- Conduct Focus groups to engage existing participants, and also attract/educate new ones
- Use advertising mediums to keep stakeholders informed of new changes, and progress being made throughout the study. (i.e. Bus ads, CT article/advertisements, dining hall cards)
- Focus groups to keep stakeholders aware of progression. Encourage App Usage/awareness.

Post Technology Deployment June 2014-August 2014

- Focus group to collect final thoughts on study (collect recommendations and comments)
- Use the same methods as mentioned about to alert stakeholders of the project's conclusion.
- Finish up analysis and release results through predetermined methods



Transit Bus Routing On-Demand: Developing an Energy-Saving System

PROJECT TIMELINE

TASK	TO BE COMPLETED BY
Develop Draft Project Management Plan	April 2013
Develop Draft Concept of Operations	April 2013
Determine bus routes to be studied	April 2013-June 2013
Develop route data needs/straw man	April 2013- June 2013
Develop functional requirements for mobile application	April 2013- July 2013
Develop data requirements for on-board data needs and methodology for system evaluation	April 2013- July 2013
Develop data requirements for demand assessment	April 2013-July 2013
Finalize Project Management Plan	May 2013
Determine most appropriate means of communication for field devices	May 2013-June 2013
Determine data collection equipment needs	May 2013- July 2013
Finalize Concept of Operations	May 2013-August 2013
Procure/lease on-board data collection equipment	June 2013- August 2013
Coordinate with power companies for provision of power for field devices	June 2013-September 2013
Procure communications test equipment	July 2013- August 2013
Perform research to determine most appropriate technology offerings for demand assessment	August 2013
Develop demand assessment procurement document	August 2013
Perform public education/surveys regarding technology offerings for demand assessment	August 2013-September 2013
Procure Mobile Application Vendor	August 2013- November 2013
Communications testing	September 2013-October 2013
Procure equipment for demand assessment	September 2013-November 2013
Install data collection equipment on buses	October 2013
Install power service	October 2013- December 2013
Develop Beta Mobile Application	November 2013- December 2013
Procurement of remaining communications equipment	November 2013-December 2013
Install/integrate demand assessment equipment	November 2013- January 2014
Installation of remaining communications equipment	December 2013
Deploy Beta Mobile Application	March 2014
Develop Final Mobile Application	January 2014-February 2014
Perform system evaluation/tests	January 2014- April 2014
Deploy Final Mobile Application	March 2014
Provide evaluation/testing results and develop report documenting the project	May 2014- August 2014

Outcomes/Goals/Expectations

1. When the project is complete, we will be able to look at App Usage. This will tell us how many people are reporting their information to us.
2. We can also gauge consumer interest and feelings, by using the survey we will be sending out in early Fall 2013.
3. The equipment we use to collect information on the bus will return bus conditions to us. Such as, how much gas was used, number of passengers, etc. We can use this information to see how the bus efficiency changes based on changing variables.
4. The demand assessment at the stop level will give us measurable information about which stops are busiest and when (on the study routes).



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Collegiate Times Article: Blacksburg Transit develops first ever official mobile app

http://www.collegiatetimes.com/news/article_e2ec6034-8ec3-11e3-8de5-0017a43b2370.html

Posted: Wednesday, February 5, 2014 7:16 pm | Updated: 10:01 pm, Wed Feb 5, 2014.

Matthew Johnson | 0 comments

Blacksburg Transit (BT) is working with two local companies to develop its first phone application.

"This is the first official Blacksburg Transit app," said Tim Witten, the company's special project manager. "In the past, we've worked with developers to provide information, but this is the first one that we've actually built."

Though none of the apps currently on the market are official Blacksburg Transit apps, they have the "BT4U live map that already exists and the texting features," said Fiona Rhodes, BT's marketing specialist.

Blacksburg Transit has been working on this with two companies at the Corporate Research Center — Nomad Mobile Guides and Automation Creations — to develop the app, which is part of the Transit Investment Greenhouse Gas and Energy Reduction (TIGGER) grant.

The app will hopefully be released by April for iPhone and Android users.

"The approval process doesn't take as long with Google as Apple, but we'd like to release them simultaneously," Witten said.

The app will function as a basic transit app with the ability to plan trips to find the best times and routes.

"We'll also provide some notifications. For example, if you establish your travel plan for Tuesdays and Thursdays, the app will let you know what trip you need to take to get to class on time," Witten said.

The app is being created with Virginia Tech students as its primary audience.

The app will also have a "go home" feature.

"Say you rode in a friend's car out to Terrace View but you live in Hethwood and you weren't exactly sure where you were and you decided to ride the bus home but didn't know where the closest bus stop was," said Rhodes. "You just hit the 'go home,' and it'll take you home."

Using Google Maps, the app will be able to give you walking directions to the nearest bus stop and tell you when the bus will arrive.

But the app won't only be giving users information — it will be collecting information as well.

"We're going to use this as a demand evaluation tool," said Witten. "Based on how many people are using the app, we'd like to see how many people are going to be at that bus stop."

The data collected from the app will help Blacksburg Transit create a better and more effective bus system for its patrons.

"Eventually we'll be able to use it to tell people if the bus is full or if they need to leave earlier or wait for a different bus," Rhodes said.

The data will also be used to improve the application itself, though a better bus system seems a more advantageous usage.

"We'll be collecting some information about how users use the application," said Witten.

To further ensure the satisfaction of the consumers, Blacksburg Transit will have a small group of testers using the product at the beginning of March.



Transit Bus Routing On-Demand: Developing an Energy-Saving System

Collegiate Times Article: BT4U introduces mobile app

http://www.collegiatetimes.com/news/article_78dfe32a-e6b4-11e3-a579-001a4bcf6878.html

Posted: Wednesday, May 28, 2014 6:07 pm | Updated: 11:31 pm, Wed May 28, 2014.

Zack Wasjgras, news staff writer | 0 comments

Standing at a stop and waiting for a bus to arrive in Blacksburg will be a thing of the past thanks to the new BT4U mobile phone app.

The app, currently available to all iPhone and Android users for free, allows users to track buses in real time, highlight routes to determine when buses will be arriving at stops and save frequently used routes.

Fiona Rhodes, a marketing specialist for Blacksburg Transit, says the app essentially took all of the functions of the BT4U website while added a few new ones that were developed in a user friendly way.

There are other apps similar to the new one but “none of them have the functionality that (our app) has,” Rhodes said.

The app can give you directions from anywhere in the Blacksburg area and can format them based on whether you are driving or walking.

While the app will make finding buses for students much easier, it will also serve as the main information generator for where the BT can send buses when needed.

Currently trippers (buses sent to busy stops to shorten wait times) can’t be sent out as quickly as BT would like. The app, however, allows the BT to determine where trippers are needed.

“We wanted to make our information as accessible as we could,” Rhodes said, “Hopefully we will be able to predict and send trippers much more effectively now (with the app).”

The building of the app began when the partnership of the BT and the Virginia Tech Transportation Institute (VTTI) received a \$1.85 million dollar federal grant. The grant is known as a T.I.G.G.E.R. grant or a Transportation Investment in Greenhouse Gasses and Energy Reduction grant.

The grant was given in order to ultimately cut down on GHG emissions and make the buses more efficient in terms of energy being used.

Andy Alden, a Professional Engineer and the principle investigator of the project from VTTI, said that the app is just one part of a much bigger plan by BT to achieve that goal.

“We want to put the power in the people’s hands,” said Alden, describing why the app made sense to create for the student population.

Alden expressed that there was a need for more information about where buses needed to be that wasn't being met by the previous method of using cameras to observe what stops had more people at them.

The data used from the app will allow BT to take buses off unused routes, park buses when a bus doesn’t need to be used for short amounts of time, and re-route buses where they are needed most.

If enough information is collected, Alden estimated that the results could mean anywhere from a 25-50 percent reduction in the amount of fuel BT uses.

Future uses for the money saved from lower fuel costs could include creating parking locations along routes for buses to park and save energy, and self-sustaining internal air conditioning for buses to reduce electricity use.

As the app gets more popular, the data will get better, which will increase reliance on the app increase, Alden said.

The app also has features including a “go home” button and beginning and ending locations to find stops along the way.



Transit Bus Routing On-Demand: **Developing an Energy-Saving System**

The optimization of routes and bus usage by BT and the added features for students could make the app a must-have for all frequent users in the Blacksburg area.

While the app itself is very helpful to students, the information gained from it is used by BT for a range of needs including making the app more efficient for users of it.

"There's a lot more to it than just the app, there is much more going on behind it all," Alden said. "The things we collect are only going to make the app better and better."



Transit Bus Routing On-Demand: Developing an Energy-Saving System

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