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Master of Engineering Project

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FEASIBILITY STUDY OF SERVICE OPTIONS FOR TOMPKINS CONSOLIDATED AREA TRANSIT IN ITHACA AND TOMPKINS COUNTY

Executive Summary

In order to improve bus services provided by Tompkins Consolidated Area Transit (TCAT) for Ithaca and the rest of Tompkins County, problem areas were identified in their existing system. Our study proposes various techniques which can be used which will allow TCAT to improve its efficiency, run cost-effective bus routes, reduce emissions into the local environment, and provide a better customer experience for Ithaca and the surrounding communities. This technical report focuses on six primary topics: addressing the issues in current TCAT operations, switching to buses which use modern green technology, implementing a bus route with a higher level of service, implementing bus rapid transit, improving system capacity with larger articulated buses, and using simulation to determine optimum setups of bus operations.

In addressing issues with TCAT's current system, we proposed a morning bus route which will be more effective than an existing route with low ridership. Direction-bound naming of routes will remove the ambiguity in many of TCAT's current route names. In addition, technological innovations such as Google Transit and HASTUS can be utilized to provide customers with real-time information on buses and assist TCAT in optimizing its driver assignments, respectively.

The composition of the current bus fleet was also addressed, and new types of bus technology could be used to improve services. Through a study of various alternative fuel sources for buses, we have determined that biodiesel may be the best option for TCAT's fleet in terms of environmental impact and cost-effectiveness. Additionally, the implementation of articulated buses, particularly those which run on green technology, can simultaneously improve bus capacity while reducing emissions.

Infrastructural and network changes can significantly decrease travel time at relatively low costs. In a study of buses with a high level of service, express routing and reduced dwell time proves to be an effective method of improving the customer experience in a cost-effective manner. Bus rapid transit, an innovation which allows buses to operate like a rail network, can be implemented at a reduced scale to achieve similar results with the use of off-board fare collection and level-platform boarding.

Assessing the effects of current or proposed services can be made possible with computer simulations. Using ProModel, this feasibility study assessed the system performance by simulating the elements of various bus network configurations and identifying optimal cases.

By applying these innovations to the existing TCAT system, the provided bus services can be dramatically improved and have significant positive benefits for the company, on the local environment, and the community.

Advisor's Foreword

This report summarizes the findings of a one-semester project analyzing the feasibility of technology and service changes at TCAT in Ithaca and Tompkins County, New York State. The project was carried out by a team of students from the 1-year Master of Engineering in Engineering Management program in the School of Civil and Environmental Engineering (CEE) at Cornell University, and advised by me in my capacity as Senior Lecturer in the School.

The genesis of the project topic comes from an agreement in 2013 with Doug Swarts, service development manager at TCAT, to offer a research project on public transportation and TCAT in particular in our engineering management program. M.Eng teams have in the past studied a range of sustainability related projects from renewable energy systems and alternative fuels for transportation to green building, and public transportation fits very well within this range of possible topics. Also, the mission of the M.Eng in engineering management projects is to mix engineering and management, and technology with the contemporary context for pursuing environmental protection and sustainability, so the projects that I advise are carried out with that objective in mind.

The students join the project not by creating the topic themselves but by choosing from among several projects that are offered by CEE faculty each year. Once the project starts, however, the student team quickly enters into a leadership role and the advisor steps back into the position of explaining the broad parameters of the project and providing feedback and technical insight. It is up to the team to take the syllabus that is provided to them at the beginning of the semester and create from it a proposal and scope of work that is approved by the advisor and partner organization (TCAT in this case), as well as their own team management structure. Once the proposal is approved, the team carries out the work and delivers both a final oral presentation, which took place at the TCAT offices on May 9, 2014, and the final report that follows. Since the organization and content of the report is the responsibility of the team (with input from myself advisor), feedback and comments on the project compiled by myself and Doug in a post-project closeout meeting appear in Appendix B, and the interested reader is referred to these comments in addition to the findings within the report.

In closing, I would like to thank TCAT and Doug for providing this opportunity. While their input is much appreciated, the contents of the report do not reflect the opinions of TCAT, Doug Swarts, or Cornell University, and responsibility for errors rests with the team and myself as advisor.

Respectfully submitted,

Francis M Vanek, PhD
Senior Lecturer and Research Associate

June 13, 2014

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List of Abbreviations

ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
AVLS	Automatic Vehicle Location System
B20	20% biodiesel in mixture
BHLS	Bus with high level of service
BRT	Bus rapid transit
CDTA	Capital District Transit Authority (Albany)
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
GHG	Greenhouse gas
GTFS	General Transit Feed Specification
ITS	Intelligent transportation system
LOS	Level of service
LRT	Light rail transit
M.Eng	Master of Engineering (Cornell degree program)
MPG	Miles per gallon
MPH	Miles per hour
NMHC	Non-methane hydrocarbon
NO_X	Nitrogen oxides
NHTSA	National Highway Traffic Safety Administration
PM	Particulate matter
RSPE	Risk Solver Platform for Education
SMR	Steam methane reforming
SUV	Sport utility vehicle
TCAT	Tompkins Consolidated Area Transit
TCQSM	Transit Capacity and Quality of Service Manual
USDOT	United States Department of Transportation

I. Introduction

Motivation

In recent decades, the United States has faced increasing economic, environmental, and energy challenges. Improving public transportation can help to mitigate these challenges and provide a better quality of life to most, if not all, segments of society. A number of cities have risen to the challenge of improving public transportation systems over the past two decades, which has resulted overall in a 34% increase in ridership nationwide (American Public Transportation Association 2014). Economically, improving public transportation results in a direct increase in jobs, provides an affordable alternative to driving, and reduces the overall consumption of gas. It is estimated that households using public transportation could save $9,700 per year on the average cost to maintain a personal automobile. Further economies can be attributed to greater fuel efficiency per passenger compared to single passenger vehicle transportation. In addition, public transit helps to reduce congestion on roadways, furthering fuel efficiency as well as time efficiency that are otherwise compromised in traffic. Finally, public transportation increases personal mobility and the independence of many segments in society, including the elderly, disabled, children, and those who cannot afford a personal vehicle.

Tompkins Consolidated Area Transit (TCAT) has been operating a bus service in the region since 1998. The system provides affordable and reliable transportation throughout Tompkins County in both rural and urbanized area. The system also services Cornell University and Ithaca College, whose students account for more than 70% of the system's boardings. In recent years, the system has seen significant growth, including more than four million boardings in 2012 to classify it as a medium sized transit system according to the APTA. Despite this growth, driving solo in an automobile still remains the most common method of commuting to work in Tompkins County. Bus service accounts for only 7% of commuters (Tompkins County 2014). As a result, TCAT is continuously trying to improve their service to meet the needs of their current users and to further its growth. This project will focus on what changes to the current system and what new technology can be utilized to increase ridership, improve the level of service, and reduce fuel consumption and carbon dioxide (CO_2) emissions of the current system.

Scope of the Project

Service Improvements

The first and foremost way of improving the TCAT experience is to focus on service improvements. Several service improvement measures have been identified to focus in the Tompkins County area, which cover a wide range of possibilities. These include focusing on current system improvements (without large infrastructural change), adding bus rapid transit, buses with a high level of service, articulated buses, flexible routes, and environmentally friendly buses. The scope of the project is to conduct a feasibility study and would focus on the cost-effectiveness or expanded capacity of service measures. The effectiveness of the service may be explained through a modeled simulation of the impact of the service.

Service Expansion

Public transit systems have the benefit of reducing emissions based on the number of passengers on the bus as compared to a car. The higher the number of passengers in public transit, the lower the environmental emissions per person. Therefore, the scope of the project includes an environmental impact assessment for the service measure under consideration, and may include ecological benefits of retaining or increasing ridership, through expanded service.

Limitations of the Project Scope

Feasibility

For all of the identified service improvement measures, a feasibility study shall be done. To do so, some basic assumptions about the components of these measures shall be taken. The feasibility study should include initial costs of the service improvement measures, operational revenues, and expenses. It is also preliminary in nature, and any options recommended by the study would require a detailed feasibility study before final adoption.

Environmental Impact

For each of the service areas, an environmental impact assessment shall be undertaken. Carbon dioxide will be the primary focus of all greenhouse gas (GHG) emissions, unless a specific technology has a substantially different type of emission. The assessment will be limited to the operational stage of the life cycle of the technology under consideration, and will not include any other stage such as manufacturing, installation, etc.

Other Factors

The main goals of this project are technical and economical in nature. It does not take into account political and social barriers. However, if such barriers do exist in the respective areas, they must be identified and stated. The technical aspects of the project do not include hardware design or design changes to the technology required for a solution, and must focus on existing technologies.

Good Faith

The cost or performance characteristics of all systems considered by the project will be truthfully stated, based on the assumptions.

Assumptions

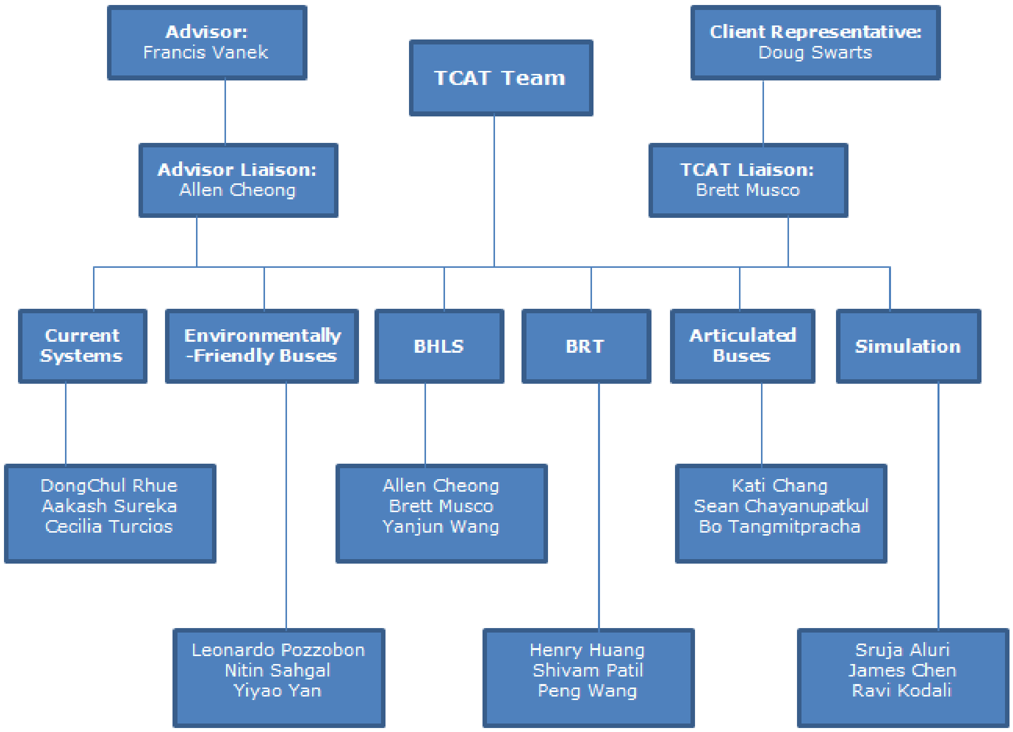
These assumptions include the lifespan of a bus is twelve years, and a 7% discount rate is assumed for the time value of money. To be conservative, the salvage value of a bus is assumed to be zero. The fuel economy of a standard diesel bus is assumed to be 3.85 miles per gallon.

Team Structure

This project is the collaborative work of eighteen graduate students at Cornell University, under the advisory of Dr. Francis Vanek, a faculty member in the Department of Civil and Environmental Engineering. These eighteen team members come from a variety of educational, professional, and cultural backgrounds. The project team will use its range of knowledge and expertise to effectively carry out the tasks of this project.

In order to examine the various service measures, the team divided into six sub-teams, each composed of three members. Each sub-team is in charge of reviewing the feasibility of a service measure, as well as its economic and environmental impact. The exception is the software sub-team, which is responsible for developing a model which will analyze and visually present the impacts of the proposed services.

Additionally, the team assigned administrative roles to certain members in order to facilitate project activities, streamline communicate, and compile project deliverables.



Team Members

Sruja Aluri was born and raised in the southern part of India. She completed her undergraduate studies at the Birla Institute of Technology & Science, Pilani, in Hyderabad, majoring in computer science. Before arriving at Cornell, she worked for a year with Microsoft in India as a software developer. With an inclination towards management, she enrolled in the engineering management program at Cornell. She enjoys spending her time with friends, singing and dancing whenever time permits. She is currently working as part of the simulation sub-team of the TCAT project and given her background and her interests, she would like to explore the area of simulation more and contribute best to the project.

Mengzhe "Kati" Chang is an M.Eng student in engineering management from Beijing, China. She obtained her B.S. in operations research and information engineering from Cornell University in May 2013. Kati has taken several courses in transportation engineering and information science (extracting valuable information from vast data) during her undergraduate studies. She has high interest in public transit systems, especially the social and environmental impacts of transit systems.

Pawit “Sean” Chayanupatkul is from Bangkok, Thailand. Currently, he is studying for his M.Eng in engineering management at Cornell. Previously, he studied operations research and information engineering at Cornell. He has previous professional experiences as a business analyst in supply chain management at Chevron and as a sales intern at Nestle. He has always been interested in applying data analytics to solving complex problems, particularly in manufacturing and supply chains. After graduation, he hopes to join a leading firm in supply chain solutions to explore his interests further. In his free time, he enjoys playing tennis and travel photography.

Chih-Horng “James” Chen grew up in Thailand and is of Taiwanese descent. He pursued a B.Eng in electrical engineering and graduated from McGill University in 2013. He has worked with BlackBerry as a camera development engineer. James has worked on the latest technologies and has substantial experiences in data analysis. Currently, James is pursuing an M.Eng at Cornell University in engineering management. He does not have prior experience in transportation systems but is ready to put his skills into practice. Ultimately, he has been enthusiastic about this learning opportunity and excited to be part of this project team.

Allen Cheong is currently in the M.Eng program in civil engineering at Cornell, specializing in transportation systems engineering. He is originally from the San Francisco Bay Area in California. He attended the University of California, Berkeley, graduating in 2012 with a B.S. in civil and environmental engineering. While at Berkeley, he had an internship in road design and a research position in developing intelligent transportation systems. Prior to graduate school at Cornell, he worked for a year in construction management of public roadways in San Francisco. After completion of graduate school, he hopes to work in design and construction of large-scale transportation infrastructure projects. In his free time, he enjoys watching football and basketball, traveling, and photography.

Yicheng “Henry” Huang is from Liuzhou, China, the “City of Bridges.” He graduated from Tongji University with B.S. in civil engineering and is currently an M.Eng student in engineering management at Cornell University. Henry has worked as a research assistant at Tongji, focusing on bridge construction and bridge design. His research included structural analysis and engineering management processes. He has internship experiences in construction management, structural design, and even the food industry. Henry enjoys learning and mastering skills from different fields. He likes to apply different skills to try to solve individual problems. He plays sports like basketball, tennis and swimming. He also enjoys reading, cooking, watching movies, and traveling, having been to France, Norway and several states in United States.

Ravi Kodali was born in Hyderabad, India. He received his bachelor’s degree in electronics and communication engineering from Jawaharlal Nehru Technological University in 2010. Over the course of his studies, however, he had become more interested in software development. Before joining Cornell for his M.Eng in engineering management, he worked as a software developer for three years at Tata Consultancy Services. He enjoys traveling and likes listening to music. He is currently working in the simulation sub-team of the TCAT project given his interest in exploring new technologies.

Brett Musco completed his undergraduate studies at Cornell University in civil engineering and is currently continuing his education, pursuing an M.Eng in transportation systems engineering. As an undergraduate, he spent two summers working close to his hometown of Hope, Rhode Island with the Rhode Island Department of Transportation, in the road design and traffic engineering divisions. In addition, he was involved in research related to freight transportation and OD estimation during his time at Cornell. He is looking forward to completing his M. Eng this spring and hopefully finding a job in the northeast.

Shivam Patil was born and raised in India, and graduated from University of Pune, India with a B.E. in computer engineering. With a desire to learn and develop technical and management-related interdisciplinary skills, he is currently pursuing an M.Eng in engineering management at Cornell University. He is pursuing courses that amalgamate management and software engineering skills. His hobbies are trekking, reading and traveling.

Leonardo Pozzobon, from Caracas, Venezuela, is studying for an M.Eng in engineering management at Cornell University, after graduating with a degree in manufacturing engineering in 2008 from Universidad Simon Bolivar. He worked for two years in strategic planning and budgeting in a city government, supervising community projects during that time. In 2011, he joined a grain storage operation, supervising the construction and tuning of a new storage facility. In the fall of 2012, he was assigned to another facility as plant manager, and in 2013 he left his job to pursue his master's degree. He will stay another year at Cornell to pursue a one-year MBA.

Nitin Sagar Sahgal is an M.Eng student at Cornell University, majoring in engineering management. He holds a B.E. in instrumentation technology from Rashtreeya Vidyalaya College of Engineering in Bangalore, India. Prior to joining Cornell University, he was employed with Larsen & Toubro in India for two years, where he designed field instruments for thermal power plants. He plans to work as a technology consultant after graduation. He enjoys swimming and playing chess in his free time.

DongChul Rhue is an M.Eng student in transportation systems engineering. He grew up in a small town, Changwon, in South Korea, and came to the United States when he was fourteen. He did his undergraduate studies at Washington University in St. Louis, where he graduated with his B.S. in mechanical engineering. From 2009 to 2011, he served in the Tiger Division of the Korean military, where he served as a driver and a dispatcher. This experience made him interested in transportation systems, so he decided to study transportation engineering at Cornell. His goal in this TCAT project is to learn how to design and improve a public transportation system by working and coordinating with other team members, an academic advisor, and a current service manager from an actual transportation company. His professional goal is to find a job related to transportation which will train and prepare him to become a licensed Professional Engineer.

Aakash Sureka is a student from Calcutta, India. He studied civil engineering with a minor in applied economics and management during his undergraduate education in Cornell University and graduated in three years. He is currently pursuing an M.Eng in engineering management. He interned with two civil engineering companies in the past few years, gaining experience in project management, project scheduling, and quality control. He plans to work as a manager in a construction firm in Calcutta in the short term and pursue an MBA later on. He hopes to head his own construction firm someday. In his free time he enjoys swimming and playing the piano and the guitar.

Kunrawee "Bo" Tangmitpracha was born in the northeast region of Thailand, in a province with a surprisingly long name, Ubon Ratchathani. After earning a bachelor's degree in civil engineering with a focus in transportation and a minor in real estate from Cornell University, she is now pursuing an M.Eng in engineering management. During her undergraduate studies, she interned at the Siam Cement Group, the largest construction material company in Thailand, as a supply chain engineer, responsible for a project to reduce the total supply chain cost for the company's subdivision that develops roof tiles, Smart Board, and SmartWood. She has a strong passion in culinary arts and patisserie. Because of that, she is determined to develop her own business that will allow her to pursue her dream to become a patissier, utilize her skills in real estate, and make good use of her knowledge in engineering, management and finance—she hopes to run a global chain restaurant focusing on modern pastries. Bo plans to attend a business school in Japan after her graduation in May.

Cecilia Turcios was born and raised in Alexandria, Virginia. She went to Cornell for a B.S. in chemical engineering and is currently working towards her M.Eng in engineering management at Cornell. Her past internships were in the consumer products and industrial gases industries but she decided that she did not want to go into typical engineering. Therefore, she will work in financial services industry upon graduation. Cecilia enjoys baking and running outdoors.

Peng Wang was born and raised in Beijing, China, and graduated from Southeast University in Nanjing, China with a B.S. in transportation engineering. During this period, she took part in a national program for new technology and independently published a research paper. She is currently pursuing an M.S. in transportation systems engineering at Cornell University with a minor in operations research and information engineering. She is interested in transportation engineering, transportation planning and network optimization. Her hobbies are music, movies, reading, and dancing.

Yanjun Wang, born in Shanghai, is currently an MPA student at the Cornell Institute for Public Affairs. He obtained his bachelor's degree in public administration from Fudan University in China. He has worked in several public departments in the United States and China. As an affiliate to the Cornell Program in Infrastructure Policy, he has interests in railway network planning, public-private partnership, and transportation policy. He will pursue a transportation engineering program at the University of Tokyo, Japan upon graduating in 2014.

Yiyao "Ina" Yan, from Shanghai, China, is an M.Eng student in engineering management at Cornell University. She has a bachelor's degree in automotive engineering from Tsinghua University in Beijing, China. She had a summer internship in R&D at Shanghai General Motors two years ago. She is interested in taking a position in operation management later in her career. She loves traveling.

Dr. Francis Vanek, faculty advisor to this project, is originally from Ithaca, New York. He has undergraduate degrees in mechanical engineering and Asian studies from Cornell (1991), and a

PhD in systems engineering from the University of Pennsylvania (1998). He has taught at Cornell since 2001, and his professional interests include sustainable transportation, energy efficiency, renewable energy, and green building. He enjoys piano, yoga, and physical fitness.

Sub-Teams

Current System & System Improvements

Members: **DongChul Rhue, Aakash Sureka, Cecilia Turcios**

The purpose of this sub-team is to identify the trouble areas for TCAT and develop suggestions for improvement given their resource and budget constraints. TCAT grew in ridership for six straight years and crossed four million riders in 2012. The sub-team explored the following topics: Route 13, real-time passenger information, and the Cornell campus morning bus routes. The average percentage change in ridership from 2011 to 2012 is +4.7%; however, for Route 13 the ridership dropped by 11.5%. This is the reason why the sub-team evaluated Route 13 and explored ways for optimization. Another topic that the sub-team explored was that TCAT currently does not have a real-time passenger information system in place. There are only fixed timings and passengers are not informed of any delays or out-of-service routes. Lastly, the Cornell campus morning routes are in high demand, causing buses to be over capacity and riders to miss the bus. The sub-team explored ways to improve the service of these stops. The team also evaluated and suggested a different naming system for TCAT's current inconsistent bus and naming system. The team also explored a way to optimize TCAT's scheduling needs.

Environmentally-Friendly Buses

Members: **Leonardo Pozzobon, Nitin Sahgal, Yiyao Yan**

The world is becoming increasingly concerned about global warming and the United States has committed to Greenhouse Gas Cuts under the Copenhagen Climate Accord. The sub-team studied relative amounts of greenhouse gases saved by different scenarios. In this project, exploration of greenhouse gas emissions focused on CO_2 at the end-use stage of the life cycle. The cost-effectiveness of the options in terms of dollars per ton of CO_2 was calculated as well. CO_2 reduction was calculated based on emissions avoided when existing riders use transit instead of driving a private automobile and when diesel buses in TCAT fleet are replaced by hybrid diesel-electric/hydrogen/electric or biodiesel buses. According to TCAT Yearbook 2012, a hybrid diesel/electric engine increases fuel efficiency from the typical 3.85 mpg of a diesel bus to 4.31 mpg, an improvement of about 12%. However, hybrid diesel/electric buses cost $100,000 to $200,000 more than non-hybrid ones, and the fuel cost savings do not cover the increased purchase cost. The sub-team also took economic feasibility into consideration when giving suggestions on environmentally-friendly buses.

Buses with a High Level of Service

Members: **Allen Cheong, Brett Musco, Yanjun Wang**

The goal of the BLHS sub-team's research was to study the feasibility of a BLHS system in the Ithaca area. The research focused on the benefits and cost of a BHLS system based on the current local situation. The sub-team learned from existing examples from other cities and discussed how these can be applied to the Ithaca region. Some transportation policy research were also included in the study, so the sub-team also looked back on related regulations from previous experiences and the communication between public transportation companies and local governments.

Bus Rapid Transit

Members: **Henry Huang, Shivam Patil, Peng Wang**

This part of the project aimed to study the feasibility of a BRT system in Ithaca. By comparing similar cases in different countries, the sub-team was able to summarize the major features and requirements for implementing the BRT. Based on the multi-criteria analysis of local conditions, the team gave its own judgment of the feasibility of BRT features in Ithaca. The sub-team proposed a "modified BRT system" that is better suited to the local area. After evaluating requirements and determining strategies, a system model was built with data provided by TCAT, and costs and revenues were assessed accordingly.

Articulated Buses

Members: **Kati Chang, Sean Chayanupatkul, Bo Tangmitpracha**

Among all types of high capacity transit vehicles, articulated buses are operated in a few metropolitan areas in North America. Some applications include peak-demand services, serving on BRT systems, high-demand special events, and commuter express service. As a part of the project, the feasibility of introducing articulated buses to the existing service was investigated. The benefits and the tradeoffs involving the level of service, the effects on dwell and running times, the capital investment, the maintenance, as well as other operating issues were taken into consideration.

Simulation

Members: **Sruja Aluri, James Chen, Ravi Kodali**

Currently, TCAT does their scheduling manually and many bus routes may not be fully optimized for different situations, such as peak hours, off-season, weekends, etc. The team built a simulation model for one bus route that displayed the current schedule's effectiveness by showing the data of average bus capacity at any given point, number of bus-full cases, and passenger wait times. The model was also used to test the need for a change in schedule, to suggest alternate schedules effectively if needed, and to show the analysis through the model. The sub-team did this by collecting the historical data that was available from TCAT. This model was designed to be flexible and be able to incorporate any changes which TCAT may consider implementing into its system, such as the service options discussed in this project.

Team Liaisons

In addition to the sub-teams described above, the project team also assigned liaison roles for two members for improved coordination between the advisor and the client.

The **Advisor Liaison** (Allen Cheong) was responsible for meeting with the advisor, Dr. Vanek, and keeping him updated on project activities. He stayed informed of progress and issues for each sub-team. In addition, he served as the chief editor of the technical report and other deliverables of the project.

The **TCAT Liaison** (Brett Musco) was responsible for streamlined communication with representatives at TCAT, primarily Doug Swarts. Whenever a sub-team required data or information from TCAT, the liaison sent the request to the client and provided this information to the sub-team when received. This was to reduce the number of emails sent to the client, as many sub-teams requested the same information.

Metrics for Use in the Project

The following metrics were of interest:

1. Life cycle cost of service improvements, including capital and ongoing non-capital costs.
2. Estimated tons per year of CO_2 emissions avoided.
3. Cost per ton of emissions reduction.
4. Confidence interval on answers using Monte Carlo simulation in RSPE or @Risk.

TCAT

History

Tompkins Consolidated Area Transit (TCAT), founded in 1998, is a consolidated transit service that serves Tompkins County, the City of Ithaca, and Cornell University. Before 1998, there were three separate public transit systems: TOMTRAN serving Tompkins County, CU Transit serving Cornell University, and Ithaca Transit serving the City of Ithaca. Because of inefficiencies in the service and operation of the separate transit systems, TCAT was born.

This transit system has flourished over the years. In 2012, annual TCAT ridership increased to over four million, giving it a new size category (4 to 30 million riders per year) for the American Public Transportation Association (APTA). There are 33 bus routes, 32 of which are fixed and one route with a demand-response component. These routes utilize a fleet of 54 vehicles consisting of 50 transit buses and four mini-buses. In 2012, this fleet operated about 1.6 million revenue miles for about 120,000 revenue hours.

TCAT became a non-profit corporation in 2005 and is funded by the State Transit Operating Assistance Fund, which provides funding based on the annual ridership and annual miles traveled. TCAT's sources of income, ranging from highest percentage to lowest, are state funds, cash fares, City of Ithaca, Tompkins County, Cornell University, and federal funds. In recent years, TCAT has been struggling with a tight budget and have made several measures to help trim their budget, such as increasing rural fares, freezing wage salaries, and making route cuts.

Bus Routes and Systems

The 33 bus routes can be divided into three main categories: urban, rural and campus.

Urban (non-campus) routes include Routes 10, 11, 13, 14, 15, 17, 30, 31, 32, 51, 70, and 72. Ridership of these urban routes has steadily increased from 2003 to 2012. The consistent ridership is heavily influenced by patterns of campus life at Cornell University and Ithaca College. By looking at the table of Routes Sorted by Ridership Gain, 2010-2012 in the TCAT 2012 Yearbook, Route 10 (C.U. – Commons), Route 81 (C.U. Weekday), Route 82 (C.U. Weekday) take 10.65% (439,494), 13.3% (548,907), and 9.5% (394,849) of the total 2012 TCAT ridership (4,128,240) respectively. Also, Route 30 (Commons – Mall), which many students take for shopping, dining, and other activities, takes 17.15 % (707,805) of the total ridership.

Rural routes can be divided into two sub-categories: minimum service and large market. Rural minimum service routes have few peak hour trips and perhaps one mid-day trip, and these routes include Routes 20, 22, 36, 37, 40, 53, 65, 74, 75 and 77. Large market routes generally serve outlying villages and these include Routes 21 (Trumansburg), 41 (Freeville/Etna), 43 (Dryden), 52 (Caroline), and 67 (Newfield). These rural routes generally have lower ridership compared to the urban routes.

Ridership by Route Type, 2002 – 2012

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Urban Total	2,416,973	2,400,221	2,735,944	2,674,183	2,713,008	2,862,428	2,869,689	3,089,507	3,407,935	3,591,621
Campus	970,879	902,264	1,026,261	876,575	850,437	848,242	833,048	1,040,386	1,154,271	1,200,811
Campus Day	813,799	805,922	912,409	777,038	752,856	743,487	718,450	903,188	979,944	995,650
Campus Night	157,080	96,342	113,852	99,537	97,581	104,755	114,598	137,198	174,327	205,161
Urban	1,446,094	1,497,957	1,709,683	1,797,609	1,862,571	2,010,748	2,036,641	2,049,121	2,253,664	2,390,810
Rural Total	371,241	339,439	358,416	391,126	393,207	455,283	482,103	488,072	536,690	536,621
Rural Large	266,528	244,298	260,432	276,983	270,646	300,824	311,317	298,674	339,617	334,036
Rural Min.	104,713	95,141	97,984	114,143	122,561	154,459	170,786	189,398	197,073	202,585
Total	**2,788,214**	**2,739,660**	**3,094,360**	**3,065,309**	**3,106,215**	**3,317,711**	**3,351,792**	**3,577,579**	**3,944,625**	**4,128,242**

Figure 1: Ridership by Route Type, 2002-2012

The TCAT 2012 Yearbook provides data on ridership by route type for previous years (see Figure 1). Urban total ridership and rural total ridership in 2009 and 2012 can be compared to determine percentage share changes of system ridership. From 2009 to 2012, the urban total ridership share increased from 85.62% (2,869,689) to 87.00% (3,591,621), while rural total ridership decreased from 14.38% (482,103) to 13.00% (536,621). Even though there is a general increase in ridership for both route types, the percentage share of urban route ridership increased while that of rural routes decreased.

There are six bus routes that run within Cornell campus. These include the C.U. Weekday routes (81, 82, 83) and the C.U. Nights routes (90, 92, 93). Additionally, there are two bus routes that run between Cornell University, Ithaca College, and the Commons. Route 10 runs between Cornell University and the Commons, while Route 11 runs between Ithaca College and the Commons. Ridership on Cornell campus routes increased with OmniRide pass distribution in 2005. Also, night service increased significantly in 2011 because of an increase in night service on Routes 11 and 90.

TCAT designates certain areas as zones (see Figure 2). Zone 1 refers to the Ithaca inbound area, and Zone 2 is the outbound (rural) area around Ithaca (Zone 1). If a passenger boards in Zone 1, the fare is $1.50 for a single ride. A passenger boarding in Zone 2 pays $2.50 for the inbound direction. Starting on January 12, 2014, a passenger boarding in Zone 2 in the outbound direction pays no fare.

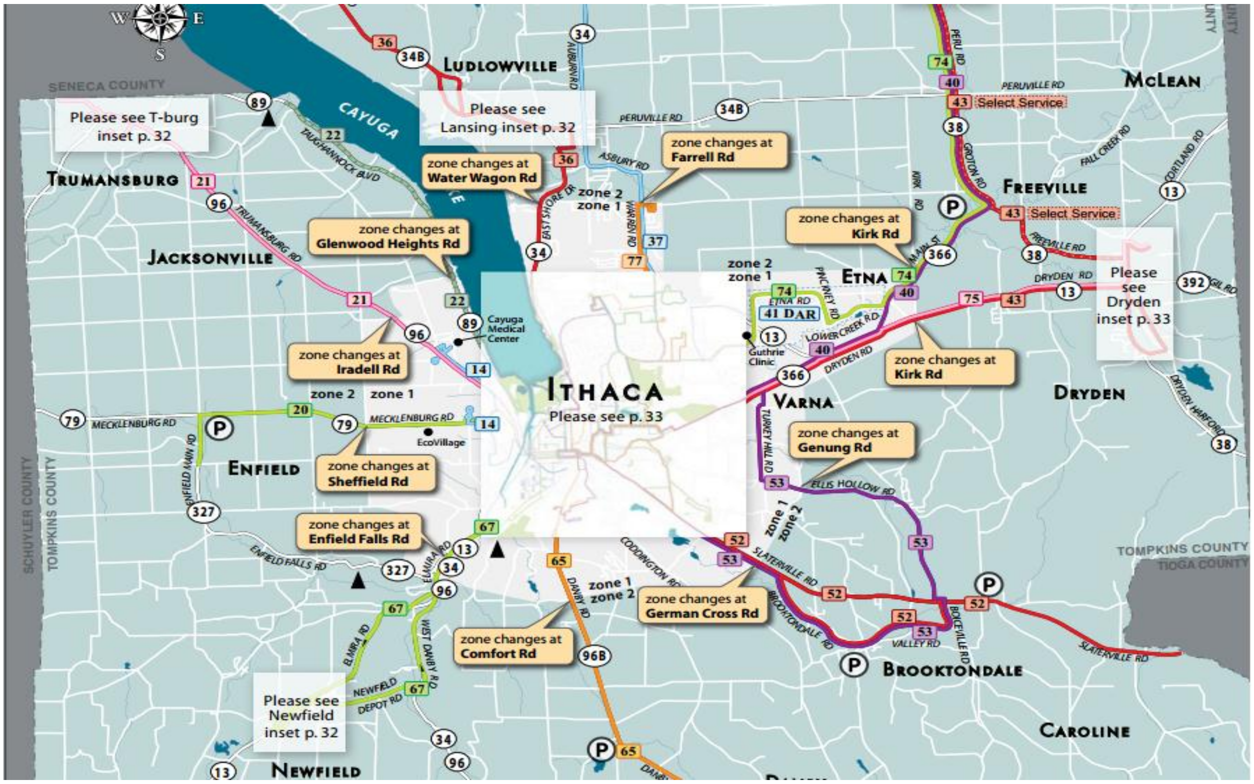


Figure 2: Map of Service Zones

Recent Improvements in Routes, Buses, Service Hours

Over the past decade, TCAT has been focused on trying to refine their system to increase efficiency and better meet public demand. Three times a year (August, January, and May) TCAT will make small adjustments to their schedules, refining the frequency and hours of operations along different routes. More major revisions are done through Transit Development Plans (TDPs), which are completed approximately every five years. These plans analyze the service provided and seek to rearrange, discontinue, and add routes. The last one of these plans was completed in 2009 and implemented in 2010. This plan included the extension of the Route 82 bus from Cornell campus to East Hill Plaza via the Maplewood Apartments. This change is associated with nearly a 25% increase in campus ridership.

Also introduced in 2010 was Route 41, the first demand-response route, which does not have a fixed route but rather serves a larger area based on demand. For the route to pick up a passenger, they must all in in advance. Currently the 41 serves the general areas of Sapsucker Woods and Etna on weekdays (this region is served by the fixed Route 74 on weekends). While the 41 is TCAT's first experiment in demand-response routes, this method could be implemented in the near future to serve other low density neighborhoods.

Along with these two significant route changes, TCAT has also been introducing new ways for riders to pay for the bus. One of the biggest changes was in 2005 when Cornell reached an agreement with TCAT to provide all students with OmniRide passes. This caused an overall increase in ridership of 13%. Two years later, this was revised to only include new students to the school, but current students could purchase a pass significantly discounted. The same year, students began to scan there cards on the buses via new electronic fair collection systems that had been installed. Further improvements were made in 2010, when the Green Street station was opened, including a coffee shop and indoor waiting area. An electronic fare box was also installed in the station, which enables riders to purchase passes for various number of rides or days, better suiting individual needs. Today, the Green Street station remains the center of the TCAT network, handling more boardings than any other stop.

Finally, TCAT has been working to update their fleet of vehicles to new, cleaner technology. Due to federal regulations, once TCAT purchases a vehicle, they must use it for 12 years before it can be retired and replaced. As a result, starting in 2006 TCAT began to replace some of its retiring vehicle with new hybrid vehicles that can be used in the urban area more efficiently. In total, the TCAT fleet now features eight hybrid-diesel buses. Furthermore, over the past decade, TCAT has switched almost all of the fleet from standard high floor buses to more accessible low floor buses. This change not only makes boarding easier for disabled passenger, but also increases the rate at which all passengers can board.

Future Plans

TCAT is assessing its information technology and data management needs in several areas. When the study is complete, TCAT plans to implement a system that can export service data in General Transit Feed Specification (GTFS) format for Google Transit. This would enable smartphone apps and other third party technologies to easily convey transit data, including real time information to alert passengers about such things as weather related, sudden traffic delays, where the buses are in real time, and the estimated arrival time of the bus to a bus stop of a particular route.

Another technology project is the implementation of the Informational Technology/Intelligent Transportation Systems Study, completed in 2012, that is providing a path which will allow streamlining many of the administrative and maintenance tasks TCAT performs daily. New software for route and service changes is on the way for TCAT, saving time on manual work for the route and service changes taking place thrice a year. In fact, with the help of the new software, changes will be very easy and their results will be available quickly. Manually creating schedules requires three people working on the route and service changes for three weeks, and the software will definitely save time and human effort.

Demand-responsive transit responds to the needs of riders not served by a fixed-route bus line by giving them more individualized, on-demand, curb-side service. Because of this flexibility, demand-response service is capable of covering larger areas of lower density development than a fixed-route bus. In the future, TCAT can run more of these services. After the studying the response of the currently implemented system, if required, instead of a full-scale implementation for a route, demand-response can act as the feeder for the high-ridership main routes.

The "What's a Bus Stop?" Project seeks to clearly establish TCAT's bus stops in urban and suburban areas, which will clarify TCAT service to riders, improve conditions for drivers and provide a basis for real-time information initiatives such as expected arrival time of the bus and its route number. TCAT can retire the 2002 New Flyers and 2001 Nova buses as soon as they reach retirement age of twelve years and replacement buses have been procured. TCAT is going to add one hydrogen buses to its fleet as a trial, which will result in fewer greenhouse gas emissions and air pollutants. If successful, more hydrogen buses will be added to the fleet. There are plans to have new garages for bus storage at Seneca Street and Green Street because the current garage is over its capacity.

Data

The data used in this report were based on average ridership data compiled by TCAT for September of 2013. This data was provided for Routes 82, 81, 13, 15, 41, and 30 in Excel format. Each Excel file contained a table of average hourly boardings and total boardings during the month, aggregated at each designated time point along the routes. The data was further broken out into weekday, Saturday, and Sunday averages. One important note is that the data does not contain boarding for each individual stop; rather, TCAT aggregates the data from multiple stops into time points, which are major stops defined by TCAT to represent that particular stop as well as the subsequent stops until the next major one. After a bus passes a time point, all boarding at future stops are counted as accounting to that time point until the bus reaches the next time point. In addition to the compiled average data file, we were also given access to the raw data, which records each individual fare payment.

While the average ridership file was our primary source of data, some analysis was also performed using timing studies conducted during the fall of 2013, as well as bus full reports from January to March 2014. The timing studies calculate the average deviation from the scheduled arrival time of the bus at a given stop. This gives insight into what routes struggle with on-time performance during peak hours. The bus full logs are a record of every time a driver reports a bus as being full and has to turn down riders. These reports have to be individually called in by the drivers at the time of the occurrence. The drivers also estimate how many passengers are left behind and note any obvious cause for the overcrowding. Other data was taken directly for TCAT's publicly available yearbooks. Additionally, some numbers were found manually through our own observations, by riding the bus and through everyday experiences.

Timeline

In order for this project to be completed within an academic semester, the project team followed many deadlines for deliverables throughout the course of the project. Throughout the project, deadlines deviated from their original dates in order to overcome scheduling challenges.

12/10/13	The project team met for the first time with Dr. Vanek to learn the purpose of the project and a general overview of what is expected of the team in the following semester.
1/28/14	The team attended two courses presented by Dr. Vanek which introduced many transportation engineering concepts to those who were unfamiliar with this field of engineering. Project information was covered in greater detail. The team members were given an assignment on calculating costs and emissions for sample transportation systems.
2/6/14	The team began holding weekly meetings to coordinate project activities.
2/7/14	Each team member submitted personal goals for the project.
2/18/14	In addition to weekly internal meetings, the team began meeting weekly with Dr. Vanek to discuss project status and deliverables.

2/21/14	The team met with Doug Swarts at TCAT's office in Ithaca and became more familiar with its operations and procedures.
3/4/14	The team completed its literature review and draft proposal.
3/11/14	The team submitted its final proposal.
3/25/14	The team evaluated its performance and progress, and submitted a midterm management report.
3/28/14	The team members evaluated each other's participation and contributions to the project to date and submitted these evaluations to Dr. Vanek.
4/29/14	The team gave an informal presentation of their findings to Dr. Vanek and some graduate students who will be participating in a Master of Engineering project next semester.
5/9/14	The team gave its final presentation to TCAT, presenting the studies they have conducted and their recommendations on the chosen service measures. This took place at TCAT's office.
5/14/14	The team submitted a draft of their technical report.
5/21/14	The team submitted its completed technical report.

II. TCAT Current System Improvements

Introduction

TCAT has experienced substantial growth over the last 10 years, where just in 2013 alone there was a 6.3% increase in ridership from 2012. As with any system, it is important to always look for ways to improve the system and TCAT is no exception. With the ridership increasing to 4.4 million in 2013 (about a 300,000 increase from 2012), it is important to identify ways for TCAT to better serve the community and their internal infrastructure.

The purpose of TCAT Current System Improvements sub-team is to analyze both the internal and external system of TCAT and identify which areas are important to explore, given the time and resource constraints.

The following are the problem areas we identified for TCAT:

- Route 13 has steadily decreased in ridership over the years.
- The increased morning demand on North Campus has exceeded the capacity of the buses, therefore leaving unsatisfied riders.
- There is currently no real-time passenger information system for TCAT customers and it is important to incorporate that into TCAT.
- The current TCAT naming system of "Inbound" and "Outbound" has ambiguous meanings depending on route and direction the bus is headed.
- Currently, there is no set optimization program for TCAT assignment of bus drivers and vehicles.

The following sections will expand on each other problem areas and suggest possible solutions to address those problems.

Declining Route 13 Ridership and High Morning Demand

Declining Route 13 Ridership

Route 13 is a route that runs from Ithaca Mall to Ithaca Commons with stops at TCAT offices, Ithaca High School, Stewart Park, etc. When we first came to visit TCAT offices as a group earlier in the semester, we rode Route 13 to get to TCAT, and we realized that there was only one passenger other than our group on the bus that morning.

To get a better understanding of Route 13, TCAT provided data for the average ridership of Route 13, and as expected, the daily average of Route 13 was very low. Its weekday daily average ridership was about 152 while the other routes, such as Route 30, had over 3,500 per day.

As we looked into more detail about Route 13, we also realized that it is not very efficient, time-wise and distance-wise. In total, Route 13 is about twelve miles long, but there are only seven stops, which means that the distance between each stops are long. Route 13 also changes to Route 31 as it approaches the Commons area, and then continues to serve other areas. This makes too long of a trip for buses that serve Route 13 and 31, which also consumes large quantities of fuel.

What makes this issue worse is that the annual average ridership of Route 13 has been decreasing over the past few years. Since 2011 to 2013, the average ridership has decreased about 10-15% every year. With declining ridership and low distance-wise efficiency, we concluded that Route 13 does not seem very profitable to TCAT.

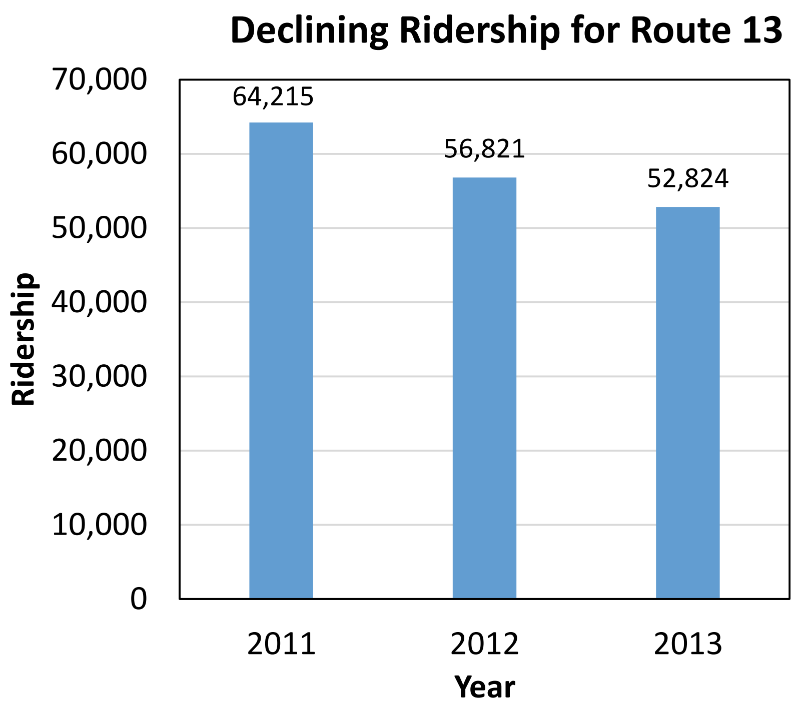


Figure 3: Declining Ridership for Route 13, 2011-2013

High Morning Demand

Another issue identified was the high morning demand of the Cornell campus routes. Currently, Routes 30, 81 and 82, which serve Cornell's north and central campus areas, are the major sources of TCAT's total ridership, and these three routes have shown consistent increase in ridership over the past years.

Routes Sorted by Ridership Gain, 2010 – 2012

Rt.	Destination	2011	2012	Δ #	Δ %
72	Wkend Airport	35,412	50,472	15,060	42.6%
90	C.U. Night	31,924	42,807	10,883	34.5%
32	Airport	199,093	254,128	55,035	27.7%
53	Ellis Hollow	11,276	13,671	2,395	21.2%
75	Wkend Dryden	6,398	7,628	1,230	19.2%
10	CU - Commons	373,820	439,494	65,674	17.6%
20	Enfield	39,154	45,884	6,730	17.2%
93	C.U. Night	40,005	46,258	6,253	15.6%
51	Eastern Heights	117,201	134,813	17,612	15.0%
92	C.U. Night	103,008	116,096	13,088	12.7%
37	North Lansing	24,896	27,687	2,791	11.2%
41	DR Lansing	17,630	19,445	1,815	10.3%
74	Wkend Groton	4,122	4,468	346	8.4%
36	South Lansing	18,071	19,584	1,513	8.4%
70	Wkend Mall	142,123	153,456	11,333	8.1%
83	C.U. Weekday	48,086	51,894	3,808	7.9%
43	Dryden - TC3	133,484	141,415	7,931	5.9%
82	C.U. Weekday	378,137	394,849	16,712	4.4%
21	Trumansburg	103,364	106,917	3,553	3.4%
30	Commons - Mall	687,790	707,805	20,015	2.9%
11	IC - Commons	204,448	207,613	3,165	1.5%
40	Groton	34,424	34,569	145	0.4%
81	C.U. Weekday	553,721	548,907	-4,814	-0.9%
15	Southside	104,363	102,966	-1,397	-1.3%
77	Wkend Warren	467	451	-16	-3.4%
67	Newfield	43,558	41,717	-1,841	-4.2%
31	NE Ithaca	127,848	121,426	-6,422	-5.0%
65	Danby	23,537	21,318	-2,219	-9.4%
22	Taughannock	8,530	7,685	-845	-9.9%
13	Northside - Mall	64,215	56,862	-7,353	-11.5%
14	West Hill	128,022	112,592	-15,430	-12.1%
17	TCAT / Fall Creek	64,440	48,924	-15,516	-24.1%
52	Caroline	59,211	43,987	-15,224	-25.7%
68	SW Shopping	3,814	129	-3,685	-96.6%
54	Turkey Hill	8568	195	-8373	-97.7%
	TOTAL	3,944,625	4,128,24	183,61	4.7%

Figure 4: Routes Sorted by Ridership Gain, 2010-2012

From the figure (Tompkins Consolidated Area Transit 2012), Routes 30, 81, and 82 take 17.15% (707,805), 13.3% (548,907), and 9.5% (394,849) of the total ridership (4,128,240) in 2012.

The ridership of Cornell campus routes have their peaks in the morning, when students who live in the north campus area are trying to get to their morning classes. These three routes seem to have their peak demand from 8 to 9 AM. The average ridership during that peak hour was more than 300, which exceeds the total capacity of the buses.

Based on the bus full log, which counted the number of passengers who were denied boarding when the buses were full, we made a figure of morning boardings denied per weekday, and we realized that current Cornell campus route services are not met with this high morning demand.

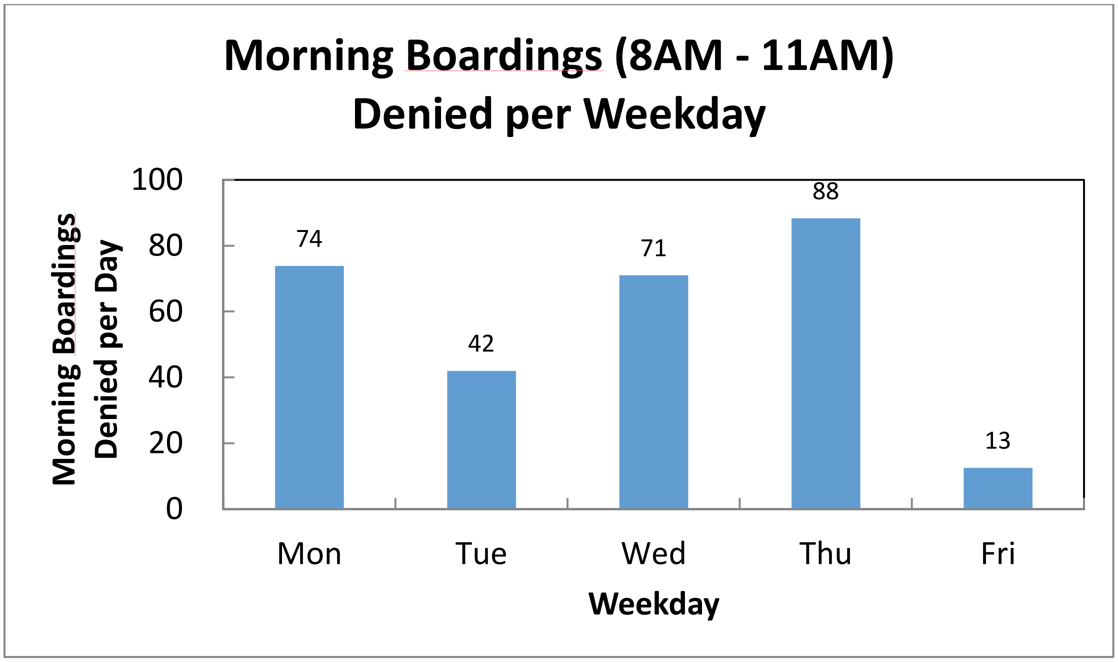


Figure 5: Morning Boardings (8 AM - 11 AM) Denied per Weekday

Proposed Solution: High Performance Campus Route (Route 84)

Our solution to these two problems is to create a new high performance route by reallocating the sources for the existing Route 13. Route 13 had low ridership, and since it was running a longer distance than the other routes, it was not very cost-effective, so we propose removing Route 13 and using its resources for a proposed new route.

Our proposed, high performance campus route, “Route 84,” will run from A Lot of north campus to Schwartz Center for the Performing Arts (Schwartz PAC) with stops at Goldwin Smith, Statler, etc. This new route is designed to be similar to the current Route 81, but has it extended to Collegetown so that it helps serve high campus demand and also serve students who live in the area. This route will only run in the morning, from 7 AM to 11 AM, since this is a route designed particularly to solve the high morning demand problem.

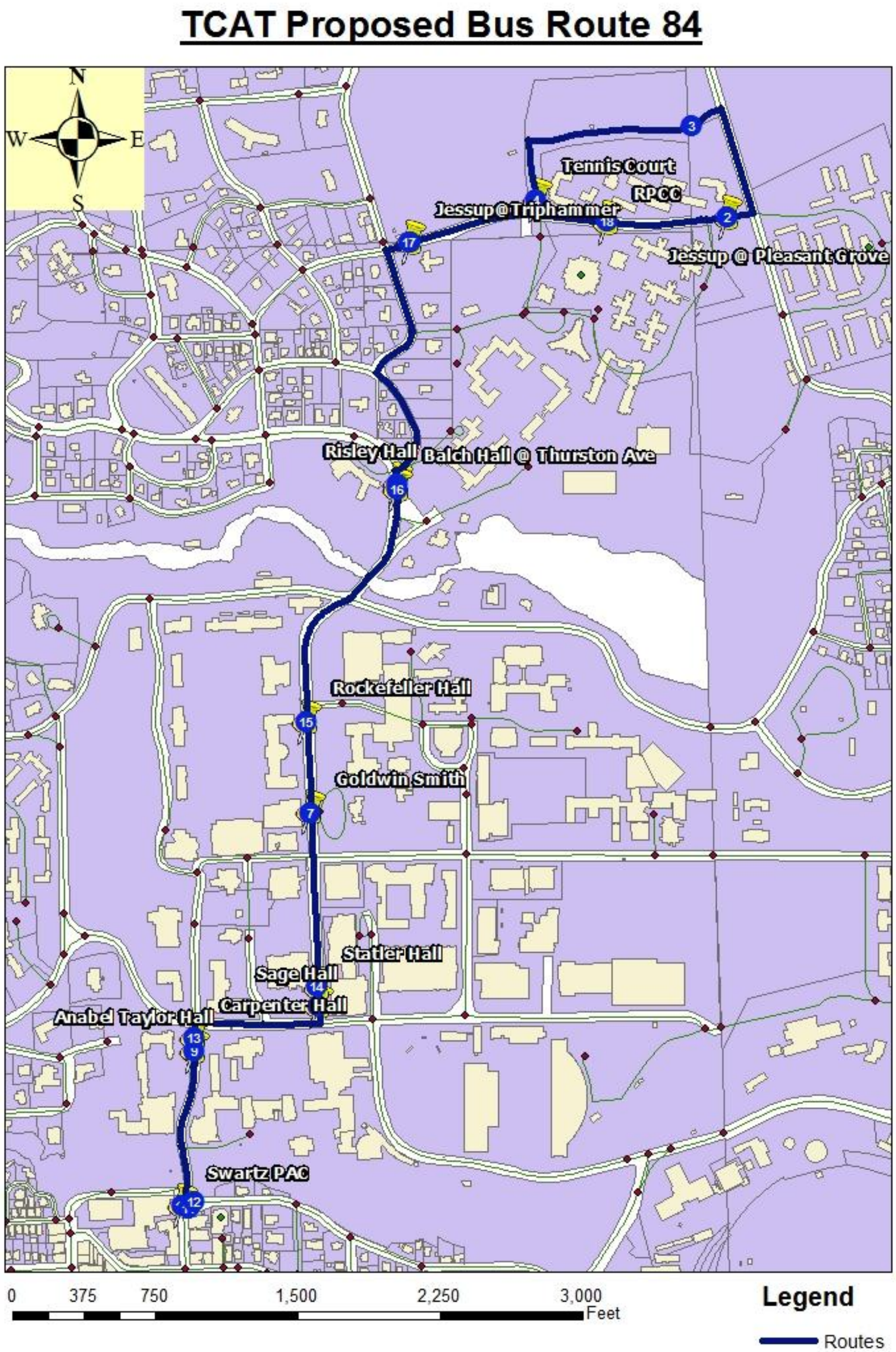


Figure 6: Proposed New Campus Route - "Route 84"

The expected demand is 250 daily passengers for this new campus route. This ridership estimation is based on the assumption that Route 84 will take all the morning boardings denied from Routes 30, 81, and 82, and that 30% of current campus route passengers will transfer to this new route.

The following figure compares the hourly ridership in the morning (7 AM – 10 AM) for Route 84 and Route 13. As expected, we got much higher ridership for Route 84.

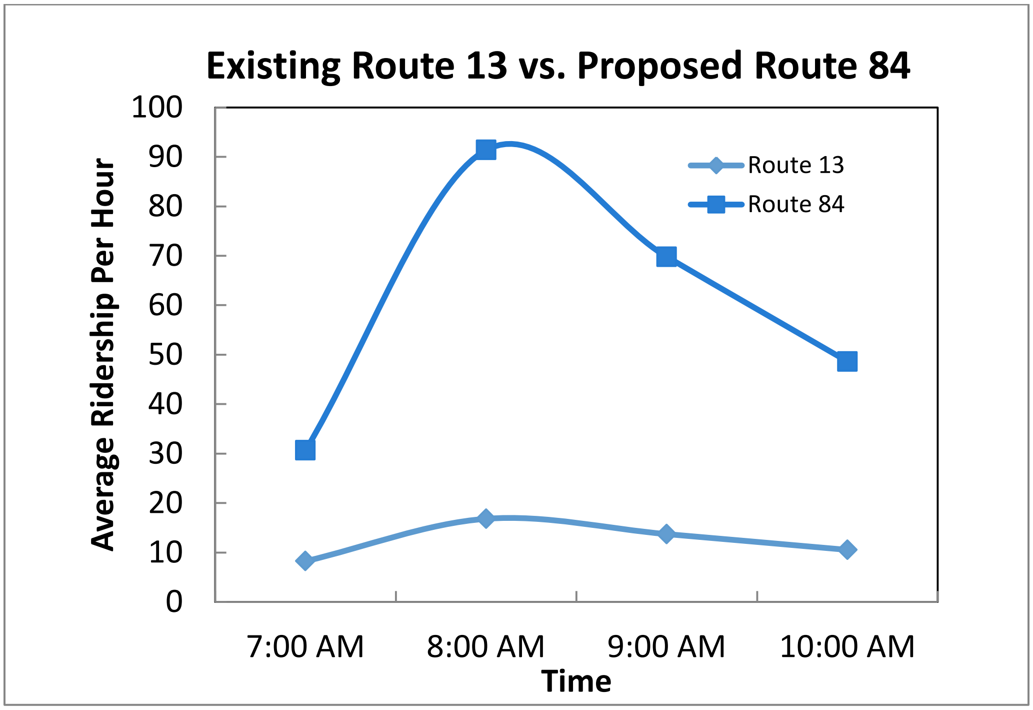


Figure 7: Hourly Ridership Comparison for Routes 84 and 13

Based on the difference in average daily ridership, miles run, and operation hours, we made economic and environmental analyses on these two routes. There was greater profit ($80,000 more), and fewer CO_2 emissions (430,000 lbs. less) for Route 84.

	Route 84	Route 13
Daily Ridership	250 passenger	-
Annual Ridership (based on 2012)	-	56,862 passengers
Total Miles run/day	2.92 miles	11.5 miles
Operation Schedule	Weekdays only, 7 AM – 11 AM	Weekdays : 8 AM – 7 PM Weekend : 7 PM – 7PM
***Total (Annual) Cost**	**$58,947**	**$74,281**
Total (Annual)Revenue	**$97,000**	**$85,293**
Total (Annual) Profit	**$91,884**	**$11,012**
Total (Annual) CO_2 Emission	**34,536 lbs. CO_2**	**462193 lbs. CO_2**

Table 1: Economic and Environmental Analyses on Routes 84 and 13

*For simple comparison, we only considered “Fuel” cost for calculating profit.

*Other costs such as maintenance/repair and wage are not counted, but their costs are available in the Appendix.

From the performance comparison figure, the proposed Route 84 will be able to run more efficiently than the current Route 13. However, TCAT should not completely get rid of the current Route 13. Even though their numbers are small compared to other routes' ridership, there are still people who use Route 13, and they still need this service. We suggest that TCAT switch to the minibuses for Route 13, and have fewer stops by removing unnecessary ones, such as the TCAT office, which is already served by Route 17.

Due to infeasibility, Route 13 resources are recommended to be used with Route 84. This recommendation does not take into account community acceptance, which is beyond the scope of the project and does not include approval procedures. However, this recommendation is justified based on the fact that Route 84 would serve more people as compared to Route 13 (which has a steeply declining ridership that is already low in the first place). Route 13 stops can also be accessed with one or two transfers using routes like Route 30, 17, etc. The resources used for Route 84 can return to Route 13 services in the afternoon, since the Route 84 service is only in the morning during the weekdays. For instance, people can either take Route 18, then transfer to Route 30 to get to the mall, or they can wait until the afternoon to take Route 13 straight to the mall. This recommendation was also based on the view that the needs of the many outweigh the needs of the few, and Route 84 was a lot more convenient. Furthermore, we do not anticipate a complete loss of Route 13 revenue, as passengers would use a slightly longer route instead. However, setting aside all considerations, the feasibility of community acceptance was not addressed as a separate problem.

Lack of Real-Time Information for Passengers

One of the major conveniences that TCAT provides its passengers is information on bus schedules and routes. This is a very important service, as it allows the passengers to know when a bus, on a particular route, would depart from which stop. This way, a passenger can plan his or her trip beforehand, rather than wait at the stop without knowledge of the bus schedule. TCAT provides this information to its passengers in very conventional ways.

The most orthodox way in which TCAT provides bus schedules is by pasting the schedules at the stops. A passenger waiting at the stop shall then have access to the schedule directly. It is not the most convenient or widely used method of planning trips. However, a major benefit of providing information this way is that it eliminates the need of technology, and provides the information as a hard copy.

The most widely used method of finding bus schedules for TCAT is using the internet to access the main TCAT website. The TCAT website consists of all information one requires about TCAT, but is mostly used to find bus schedules. The website consists of two convenient ways of finding bus and route schedules.

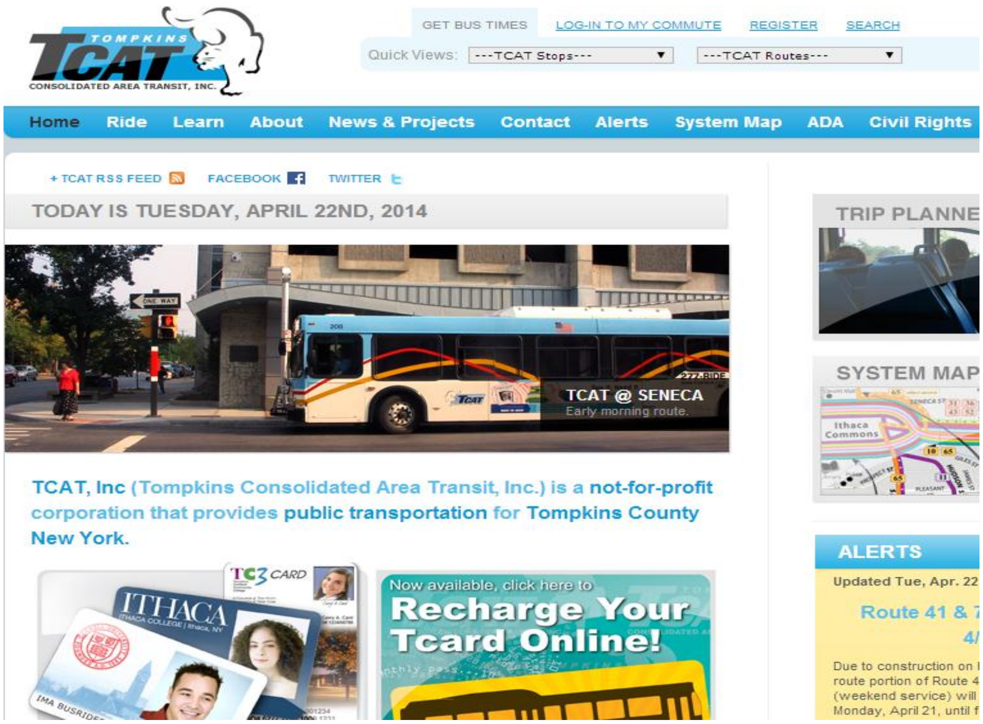


Figure 8: Screenshot of TCAT Website

The first way is by looking at route schedules. The TCAT website has a tab at the homepage which says TCAT Routes. When clicked, a dropdown menu appears in which all the various TCAT routes are mentioned. By clicking any one of them, the departure schedule for each stop for that route opens up as a new page. The bus schedule currently is divided into two sections – weekdays and weekends. Each section has two subsections for distinguishing between inbound or outbound departure times at each major stop. It does not include all stops that TCAT has, but has enough to provide a general route and time. This is a convenient way to get bus information because one can see all departure times for the entire day and plan his/her schedule accordingly.

OUTBOUND FROM CENTER OF ITHACA

Seneca @ Commons	Green @ Commons	College @ Dryden	Statler Hall	Highland @ Wyckoff	Triphammer @ Hanshaw	Shops at Ithaca Mall @ Sears
O	A	B	C	D	E	J
--	6:00AM	6:05AM	6:09AM	--	6:18AM	6:27AM
--	6:30AM	6:35AM	6:39AM	6:42AM	6:46AM	6:55AM
--	7:00AM	7:05AM	7:09AM	7:12AM	7:16AM	7:25AM
--	--	--	--	--	--	--
7:23AM	7:30AM	7:35AM	7:39AM	7:42AM	7:46AM	7:55AM
--	7:45AM	7:50AM	7:54AM	7:57AM	8:01AM	8:10AM
7:53AM	8:00AM	8:05AM	8:09AM	8:12AM	8:16AM	8:25AM
8:06AM	8:15AM	8:20AM	8:24AM	8:27AM	8:31AM	8:40AM
8:23AM	8:30AM	8:35AM	8:39AM	8:42AM	8:46AM	8:55AM

Figure 9: Screenshot of Route 30 Bus Schedule

The second way of finding a departing bus time from a particular stop is by choosing the TCAT Stops tab instead. A dropdown menu would appear again, which provides the next few departing buses at that stop. This too is a highly convenient method of finding different buses from one stop. It eliminates the need to search multiple bus schedules for a particular stop and easily gives the time of the next 5-10 departing buses from that stop. The only prerequisite is that the passenger should know which bus stop he or she will be using.

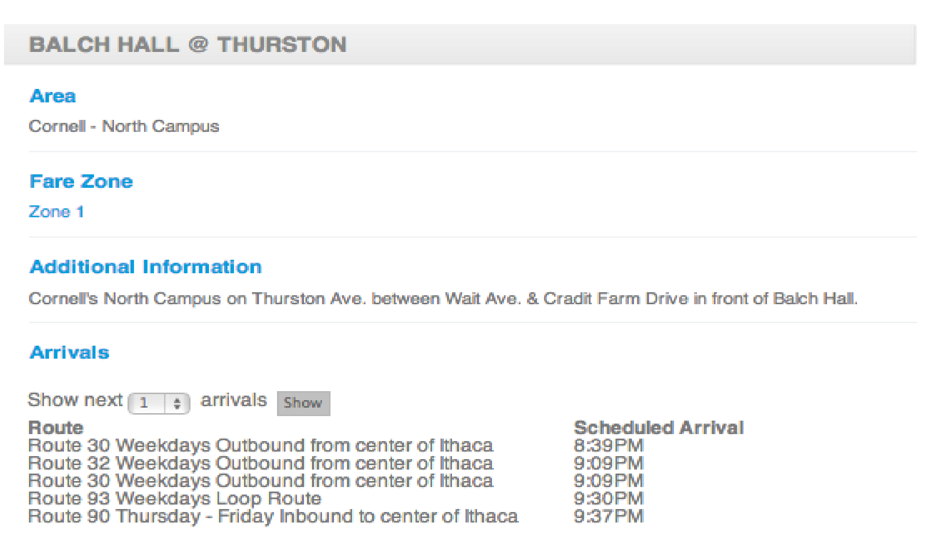


Figure 10: Bus Arrivals at Balch Bus Stop Using the Stops Tab

These are convenient ways of finding schedules if the passengers know which route they need to take or which stops they are at. However, in situations where the passengers do not know either of the parameters, the TCAT website provides a third option of using a Trip Planner guide. To access this guide, one needs to click the "Ride" tab on the main website and click on the "Trip Planner" tab from the resulting dropdown menu. The passenger then needs to type their origin and destination, and provide their desired departure times to access the trip planning guide which then would provide a series of instructions and buses to use.

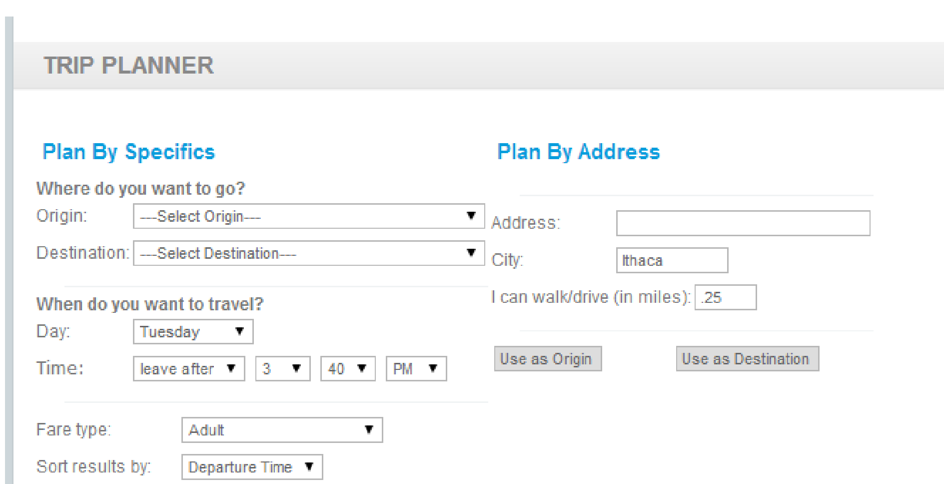


Figure 11: Trip Planner

These are the ways to access passenger information using the website. However, to keep up with current technology and the demand for mobile information, TCAT also came up with a mobile software application called Ride14850. This software application is available on the Apple Store for $0.99 and can only be used in mobile devices running the iOS system. The app is similar to the website and provides just route schedules and departures at each stop.

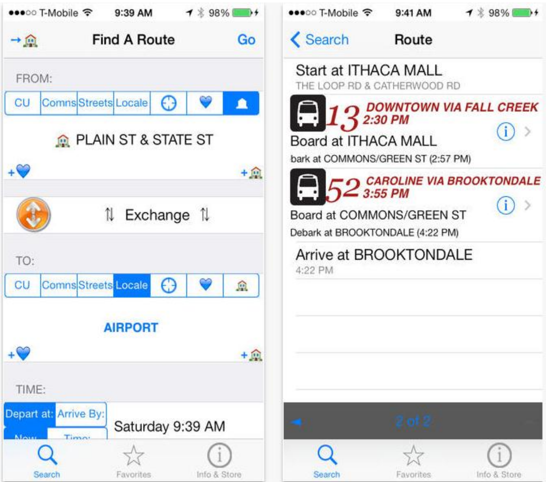


Figure 12: Ride14850

Although the methods by which TCAT provides passenger information appears to be sophisticated, it is highly outdated. It is evident that, in this fast paced world, it takes relatively more time and effort to access this information. One needs to have access to the internet at all times to access the website or know which buses or routes to take without knowing the shortest possible routes. It does not provide information on any other mode of transit and is relatively inconvenient. In short, the current information system is very tedious.

Another major problem with the current information system at TCAT is that it does not provide any real-time passenger information. Real-time information is information that is delivered almost immediately after collection. In terms of transportation, it is information provided to passengers on the current state of public vehicles, including but not limited to information related to current arrival time of the vehicle at a particular destination and departure time from a particular destination, all in real-time. A good information system provides all of the data, including other conveniences such as route planning, visual aids, etc. TCAT, however, does not have any such way of providing information to passengers as of now. During peak hours, the buses are usually late at particular stops, or are already full by the time they arrive at certain stops. This leaves the passenger waiting at the stop stranded, resulting in them deviating from their schedule or being late. This results in decreasing customer satisfaction, and is harmful to TCAT in the short and long run. The need at present is to provide the customers with a convenient, easy-to-use information system that provides schedules and real-time bus information and other services. This system should not be too expensive and easy to incorporate into TCAT's current system.

Proposed Solution: Incorporate into Google Transit

Our proposed solution is to incorporate the current information system and provide real-time information into Google Transit. Google Transit is Google Maps' public transportation planning tool that combines agency data with Google Maps. It integrates transit stops, routes, schedules, and fare information to make trip planning quick and easy for everyone. The major benefit of a real-time information system is that it reduces the perception of waiting time for the passenger, leading to increased customer satisfaction. In a survey of OneBusAway users, which is another real-time information system, more than 90% of the customers claimed to be more satisfied after installation (Badger 2014).

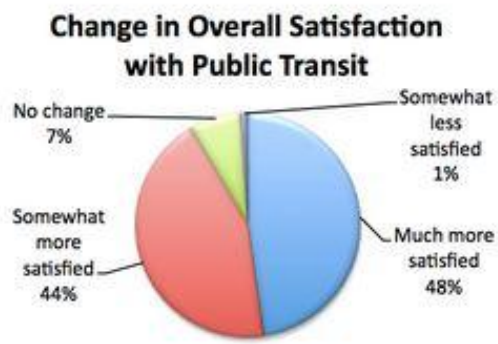


Figure 13: Change in Overall Satisfaction with Public Transit

The first and foremost benefit of using Google Transit is that it is completely free and incorporates itself into Google Maps which is the industry standard and the most commonly used map system. A user just needs to type their destination, which Google Maps automatically searches for while typing. Once the destination is selected, Google Maps gives turn-by-turn instructions of using public transit. It also provides a mapping system for different modes of transportation such as subways, bicycles, cars and walking (Google Maps 2014).

Another benefit of using Google Transit is that Google Maps already has its own version of a mobile application for most smartphones, and not just limited to iOS devices. There would be no need for TCAT to come up with a separate mobile application with real-time information, thereby costing TCAT nothing.

The following example is how Google Transit provides information to passengers traveling from Port Authority to the World Financial Center in New York, New York. The following figures show the methodology in which the maps show information to the passenger. The information is in real time for the subways and would be similar if TCAT were to venture into this.

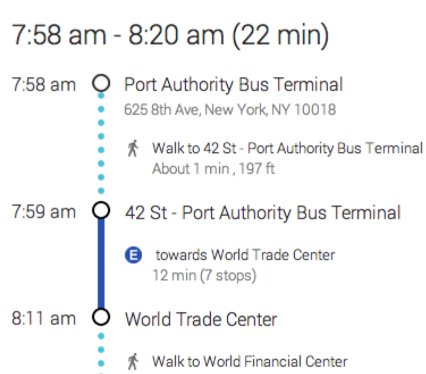


Figure 14: Google Maps - Trip Breakdown

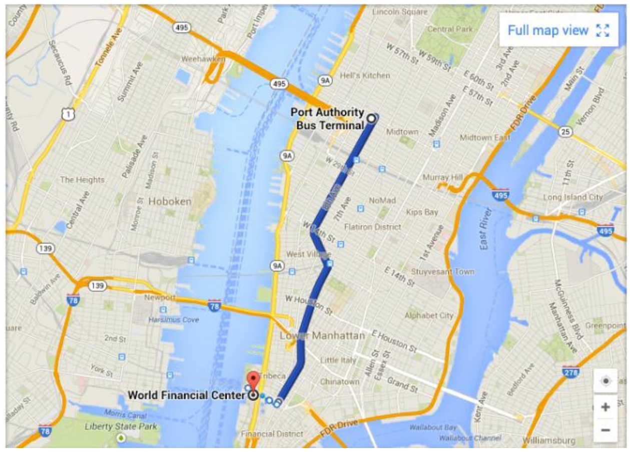


Figure 15: Google Map - Map View

Figure 16: Comparison of Times by Different Routes

Technical Functioning of Google Transit

Google Transit requires a special kind of data for incorporation. This data is called General Transit Feed Specification (GTFS). Google uses two types of GTFS feeds – the first is GTFS and the second is GTFS-Realtime. Both feeds are very similar, with some additional information in GTFS-Realtime, which contains data pertaining to real-time information also.

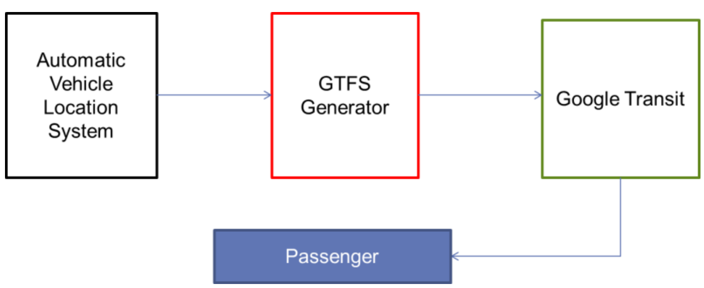


Figure 17: Processing of Information in Google Transit

The processing of information is very simple. To deal with real-time information processing, there must be an Automatic Vehicle Location System (AVLS) installed in the bus (for which real-time information is being used). The AVLS is a device that sends the vehicle location data in terms of coordinates to a server. The cost of an AVLS system varies. TCAT already has a location system, which gives the coordinates from buses to a server at the TCAT office. The frequency of uploaded data depends on the network connection (AT&T in TCAT's case). They may however require a new AVLS in case there might be compatibility issues with the GTFS generator.

A GTFS generator is a type of software which converts the data automatically as it gets uploaded. A GTFS generator converts the uploaded coordinates to GTFS feed type. This type of

GTFS feed would be GTFS-Realtime. The software should also be able to convert the first GTFS type feed (without real-time data), which could be used in Google Maps to just provide basic schedules. GTFS feed type is a series of coded data in text files collected as a .ZIP file. The text files contain information on the agency name, stop, route, trips, stop times, calendar dates, fares, frequencies, transfers, etc. GTFS-Realtime is similar, but contains an additional formatting of the vehicle location, time-distance, cause of delay, etc. In the case of TCAT, we suggest using an integrated and modular software like HASTUS (developed by Giro) which would act as a GTFS generator. HASTUS provides passenger information and converts AVLS to GTFS feed. Since HASTUS has multiple applications, such as scheduling, and its details and costs will be discussed in a later section.

agency.txt

```
agency_id, agency_name,agency_url,agency_timezone,agency_phone,agency_lang
FunBus,The Fun Bus,http://www.thefunbus.org,America/Los_Angeles,(310) 555-0222,en
```

stops.txt

```
stop_id,stop_name,stop_desc,stop_lat,stop_lon,stop_url,location_type,parent_station
S1,Mission St. & Silver Ave.,The stop is located at the southwest corner of the intersection.,37.728631,-122.431282,,,
S2,Mission St. & Cortland Ave.,The stop is located 20 feet south of Mission St.,37.74103,-122.422482,,,
S3,Mission St. & 24th St.,The stop is located at the southwest corner of the intersection.,37.75223,-122.418581,,,
S4,Mission St. & 21st St.,The stop is located at the northwest corner of the intersection.,37.75713,-122.418982,,,
S5,Mission St. & 18th St.,The stop is located 25 feet west of 18th St.,37.761829,-122.419382,,,
S6,Mission St. & 15th St.,The stop is located 10 feet north of Mission St.,37.766629,-122.419782,,,
S7,24th St. Mission Station,,37.752240,-122.418450,,,S8
S8,24th St. Mission Station,,37.752240,-122.418450,http://www.bart.gov/stations/stationguide/stationoverview_24st.asp,1,
```

routes.txt

```
route_id,route_short_name,route_long_name,route_desc,route_type
A,17,Mission,"The ""A"" route travels from lower Mission to Downtown.",3
```

trips.txt

```
route_id,service_id,trip_id,trip_headsign,block_id
A,WE,AWE1,Downtown,1
A,WE,AWE2,Downtown,2
```

Figure 18: Example GTFS Feed with Route Information

```
header {
  gtfs_realtime_version: "1.0"
  incrementality: FULL_DATASET
  timestamp: 1284457468
}
entity {
  id: "0"
  alert {
    active_period {
      start: 1284457468
      end: 1284468072
    }
    informed_entity {
      route_id: "219"
    }
    informed_entity {
      stop_id: "16230"
    }
    cause: CONSTRUCTION
    effect: DETOUR
    url {
      translation {
        text: "http://www.sometransitagency/alerts"
        language: "en"
      }
    }
    header_text {
      translation {
        text: "Stop at Elm street is closed, temporary
stop at Oak street"
        language: "en"
      }
    }
    description_text {
```

```
]- header information
  ]- version of speed specification. Currently "1.0"
  ]- determines whether dataset is incremental or full
  ]- the time where this dataset was generated on server
     for determining the sequence of alert feeds
]- multiple entities can be included in the feed
  ]- unique identifier for the entity
  ]- "type" of the entity
    |- multiple periods can be defined when alert is active
    |- start time in POSIX epoch format
    |- end time in POSIX epoch format

  ]- selects which GTFS entities will be affected
    ]- valid parameters: agency_id, route_id, route_type,
      stop_id, trip (see TripDescriptor)
    ]- multiple selectors (informed_entity) can be given


  ]- cause of the alert - see gtfs-realtime.proto for valid values
  ]- effect of the alert - see gtfs-realtime.proto for valid values
  ]- the given url provides additional information
    ]- multiple languages/translations supported
      page hosted outside of Google (at provider/agency, etc.)



  ]- header for the alert will be highlighted
    ]- multiple languages/translations supported






  ]- Alert description. Additional info to the header text
```

Figure 19: Example GTFS Real-Time Alert Feed

The last step in the process is uploading the .ZIP file containing the GTFS feed files to Google Transit. All the generator needs to do is upload the .ZIP file to hosted server. Google will automatically fetch the .ZIP file from this server. To set up this relationship with Google, the agency would have to contact the Google Transit team. The feed then automatically gets incorporated to Google Maps. The agencies can preview the working of their feed privately before opening to the public. Details of steps of incorporation are available in the Google Maps website (Google Maps 2014).

Once the data is in Google Maps, all the passenger needs to do is use Google Maps on a normal browser or on his or her smartphone, free of cost. This way, real-time information would be provided to passengers, leading to a higher customer satisfaction.

Ambiguous Naming System

The current TCAT naming system for bus routes has ambiguous meanings depending on the route and direction of the bus. For the routes that are not a loop, TCAT employs an "inbound" and "outbound" naming system. "Inbound" generally means that the bus is headed to downtown Ithaca and "outbound" means that the bus is headed away from downtown Ithaca.

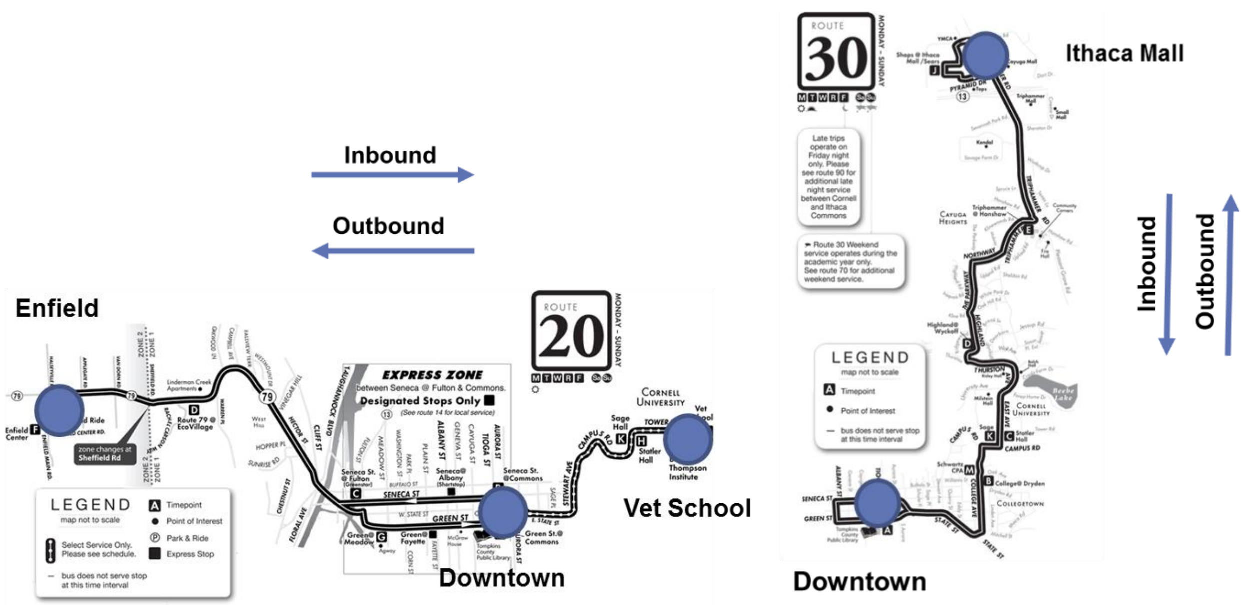


Figure 20: Route 20 and Route 30 with Inbound and Outbound Naming

Route 20 and Route 30, for example, demonstrate the ambiguity of the "inbound" and "outbound" naming system. For Route 20, inbound means that the bus is headed to the College of Veterinary Medicine at Cornell when coming from Enfield, but for Route 30 inbound means that the bus is headed to downtown Ithaca when coming from Ithaca Mall. Inbound naming is inconsistent across all routes that use this naming system.

Proposed Solution: Direction-bound Naming System

Our solution is to have a direction-bound naming system that could easily identify where the bus is headed. The direction-bound naming clearly shows which direction the bus headed and is consistent across all routes.

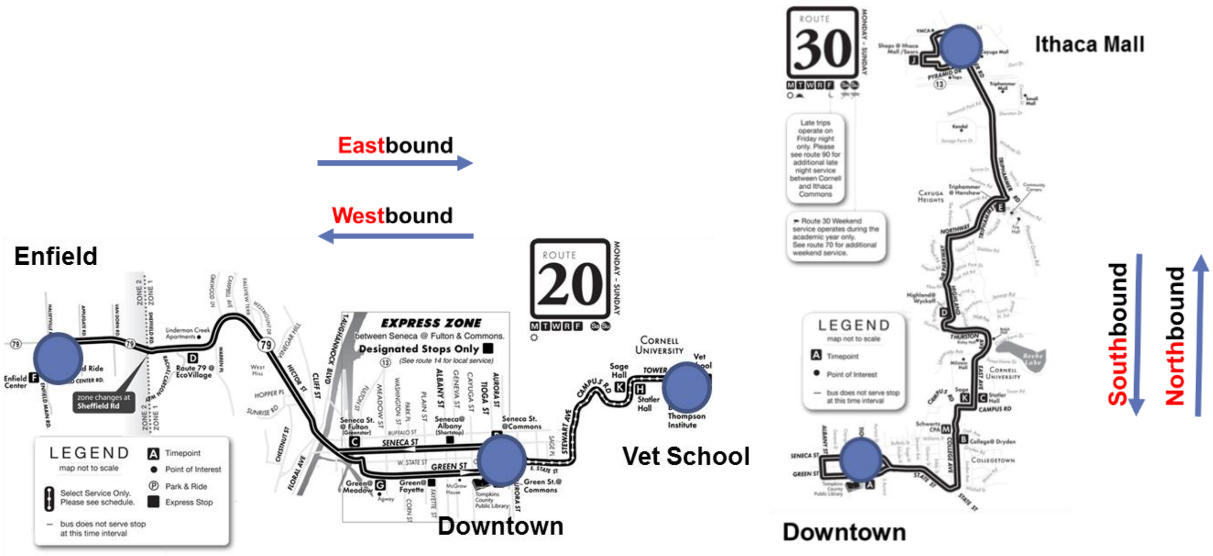


Figure 21: Route 20 and Route 30 with Direction-Bound Naming

Using direction-bound naming for Route 20 and Route 30, in our example, is clearer and more consistent than "inbound" and "outbound" naming. The proposed name changes are summarized in a table.

Route	Destination		Endpoint		Endpoint
10	CU-Commons	Loop			
11	IC-Commons	Loop			
13	Northside-Mall	Northbound	Mall	Southbound	Commons
14	West Hill	Northbound	Cayuga Medical	Southbound	Commons
15	SW Shopping	Loop			
17	TCAT-Fall Creek	Northbound	TCAT Office	Southbound	Commons
20	Enfield	Eastbound	Vet School	Westbound	Enfield
21	Trumansburg	Northbound	Trumansburg	Southbound	Commons
30	Commons-Mall	Northbound	Ithaca Mall	Southbound	Commons
31	NE Ithaca	Loop			
32	Airport	Northbound	Airport	Southbound	Commons
36	South Lansing	Northbound	South Lansing	Southbound	Commons
37	North Lansing	Northbound	North Lansing	Southbound	Commons
40	Groton	Northbound	Groton	Southbound	Commons
43	Dryden-TC3	Eastbound	TC3	Westbound	Commons
51	Eastern Hts	Loop			
52	Caroline	Eastbound	Caroline Turnaround	Westbound	Commons
53	Ellis Hollow	Loop			
65	Danby	Northbound	Commons/Cornell University	Southbound	Hillside View Trailer Park

67	Newfield	Northbound	Commons/Cornell University	Southbound	Newfield
70	Weekend Mall	Northbound	Ithaca Mall	Southbound	Commons
72	Weekend Airport	Northbound	Airport	Southbound	Commons
74	Weekend Groton	Northbound	Groton	Southbound	Commons
75	Weekend Dryden	Eastbound	TC3	Westbound	Commons
81	C.U. Wkday	Loop			
82	C.U. Wkday	Loop			
83	C.U. Wkday	Loop			
90	C.U. Night	Loop			
92	C.U. Night	Loop			
93	C.U. Night	Loop			

One of the limitations of this solution is that if the current TCAT riders are already accustomed to "inbound" and "outbound" naming system, then it will be difficult for them to understand this new naming system.

A few routes, such as Routes 81 through 93 on the table above, are considered loops in the current naming system, even though they do not run in a circular route. Although this is ambiguous, there is no proposed change to these routes. This took into account the fact that these routes are relatively shorter than other routes and do not have a clear direction for their stops. For example, Route 81 starts at A Lot in the north, goes south and takes a turn towards B Lot in the east, and returns to A Lot along the same path. Because of this, naming these routes either Northbound or Eastbound would be confusing. Furthermore, these routes are already name as loops, which are how most passengers know them, and are comfortable with them. This would not contradict the proposed naming system.

Scheduling Buses and Drivers

There is no software at TCAT dedicated for driver and vehicle scheduling. The current process involves using Microsoft Excel and a long, tedious process of trial and error to have bus drivers have their 40-hour work week, ensuring all the routes at TCAT are covered, and complying with union rules. The staff may get a solution from Excel that may not be the optimal solution.

Because this scheduling method is done manually, it is not easy to make changes to one driver's schedule and immediately see the effects of these changes. Driver and vehicle scheduling is very critical to any transit company because it is important to optimize their resources (their drivers and vehicles) and to also reduce staff time for scheduling processes.

According to Torrance et al.'s paper, "Vehicle and Driver Scheduling for Public Transit," there are four steps to driver and vehicle scheduling:

1. Trip building: This step determines time tables for scheduling vehicles to arrive at specified locations at specified times. This will help determine the master schedule.
2. Blocking: This step involves creating a sequence of trips made by a single bus. The blocks can then be divided among different drivers.
3. Runcutting: This step assigns drivers to vehicles, determining the number of drivers that the transit agency will need in order to operate in compliance with the master schedule.
4. Rostering: This step involves grouping daily operator runs into a weekly run package and finding individual drivers to fulfill each role. (Torrance, Haire and Machemehl 2009)

This may seem pretty straightforward, but there are constraints with driver and vehicle scheduling that make scheduling a challenge. With drivers, they need to have a legal set of shifts that also cover the blocks of the vehicle schedule. On top this, there are local and national rules that need to be considered such as total work hours, days off per week, meal breaks per shift, etc. The goal of driver scheduling is to minimize the amount of changes made.

With vehicles, there are problems with determining span of service, assigning vehicles to routes, and ensuring that the vehicles have recovery time and that the blocks are satisfied. Also, there are challenges with vehicle scheduling especially when there are changes in services between weekdays and weekends. The goal of vehicle scheduling is to maximize the number of hours the vehicles would transport passengers.

Proposed Solution: HASTUS

Our solution to the manual driver and vehicle scheduling system is to employ software that automatically does this. Torrance et al. found that the 20 largest transit companies in the US, based on data of annual passenger trips, used two programs for transit scheduling. The two programs are TRAPEZE, developed by the Trapeze Group, and HASTUS, developed by Giro, Inc. in Montreal. The goal of both of these programs is to minimize the costs with the drivers and the vehicles required to operate a transit service. Both programs try to solve the same problem but have slightly different methods to solve it.

The benefits of using software such as TRAPEZE or HASTUS are that more efficient schedules will be created which reduces costs, less staff time will be allocated to driver and vehicle scheduling, and there could be more flexibility in scheduling.

We propose using HASTUS over TRAPEZE for TCAT. It is used over by 250 bus and rail companies, which include New York City Transit (MTA NYCT), Chicago Transit Authority (CTA), and Santa Cruz METRO (California Transit). The optimization tool, developed over 25 years ago, has evolved to adapt to the needs of individual transit companies. A great feature about this software is that it can solve vehicle and driver scheduling problems jointly or separately. It cuts blocks into pieces of work, matches pieces of work to form drivers' schedules, assigns the actual operators, and finally improves the solution heuristically.

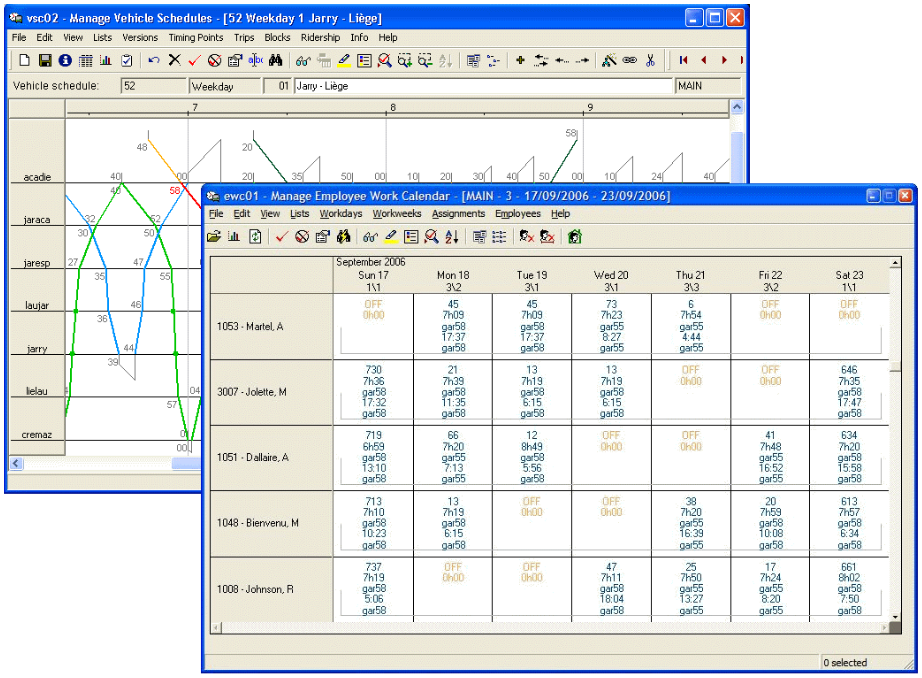


Figure 22: HASTUS Work Calendar and Schedules

HASTUS was developed by transit people who learned software design whereas it was the opposite case for TRAPEZE. Therefore, HASTUS is easier to use, and according to Christine McFadden, Manger of Service Development for Detroit, “the algorithms are stronger, provide better solutions, and are more easily customized than TRAPEZE’s.”

HASTUS pricing depends on the size of the individual transit system (MacKechnie 2014).

Transit Company	# Peak Buses	Contract Value
Jacksonville, FL	160	$240,534 (plus $16,112 in annual maintenance costs)
San Francisco, CA	172	$288,925
Los Angeles, CA	Over 2,000	$2,000,000+

Table 2: Value of HASTUS Contracts

The cost of the software includes costs for project management, specifications, training, customization, implementation support, configuration, and installation, and an extended warranty. Maintenance costs are priced per module and are paid the first year after the warranty period. Based on the contract value per number of buses, a rough estimate of implementing HASTUS for TCAT would be $86,400 (average cost of about $1,600 per bus).

HASTUS is a modular software where you can purchase modules that meet each transit company’s needs. Some HASTUS modules are daily vehicle, daily crew, minibus and roster optimize. Daily vehicle and daily crew are the already integrated modules in HASTUS. These two modules focus on maximizing driver and vehicle scheduling and assigning. Minibus and roster optimize are more advanced optimization tools that maximize the efficiency and effectives bus, route, and crew assignment from multiple garages (English 2009). Daily vehicle and daily crew suffice for TCAT purposes.

Further analysis needs to be done to see if the benefits from using this software outweigh the potential costs of a HASTUS contract.

Conclusion

In summary, our recommended solutions to each problem we identified are as follows.

Declining Route 13 ridership and high morning demand

- A new high performance campus route, "Route 84"

No real-time information

- Google Transit

Ambiguous naming system

- Simple direction-bound naming system

No concrete driver and vehicle scheduling program

- HASTUS

The next step is for TCAT to determine which proposed solutions would be the best for them within their budget constraints and with greatest ease of implementation. Further inquiry needs to be put into Google Transit and HASTUS to obtain more accurate estimates for the cost of integrating the systems into TCAT and the time it will take to implement them. What will be important for this upcoming August is to figure out how to tackle morning demand as this school year is coming to a close and there will be even more Cornell students who would like to use TCAT to get to their classes.

It is important for TCAT to always look for ways to improve their internal infrastructure to not only better serve themselves but most importantly their riders. We believe that these proposed solutions would benefit all the stakeholders for TCAT and would improve their current system.

III. Environmentally-Friendly Buses

Introduction

Every day new technology appears: new devices, new products, new airplanes, and new cars. In this fast-paced technologically advancing world we discover new ways to harness energy. The scientific community also comes up with new discoveries concerning health issues and how vehicle exhaust gases affect our health and well-being. With these factors in mind, we chose to study the new powertrain technologies that are promising to cut greenhouse gases and other pollutants in public transport systems. Many fuel systems exist that use the same basic principles of internal combustion engines, others have been developed to provide electricity to electric motors, and others have now been developed as turbines. Not all of these fuel systems are technically viable though, and on our study we have focused onto four fuel systems that are in current use or in active development, with promising results. These are biodiesel, hybrid diesel electric, compressed natural gas and hydrogen fuel cells.

Motivation

Conventional engines cause pollution and emit greenhouse gases in large quantities, as can be seen in large cities, and eventually cause health hazards. We believe that people in Ithaca would prefer to stay out of that list of polluted cities, and TCAT can help by exploring new technologies that reduce emissions. Currently, in the US there are tax breaks for low emission passenger vehicles. These are unlikely to apply to buses, but in the future there may be similar tax breaks placed for low emission buses. Another motive to explore these options is the fact that waste can and is used to generate biofuels in many places around the country, and synergy between waste disposal companies and TCAT could lead to fuel cost cutting for TCAT. Improvements in fuel efficiency can also lead to fuel cost reduction, as well as emissions reductions. In all, many positive aspects can be found in exploring new technologies that would make it worthwhile.

Pollutants

Carbon dioxide (CO_2) is the most important greenhouse gas emission worldwide. It is produced by combustion from almost every fossil fuel, and is a major cause of climate change.

Nitrogen oxides (NO_x) are polluting gases, produced by high temperatures found inside a diesel engine. They cause ground level ozone, which is a harmful pollutant gas.

Non-methane hydrocarbons (NMHC) are highly harmful gases, often carcinogens, products of gas leaks, volatile products in petroleum derivates and incomplete combustion inside engines. Some of these gases have also been linked with the greenhouse effect.

Carbon monoxide (CO) is also a very harmful gas, poisonous for humans in high quantities, and also an important factor in the formation of ground level ozone, which is harmful to lungs.

Particulate matter (PM) are solid particles formed inside the combustion chamber that become suspended in the atmosphere in highly polluted cities. It is highly related to serious health hazards, including lung cancer and other cardiopulmonary affections.

Fuels

Biodiesel is actually oil derived from animal or plants, usually mixed with mineral diesel between 5% and up to 100% biodiesel. The percentage of the mixture is represented as a capital B followed by a number, representing the percentage of biodiesel in the mixture. For our study, we evaluated the effect of 20% biodiesel, which is represented as B20.

Hybrid diesel electric vehicles have an electric motor and a battery, which work in conjunction with a conventional diesel engine to improve its efficiency, mileage and range. Various hybrid systems exist in cars and buses, with positive results in miles per gallon (mpg) and emissions reductions for both.

Compressed natural gas (CNG) is currently used in power generation all around the world, and is also used in several parts of the world as a fuel for vehicles, mainly due to its low price and its reduced CO_2 emissions compared to diesel and gasoline.

Hydrogen fuel cells are a relatively new system that uses hydrogen atoms to power an electric motor, and this system produces water vapor as the only exhaust emissions, which means the only emissions come from the production of pure hydrogen.

Each of these alternative fuels promise benefits, which certainly will come at a cost, and we will analyze the experience of other public transport operators to come up with alternatives for TCAT.

Parameters for Evaluation

Switching an entire bus fleet of 54 buses from one fuel system to another would mean incurring in purchasing costs, fuel costs, maintenance costs, amongst others. It would also mean change in the amount of emissions, potential fuel cost savings and an entirely new required price scheme for TCAT to be able to pay its bills. We have considered the aforementioned factors and grouped them in the following parameters to evaluate what the best option would be for TCAT.

Yearly cost of operation: The costs of operation will include labor costs, operation costs as computed by other bus operators, fuel costs, and purchasing costs, spread over a 12 year period with a 7% discount rate.

Operating expense per boarding: The total yearly costs of operation previously calculated will be divided by the number of passengers served yearly by TCAT, to estimate the cost of each passenger, and therefore the price TCAT would have to charge for it to break even in costs and revenues.

Operating expense per revenue mile: The same yearly costs of operation previously calculated, this time divided by the total amount of revenue miles, so as to have an estimation on what each revenue mile (miles traveled by each passenger) to know what the cost of carrying a passenger over one mile is for TCAT.

Fuel cost savings or expenses vs. diesel: This parameter will compare total savings (or expenses) in fuel costs, compared to the conventional diesel bus system. Some fuel systems may be cheaper, others may be more efficient.

Total annual emissions (combustion and production) for CO_2, NO_X, PM, NMHC, CO: Through this parameter we will compare the total emissions by each fuel type, for a hypothetical entire fleet. With this, we will compare the reduction in emissions compared to the current diesel fleet.

Cost per ton of CO_2 reduction: With this parameter, we will compare the costs of operating the current diesel fleet with each of the other fleets and the CO_2 emissions, and come up with a figure that will describe the hypothetical price TCAT would be paying for each ton of CO_2 not emitted with the current Diesel fleet. This factor could come in handy if in the near future, as state or federal governments offer subsidies based on CO_2 emissions reductions.

Bus Types

Electric Buses

The concept of electric vehicles has existed over a century, with numerous inventions adding to its credit. In 1891, William Morrison built what is considered the first successful electric vehicle in the United States. Morrison's car was equipped with a 4 horsepower motor, and a power supply which consisted of a 24-cell battery. The car was capable of traveling at approximately 22 km per hour, or 13 miles per hour. The first large scale U.S. manufacturer of electric vehicles was the Pope Manufacturing Company of Hartford, Connecticut, whose car was capable of traveling at 22 km per hour, with a range of 48 km per charge (Monaco 2011). Because these cars had a short range, they were not widely popular.

Gas powered vehicles became the standard with the mass production of Henry Ford's Model T, along with Charles Kettering's electric automobile starter, which eliminated the need to hand crank. In the 1960s and 1970s, further research and development of electric vehicles became more prominent because of the rise in fuel costs and fear of exhausting fuel supplies. In the late 1990s, General Motors began producing the EV1, the first electric car of the modern era to be mass produced, but was also extremely expensive (Romero 2009). The Tesla Roadster, manufactured by Tesla Motors in California and first became available in 2006, started at $90,000, which shocked many consumers. With a lithium-ion battery, the vehicle could travel 245 miles (Kelty, et al. 2006).

It comes to the same situation when it concerns buses. The oldest kind of electric buses that can be seen are trolleybuses. These buses are powered by overhead electric wires than run throughout the route of the bus. The first demonstration was done in 1882, in Berlin. After that, Leeds and Bradford in Great Britain introduced the trolleybus in 1911. Trolley buses are uncommon in the United States today, although cities such as Philadelphia and Seattle do operate them. They still exist in Europe and Asia (Dubar 1967).

Battery-powered electric buses were introduced in America after the research in battery storage increased. With the improvement of lithium-ion batteries, it became viable for electric buses to come to service. Major success of electric buses can be seen in Chattanooga, Tennessee (U.S. Department of Energy 1997).

They have 16 electric buses which have been in operation since 1992 and have a range of 45 to 60 miles. Since September 2010 in the US, the first battery-electric, fast-charge bus has been in operation in Pomona, California. The buses use lithium-titanate and are able to fast-charge in fewer than ten minutes (Proterra Inc. 2010).

Types of Electric Buses in Use

The two major types of autonomous electric buses available are the battery powered buses, and the supercapacitor powered buses. Battery powered buses use chemical energy in the rechargeable batteries to power the buses. These buses have a short range, and need to be recharged for a long time at the recharge stations. Instead of recharging the bus, fully charged batteries can be replaced after every charge cycle. In 2008, during the Beijing Olympics, 50 lithium-ion battery powered buses were used with a drive range of almost 120 km with a replacement of battery after every 24 hours of charge (Sun 2007).

The supercapacitor-powered buses, also known as capabuses, have an extremely short range. The supercapacitors are able to store only about 5% of the power lithium-ion batteries could store. However, they have an extremely short recharge time, which makes them a convenient and plausible solution (Hamilton 2009). Because of the low capacity, the capabuses need to charge their batteries every few miles of operation (as low as 3.5 miles). Therefore, every such distance, there is a stop that acts as a recharge point. The buses are recharged at these stops, giving them enough energy to reach the next recharge stop. At each recharge point, the charger touches the vehicle on top, and recharges it quickly. Recently, wireless induction charging of the ultra-capacitors is being tested, where the charger is embedded in the ground in front of the bus stops, quickly recharging the batteries. This is a very upcoming technology with major research being done in this area, with some claiming that the research is moving faster than batteries (IDTechEx 2013). Sinautec Automobile Technologies in Virginia, in collaboration with its Chinese partner, Shanghai Aowei Technology Development Company, has spent the past three years demonstrating the approach of capabus technology with 17 forty-one seat municipal buses on the outskirts of Shanghai (Hamilton 2009).

Cost and Feasibility

The feasibility of electric vehicles has been increasing as research improves. The major concern in terms of cost of electric vehicles is the high initial cost. However, it has great implications in terms of fuel and maintenance savings. The electric buses in Chattanooga, Tennessee cost $160,000 to $180,000 for the 22 feet and 31 feet vehicles respectively (U.S. Department of Energy 1997). Proterra, a leading manufacturer of electric buses, estimates a total of $430,000 in fuel savings, and another $75,000 to $150,000 in maintenance savings. Its estimated initial cost for the Proterra EcoRide may exceed $950,000 (Proterra Inc. 2012). An additional cost for the charging stations may be included, which might drive costs higher.

Environmental Impact of Electric Buses

In the early 1990s, Oxford, England ran a test fleet of four electric minibuses and showed a reduction of 21% CO_2, 98% CO and a reduction of more than 95% particulates when compared to diesel fueled buses (Smiler 2013). Capabuses also have a major environmental benefit. The supercapacitors themselves are 70% recyclable. An assessment of capabuses in Beijing showed that there was more than 25% reduction in CO_2 levels and 80% NO_2 levels when compared to diesel fuel buses (Supercapacitor Buses 2012). Thus, assessment shows great improvement in air quality and long lasting environmental benefits when compared to diesel fueled buses.

Future Prospects

The future of electric vehicles depends on advancements in battery and charging technology. The range, performance, price, reliability, and convenience factor must be at that of the gasoline-powered automobile, if not superior, in order for them to become successful. Affordable all-electric vehicles may become the standard if this technology advances.

Hybrid Buses

Hybrid vehicle technology is not new; in fact it is very old. The first hybrid electric vehicle ever was designed by Belgium carmaker Pieper in 1899 (Bouchat 2005). Not much later than that, the Fischer Motor Vehicle Company designed the first hybrid electric omnibus in 1905. Due to mass adoption of gasoline vehicles, hybrid vehicles fell into disuse until late in the twentieth century, until various Asian and American companies manufacturing diesel-electric hybrid buses in the 1990s. Since then, gas prices and environmental awareness has caused manufacturers to flood the market with different models of hybrid cars and buses.

Technology

Hybrid-electric vehicles use one internal combustion engine and one electric engine in different configurations to power the wheels. There are three different arrangements for hybrids: a parallel system, where both the electric and the combustion engine are connected to the wheels; the series system, where the internal combustion engine powers a generator that recharges a battery that in turn powers the electric motor that turns the wheels; and a mixtures of both systems called series-parallel hybrid that can split power from both sources and couple or decouple both engines from the wheels as needed by the driver. In heavy vehicles (e.g. buses, trucks), an internal combustion engine is used to power a generator that will power one or more electric motors connected to the wheels. With this configuration, engines can be run at optimum efficiency and weight can be saved by dispensing with very large gearboxes, greatly increasing fuel efficiency. Another technology currently used in hybrids is regenerative braking, which means that when slowing down or going down a slope, the electric engines can recover energy from the momentum of the bus and recharge the batteries. These technologies have greatly increased fuel efficiency in hybrid buses compared to conventional buses. Some new models have traded the internal combustion diesel engine for gas turbines, which produce very little polluting particulate matter.

Adoption

Car makers have been manufacturing hybrid vehicles since the beginning of the 21st century, and the sector has grown massively, reaching 2.2% of all car sales in the United States and 17.1% in Japan in 2011. Many car makers have been releasing hybrid versions of their standard models and this has helped increase adoption in the US and Europe. However, due to the increased complexity of the drivetrain and the cost of the battery and extra electrical system, hybrid cars turn out to be much more expensive than their conventional counterparts, both in manufacturing and maintenance, and this has been one of the major barriers holding back this technology. Hybrid systems for mass transit do not escape from these problems. The goal of hybrid bus manufacturers is to surpass these hurdles by offering very efficient vehicles that save money on fuel for adopters and offer cleaner emissions for citizens.

Currently, hybrid buses had been adopted by 69 transit authorities in different cities in the US and more than 45 cities worldwide (Federal Transit Administration 2005). Different agencies worldwide fund the deployment of hybrid buses, namely the Department of Energy in the United States and the Green Bus Fund in the United Kingdom. Some of these cities do not have full deployment of hybrids, and in other cities hybrid buses are deployed as test units.

Benefits

Due to the nature of the diesel engine cycle, which uses high compression to spontaneously combust fuel, high polluting nitrous oxides and carbon monoxide and dioxide are released through the exhaust pipe, together with particulate matter produced by impurities in the diesel fuel. Thanks to the increased efficiency on which combustion engines can run on hybrid systems, particulate matter emissions can be cut by 90%, NO_x emissions can be reduced by 50%, and carbon emissions are reduced proportionally to fuel consumption reduction; however, these numbers will vary depending on driving habits. Bus tests in London have claimed fuel savings of 30% (Transport for London 2014), and manufacturers like Volvo claim similar numbers. The most impressive numbers (Volvo 2011), however, have been shown in tests in Sweden, where hybrid buses with plug-in capability (where batteries can be recharged by directly connecting the bus to the electrical grid) have shown decreased fuel consumption by 81%, for a total of 11 liters per 100 km (21 mpg), where standard numbers for buses are 3 to 4 mpg.

Cons

As mentioned before, the increased complexity in hybrid systems, coupled with all the technological developments required for feasible hybrids, dramatically increase bus prices. According to one study for a city in the state of Indiana, US, conventional buses can cost around $335,000 and the price for hybrids is $540,000. Also, as the powertrain of buses becomes more complex, it becomes harder and more expensive to maintain and repair. When considering the purchase of hybrid buses, transit agencies must account for these increased costs and balance with fuel savings and cleaner emissions. Batteries are one of the main components on hybrid vehicles, and the new generation of hybrids uses mostly NiMH and lithium-ion batteries. Lithium is being mined extensively to satisfy the increasing demand for batteries around the world, but there are few places where this metal can be found. This makes it subject to geopolitical conflict and volatile prices.

In the Future

With mass deployment of hybrid buses, economies of scale can be achieved and manufacturers will be able to greatly decrease prices for these buses. However, in the future, the internal combustion engine will still be emitting high polluting gases, so hybrids are a short and mid-term solution to pollution and climate change issues. On the other hand, other technologies require great investments in infrastructure, which is not the case with hybrid systems, so this technology will be massively deployed in the next decades while the current generation depends on fossil fuels.

Hydrogen Buses

Hydrogen buses exist in the market today in different design configurations, including hydrogen fueled internal combustion engines and many variants of fuel cells. Fuel cells are electromechanical conversion devices that use a chemical reaction between oxygen, hydrogen and a catalyst (usually platinum) to produce water and electricity. Unlike batteries which die out when the energy within it depletes, fuel cells continue to produce a charge as long as fuel is supplied.

Modern fuel cell systems used in automobiles are based on Proton Exchange Membrane (PEM) stacks. Each fuel cell designed for use in these vehicles produces 1.6V of electricity, which is far from sufficient to power a vehicle. As a result, multiple fuel cells are arranged in a stack. The power output of a fuel cell stack depends on the number and the size of individual fuel cells assembled in the stack (U.S. Department of Energy 2014). Energy storage systems of these vehicles are generally based on battery packs (NiMH or Li-ion) and ultra-capacitors. Hydrogen storage systems are generally based on Type III cylinder technology, storing compressed hydrogen at a pressure of 350 bar. Liquid cooled systems with radiators to dissipate the heat are used to cool the fuel cells by most manufacturers (Zaetta and Madden 2011).

In a hydrogen internal combustion engine, hydrogen is burnt instead of gasoline and the energy released in the form of heat is made to do useful work by pushing a piston. These engines can be either cylindrical or rotary. The energy efficiency of a hydrogen ICE is 20 to 25% better than a gasoline engine due to a leaner air-to-fuel and compression ratios.

Current Trends in the Technology

"Hydrogen fueled buses: The Bavarian fuel cell bus project" by Gruber et al. provides details of the impact of the prototype hydrogen bus that was implemented in the city of Munich, Germany for public passenger transport. The report states that the drive system of these buses was found to be superior to their diesel counterparts when utilized at 75% of its designed capacity. The fuel efficiency was also found to be better when compared with heavy duty vehicles. The drivers also observed no difference in the handling of these buses compared with diesel buses (Gruber and Wurster n.d.).

Recently, the BC Transit fleet in Whistler, British Columbia with 20 hydrogen fuel-cell buses is reported to have reduced carbon dioxide emissions by more than 4,400 tons over five years. However, due to high cost to fuel and maintain these buses, BC Transit is replacing its hydrogen bus fleet with diesel buses (Zeidler 2013).

In the HyFLEET:CUTE (Clean Urban Transport for Europe) project implemented across nine cities globally, a fleet of 33 buses achieved an average speeds of 10.2 miles per hour and a fuel consumption of 21.9 kg per 100 km, or 9.94 mpg for a diesel equivalent. On the negative side, the project observed degradation of the performance of the fuel stack with time due to the increased levels of pollutants in the hydrogen fuel. One of the interesting facts reported was that given a choice between a conventional bus and a hydrogen bus, the majority of people preferred the hydrogen bus option (HyFLEET:CUTE 2009). This suggests a growing acceptance of this technology among the general public.

Cost

Each of the hydrogen fuel cell buses costs close to two million dollars, which is almost four times of what the conventional diesel buses cost. The hydrogen fuel cells cost $2.28 per km, which is three times the cost of diesel. The maintenance cost for these buses is $1.00 per km as opposed to 65 cents per km for diesel buses (Sinoski 2013). However, these comparisons should be kept in context, since the hydrogen buses are at a prototype stage and prices could be expected to fall if they are mass-produced.

Advantages and Limitations

Hydrogen buses have the following advantages.

- Improved fuel efficiency, 2 to 3 times more fuel efficient than combustion engines.
- Greenhouse gas emission reductions.
- Air quality is improved by a decrease of NO_X emissions and particulate matter in the air.
- Better rider experience, as the fuel cells are silent.
- Hydrogen is an abundant, clean and renewable resource.

However, there are still various technical and commercial constraints that ail this technology.

- Fill time of hydrogen bus vehicles is around ten minutes as compared to three minutes for diesel buses, which poses a hindrance for bus operators with large fleets.
- The lack of high availability of hydrogen fueling stations.
- The total cost of operating a hydrogen bus is significantly higher than that of a diesel bus.
- Higher maintenance cost.

Future of Hydrogen Buses

The recent advancements in alternate fuel technology is fast beckoning a paradigm shift in the transportation system. The hydrogen bus performance and fuel cell system durability have continued to demonstrate improvements; however, there are still barriers that restrict the fuel cell technology from becoming a viable commercial product. Increasing the reliability of components and lowering capital and operating costs are some of the areas in which the industry needs to focus (Eudy and Gikakis 2013).

The cost of hydrogen and capital investment is likely to go down with the start of mass production and increased spread of hydrogen vehicles. The PEM fuel cell price is expected to drop significantly as the production of these fuel cells increases. Despite the challenges that remain in hydrogen vehicle technology, the hydrogen buses continue to show progress towards meeting the technical targets for commercialization.

Emission and Cost Analysis of Alternate Fuel Type Buses

The purpose of this study was to evaluate the alternate fuel type buses that TCAT could look towards procuring in the future that would be financially viable and environmentally friendly at the same time. This report presents emission and cost analysis, comparing diesel buses with its diesel-hybrid, hydrogen fuel cell, CNG, and biodiesel counter parts.

As of 2012 the TCAT fleet consisted of a total of 54 buses comprising of 42 diesel, eight hybrid, and four gasoline operated buses. To assess the potential environmental and financial impacts of the alternate fuel type buses, the study assumed an entire fleet of 54 buses of the different fuel technologies. Table 4 lists a detail account of assumptions of the report.

	Diesel	Diesel-Hybrid	Hydrogen	CNG	Biodiesel [B20]
Annual Discount Rate -%-	7	7	7	7	7
Average Operating Life of Bus - yrs -	12	12	12	12	12
Number of buses in the Fleet	54	54	54	54	54
Annual Vehicle Revenure Hours	120098	120098	120098	120098	120098
Annual Vehicle Revenue Miles	1571258	1571258	1571258	1571258	1571258
Annual Passenger Boardings	4128242	4128242	4128242	4128242	4128242

Table 3: Assumptions for Emission and Cost Analysis for 54 Buses

The figures for the annual vehicle revenue hours per mile and passenger boardings were sourced from the data provided by TCAT.

Cost Analysis

The economic and technical specification of an average bus in the different fuel type segments is listed in Table 5.

	Diesel	Diesel-Hybrid	Hydrogen	CNG	Biodiesel [B20]
Average Fuel Economy - mpg -	3.85	4.31	7	3.14	3.77
Average Fuel cost - $/g -	3.6	3.6	10.55	2.1	3.69
Maintenance Cost -$/mile-	0.54	0.4	1.2	0.8	0.51
Average Bus Cost - $ -	390000	530000	1300000	470000	390000
Bus Length	40-feet	40-feet	40-feet	40-feet	40-feet

Table 4: Economic and Technical Specification of Alternate Fuel Type Buses

The fuel economy and fuel cost of the different fuel technologies have been taken as per gallon equivalent. The fuel cost for dispensed hydrogen does not include any capital or transportation costs. The cost analysis also excludes any refueling station and depot modifications that may be required to incorporate the fuel technology. The mileage for biodiesel buses is slightly lower than diesel buses due to the lesser energy content of biodiesel due to presence of oxygen in it.

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG	Biodiesel [B20]
Total Operating Labor Cost/yr. -$50/hr.-	$6,004,900	$6,004,900	$6,004,900	$6,004,900	$6,004,900
Total Maintenance Cost/yr	$848,479	$628,503	$1,885,510	$1,257,006	$801,342
Total Fuel Cost/yr	$1,469,228	$1,312,420	$2,368,110	$1,050,841	$1,536,693
Annual installment per year per bus	$49,102	$66,728	$163,673	$59,174	$49,102
Capital Cost for 54 buses/yr	$2,651,496	$3,603,315	$8,838,320	$3,195,392	$2,651,496
Annual Operating Expense - $/yr. -	$10,974,103	$11,549,138	$19,096,839	$11,508,140	$10,994,430

Table 5: Annual Operating Expense for 54 buses of Different Fuel Types

The annual operating expense per fuel type bus fleet Table 6 includes the annual fuel, labor, maintenance and capital cost. For the ease of calculation the labor cost has been arbitrarily set at $50 per hour and is not intended to reflect TCAT's current labor rate.

The results of the annual operating expense computations shows that the annual cost of operation of hydrogen fuel cell buses was almost twice of the diesel powered buses. For biodiesel buses the cost was marginally more than diesel buses.

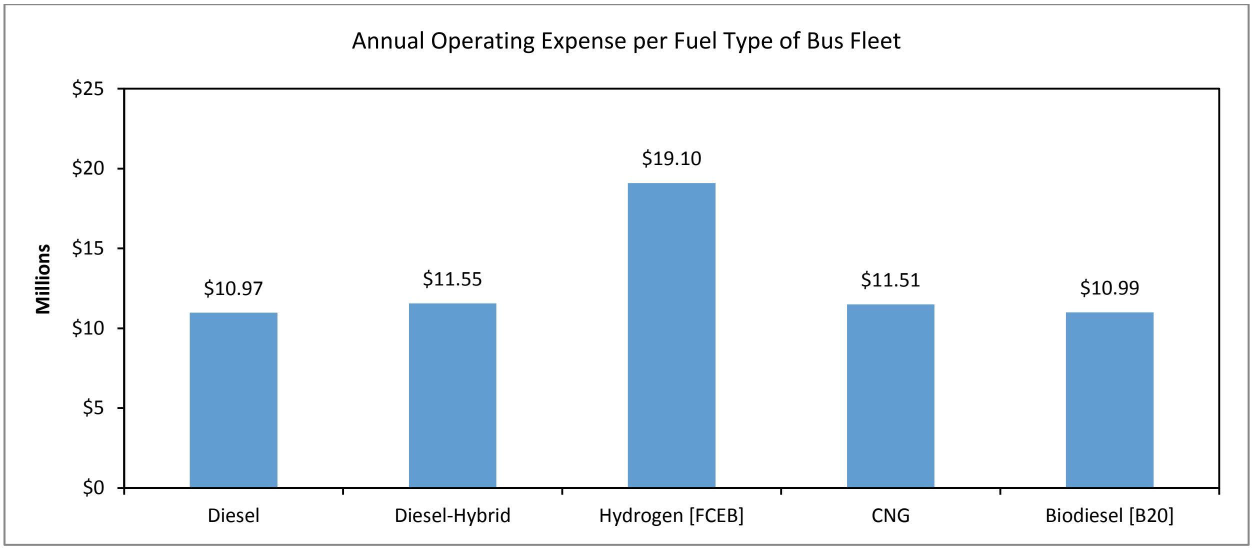


Figure 23: Annual Operating Expense per Fuel Type of Bus Fleet

The annual fuel consumption of each bus type and fuel cast savings compared to diesel buses as the benchmark is shown in Table 7. The fuel cost is calculated by taking the product of average mileage, fuel cost and the fuel economy. The results indicated that the fuel cost per year for hydrogen buses was 62% higher than diesel buses. The maximum fuel cost savings can be incurred if the CNG bus option is adopted however, these buses come with a higher price tag and an increased maintenance cost.

Fuel Cost Comparison	Diesel	Diesel-Hybrid	Hydrogen	CNG	Biodiesel [B20]
Gallons of Fuel Consumed/yr	408,119	364,561	224,465	500,401	416,448
Annual Fuel Cost saving compared to Diesel	N/A	$156,809	-$898,882	$418,387	-$67,465
Annual % Fuel Cost saving compared to Diesel	N/A	10.67%	-61.18%	28.48%	-4.59%

Table 6: Fuel Cost Comparison of Alternate fuel types

To give further insights into the financial impact of the alternate fuel technologies being explored, the operating expense per passenger boarding and operating expense per vehicle revenue mile was calculated in Table 8. The annual operating expense per fuel type fleet divided by the number of boarding's gives the operating expense per boarding and dividing annual operating expense per fuel type fleet by the annual vehicle revenue miles gives the operating expense per revenue mile.

	Diesel	Diesel-Hybrid	Hydrogen	CNG	Biodiesel [B20]
Operating Expense per Boarding	$2.66	$2.80	$4.63	$2.79	$2.66
Operating Expense per Vehicle Revenue mile	$6.98	$7.35	$12.15	$7.32	$7.00

Table 7: Operating Expense per Boarding and per Vehicle Revenue Mile

The operating expense per boarding and vehicle revenue mile is significantly larger for hydrogen buses. For other fuel options there is a marginal change compared to diesel buses.

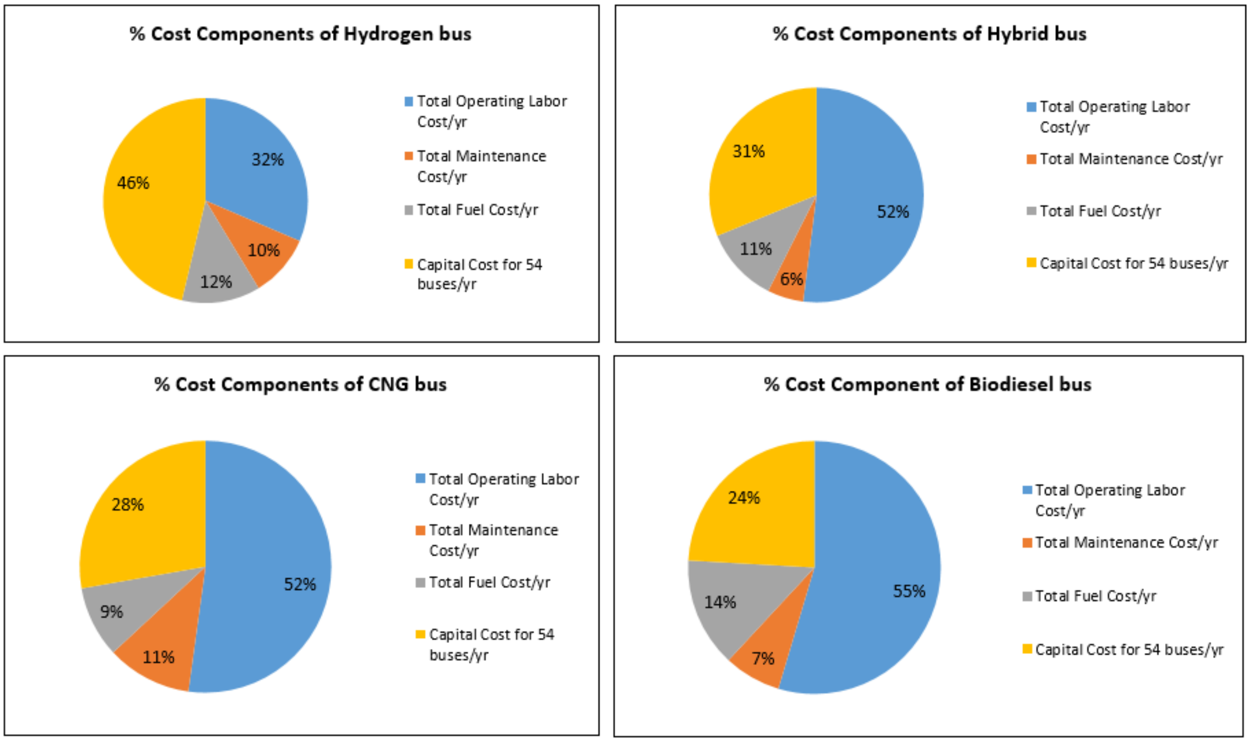


Figure 24: Percentage Cost Breakdown of Alternate Fuel Type Buses for Entire Fleet

In the cost breakdown analysis in Figure 24, we see that the high capital cost of hydrogen buses is one of the main reasons why this technology is not being widely adopted. The increased fuel efficiency of hydrogen and diesel-hybrid buses does not cover the increased purchase cost.

The cost analysis results indicate that diesel continues to remain the most economical technology. However, out of the alternate fuel technologies evaluated, biodiesel could possibly be a financially viable option.

Emission Analysis

In order to evaluate the environmental footprint of alternate fuels, it is important to carry out life cycle analysis. Life cycle analysis accounts for emissions produced in both combustion and production stages of the fuel. For example, hydrogen fuel cells produce almost no greenhouse gases during combustion but the emissions emitted during the fuel production process need to be taken into consideration. For this study, emissions and pollutant figures for hydrogen production via the steam methane reforming (SMR) for CO_2 sequestration method is used.

The figures for the average greenhouse gases and pollutants released in the combustion and production cycles for the alternate fuel technologies are listed below in Tables 9 and 10. The data for combustion emission (diesel, diesel-hybrid, and CNG) was obtained from the Transit Vehicle Emissions Program Report (Federal Transit Administration 2013). The production emission values (diesel, hydrogen, CNG) were sourced from "A Cost-Benefit Analysis of Perth's Hydrogen Fuel Cell Buses" (Murdoch University 2006).

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG	Biodiesel [B20]
CO Emissions g/mi	6.98	0.22	0.00	3.44	6.12
NMHC Emissions g/mi	1.15	0.03	0.00	0.89	0.92
NOx Emissions g/mi	28.84	9.87	0.00	18.21	28.84
PM Emissions g/mi	0.66	0.02	0.00	0.02	0.58
CO2 Emissions g/mi	2,853	1,608	0	2,296	2,417

Table 8: Average Combustion Emissions

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG	Biodiesel [B20]
CO Emissions g/mi	6.98	0.22	0.00	3.44	6.12
NMHC Emissions g/mi	1.15	0.03	0.00	0.89	0.92
NOx Emissions g/mi	28.84	9.87	0.00	18.21	28.84
PM Emissions g/mi	0.66	0.02	0.00	0.02	0.58
CO2 Emissions g/mi	2,853	1,608	0	2,296	2,417

Table 9: Average Production Emissions

The annual GHG emissions and pollutants for the different fuel technologies for a fleet of 54 buses are given in the table below. The annual vehicle revenue miles considered for the calculation is 1,571,258 miles. This figure is in accordance with the total revenue miles covered by the TCAT fleet in 2012.

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG	Biodiesel [B20]
Annual CO emissions -g/year-	12,073,546	1,451,842	351,962	5,832,510	10,648,233
Annual NMHC emissions -g/year-	4,547,221	2,787,412	3,519,618	2,906,827	3,987,721
Annual NOx emissions -g/year-	50,167,125	20,360,361	1,608,968	30,221,576	50,037,576
Annual PM emissions -g/year-	1,301,002	295,397	20,364	59,079	1,159,556
Annual CO2 emissions -g/year-	5,412,983,810	3,456,767,600	250,898,477	4,336,672,080	4,583,275,367

Table 10: Annual Emissions and Pollutant Levels for 54 Buses

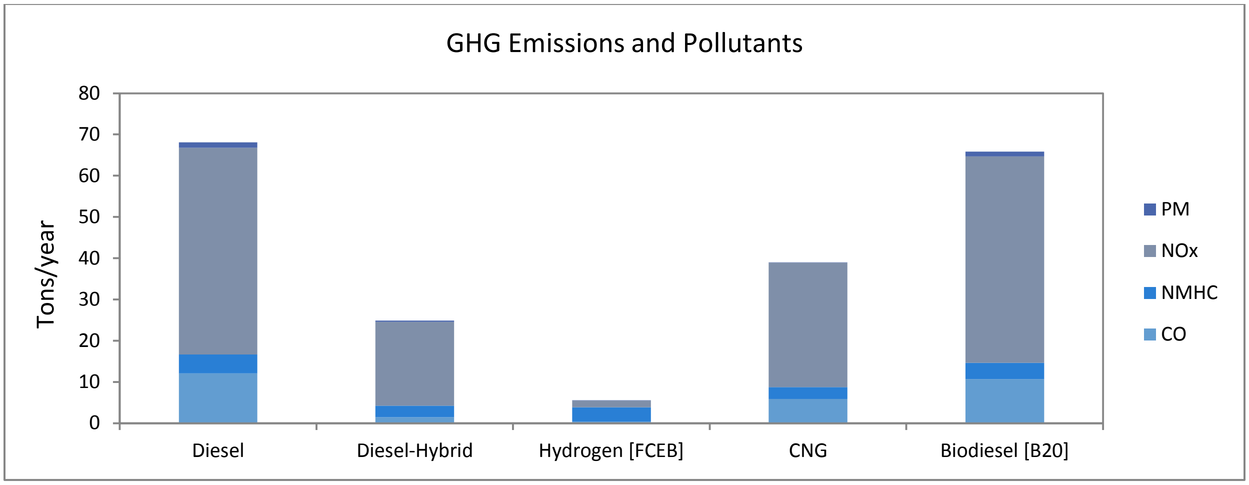


Figure 25: Annual Emission and Pollutant Comparison of Different Fuel Types

The CO_2 emission content was analyzed further against diesel buses, as shown below.

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG	Biodiesel [B20]
Annual CO2 reduction compared to Diesel -tons-	N/A	1,956	5,162	1,076	830
Annual % CO2 reduction compared to Diesel -%-	N/A	36.14%	95.36%	19.88%	15.33%
Cost per ton CO2 reduction -$/ton-	N/A	$293.95	$1,573.54	$496.17	$24.50

Table 11: Carbon Dioxide Emission Reduction

The emission and cost analysis results show that for a marginal increase in operating cost per year, a switch to biodiesel could facilitate a significant reduction in the carbon foot print for TCAT. The hybrid, hydrogen, and CNG buses offer a cut in emissions at a much higher price tag. The biodiesel fuel option could be explored further by TCAT, as a switch to biodiesel can be made for its existing fleet of diesel buses.

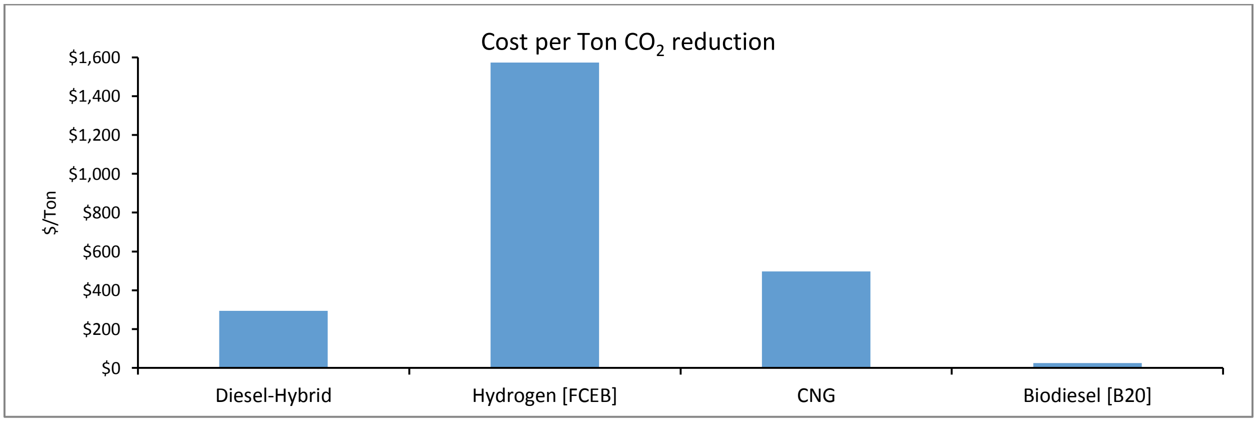


Figure 26: Cost per Ton CO_2 Reduction

Route 30: Emission and Cost Analysis for Alternate Fuel Type Buses

To delve further into the impact of alternate fuel technologies, the analysis was repeated for the hypothetical operation of different fuel type buses on Route 30. This route was specifically chosen as it has the maximum number of boardings per year in comparison with all other routes on which TCAT operates.

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG/LNG	Biodiesel [B20]
Annual Vehicle Revenue Hours	12805	12805	12805	12805	12805
Annual Vehicle Revenue Miles	137227.2	137227.2	137227.2	137227.2	137227.2
Annual Passenger Boardings	707876	707876	707876	707876	707876

Table 12: Assumptions for Analysis of Alternate Fuel Buses on Route 30

The figures listed above were sourced from the data provided by TCAT.

In order to carry out our analysis the number of buses required to operate on Route 30 were found using the following methodology. It was found that seven buses are required to operate on the route.

Route Length - miles - (L)	10.74
Average speed - mph - (S)	14
Cycle time = (120 * L/S) – minutes-	92
Average Seating Capacity per bus - (C)-	38+28
Peak Point Demand - passengers/hr. - (PD)	296
Peak Headway = (PD)/(C) - minutes - (PH)	13.38
Peak vehicles = cycle time/PH	7

Table 13: Number of Buses Required to Operate on Route 30

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG/LNG	Biodiesel [B20]
Total Operating Labor Cost/yr. -$50/hr.-	$640,250	$640,250	$640,250	$640,250	$640,250
Total Maintenance Cost/yr	$74,103	$54,891	$164,673	$109,782	$69,986
Total Fuel Cost/yr	$128,316	$114,621	$206,821	$91,776	$134,208
Annual installment per year per bus	$49,102	$66,728	$163,673	$59,174	$49,102
Capital Cost for 7 buses/yr.	$343,712	$467,096	$1,145,708	$414,218	$343,712
Annual Operating Expense - $/yr. -	$1,186,381	$1,276,859	$2,157,452	$1,256,025	$1,188,157

Table 14: Annual Operating Expense for Route 30 (7 buses)

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG	Biodiesel [B20]
Operating Expense per Boarding	$1.68	$1.80	$2.83	$1.77	$1.68
Operating Expense per Vehicle Revenue mile	$8.65	$9.30	$14.59	$9.15	$8.66

Table 15: Operating Expense per Boarding and per Vehicle Revenue Mile for Route 30

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG/LNG	Biodiesel [B20]
Gallons of Fuel Consumed/yr	35,643	31,839	19,604	43,703	36,371
Annual Fuel Cost saving compared to Diesel	N/A	$13,695	-$78,505	$36,540	-$5,892
Annual % Fuel Cost saving compared to Diesel	N/A	10.67%	-61.18%	28.48%	-4.59%

Table 16: Fuel Cost Comparison of Alternate fuel types for Route 30

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG/LNG	Biodiesel [B20]
Total CO emissions/yr -g/yr-	1,054,454	126,798	30,739	509,387	929,973
Total NMHC emissions/yr -g/yr-	397,136	243,441	307,389	253,870	348,271
Total NOx emissions/yr -g/yr-	4,381,390	1,778,190	140,521	2,639,428	4,370,076
Total PM emissions/yr -g/yr-	113,624	25,799	1,778	5,160	101,271
Total CO2 emissions/yr -g/yr-	472,747,704	301,899,840	21,912,439	378,747,072	400,284,387

Table 17: GHG Emissions and Pollutants for Route 30

	Diesel	Diesel-Hybrid	Hydrogen [FCEB]	CNG/LNG	Biodiesel [B20]
Annual CO2 reduction compared to Diesel -tons-	N/A	171	451	94	72
Annual % CO2 reduction compared to Diesel	N/A	36.14%	95.36%	19.88%	15.33%
Cost per ton CO2 reduction -$/ton-	N/A	$529.58	$2,153.94	$740.89	$24.50

Table 18: Cost per Ton CO_2 Reduction for Route 30

Monte Carlo Simulation

The Monte Carlo simulation is carried out for the cost for per ton CO_2 reduction for each of the alternative fuel options. It is assumed that fuel economy, fuel cost, and maintenance cost all follow normal distributions with coefficients of variation of 3%, 5%, and 10% respectively. They have the same expected values as in the previous calculations. All other input data are kept as the same as before. The simulation is carried out using @Risk. We ran a thousand iterations for each option. The results are shown in the following figures. We focused on the 90% confidence interval around the mean.

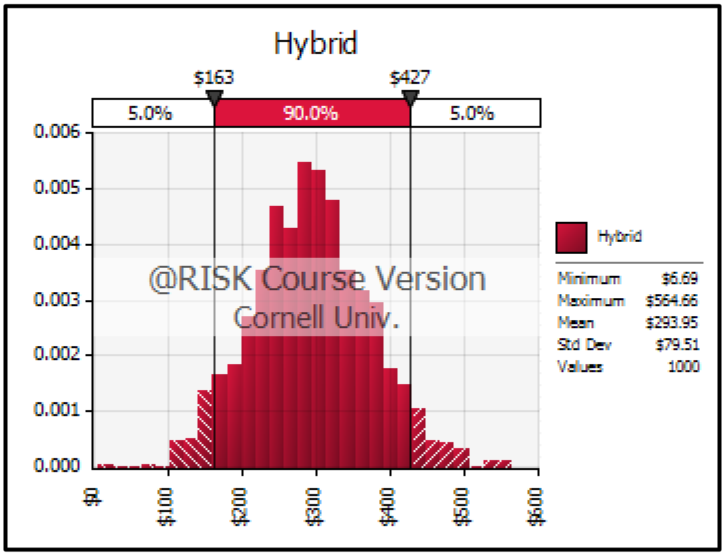


Figure 27: Simulation Result for Hybrid Buses

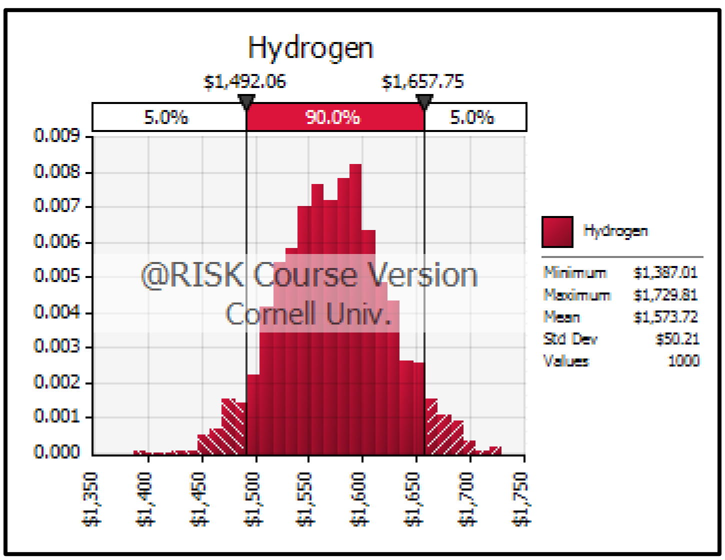


Figure 28: Simulation Result for Hydrogen Buses

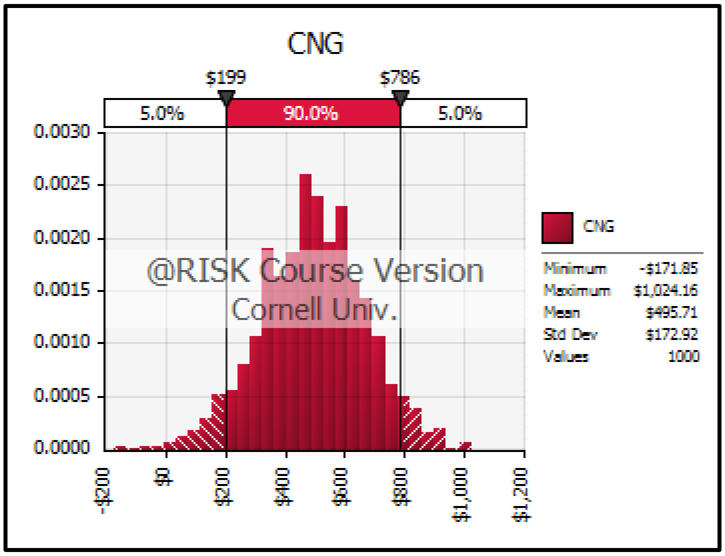


Figure 29: Simulation Result for CNG Buses

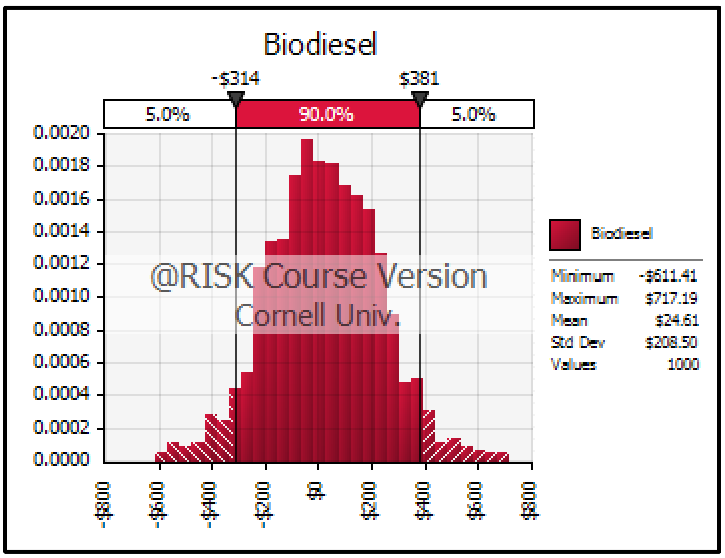


Figure 30: Simulation Result for Biodiesel Buses

It is worth mentioning that for the biodiesel option, there is good chance that the cost for per ton CO_2 reduction is negative, which means using biodiesel can both save money and reduce CO_2 emission. This makes biodiesel a very favorable option in terms of cost efficiency of CO_2 reduction.

Vehicle Substitution

We have estimated the emissions a hypothetical fleet of passenger cars would emit, had TCAT not existed. Considering that TCAT serves most of Tompkins County, we have included this population into our study. Two figures were used in this study: according to the National Highway Traffic Safety Administration (NHTSA), the average car ridership for cars traveling to work is 1.1 persons per car, while the national average car ridership is 1.6 (Naviaux 2011). We have used the same figure for annual ridership TCAT uses, of 4.13 million passengers, and estimated that 90% of the population of the City of Ithaca and 40% of the remaining population of Tompkins County is served by TCAT, and that both these groups of people have different average miles traveled, as shown in Table 20.

	Ithaca	Tompkins
Population	30,014	101,564
Density (/sq mi)	5,364	221
Area (sq mi)	6.1	476
Assumed square	2.5	21.8
Average distance	2.5	15.4
% population	30%	70%
Commuters	27,013	28,620
% commuters	90%	28%
Weighted avg. dist.	2.22	4.35
Est. Driving Distance	**6.57**	**miles**

Table 19: Estimation of Commuter Driving Distance

An average distance of 6.57 miles in all would be the commuting distance per person. Switching off the entire bus transit for this exercise means that the 4.13 million rides in the bus system are translated into car rides averaging 6.57 miles. Table 21 shows the estimated passenger vehicle miles driven, with both vehicle ridership values.

	TCAT	
Annual Ridership	4,128,242	passengers
Average distance	6.57	miles/person
Commute (1.1/car, mi)	3,752,947	car rides
Commute (1.6/car, mi)	2,580,151	car rides

Table 20: Total Miles Driven per Estimated Car Ridership

Depending on actual car ridership figures, passenger vehicles will travel between 2.58 and 3.75 million miles per year. According to recent research, the average fuel consumption nationwide for new cars sold has reached 24.6 mpg (Ingram 2013). This number includes gas-guzzling sport utility vehicles (SUV) and pickup trucks, which are not common in Ithaca, but also does not include old cars with lower mpg values, so we consider this number to be accurate enough. Finally, one gallon of gasoline will produce 19.6 pounds of CO_2. These are all the assumptions, contained in Table 22.

CARS		6.57	miles per trip, 2 trips per day
Passengers per car	1.10	1.60	occ
Rides per year	3,752,947	2,580,151	car rides
CO2 emissions	19.60	19.60	lbs CO2/gal gasoline
Fuel economy		24.6	mpg
Miles traveled	24,657,325	16,951,911	total miles
Fuel consumed	1,002,330	689,102	total gallons
Total emissions per year	**19,645,674**	**13,506,401**	lbs CO2
BUSES			
Total emissions per year		**9,882,880**	lbs CO2
Percentage increase in emissions	**99%**	**37%**	

Table 21: Total Emissions by Passenger Vehicles

As can be seen, the result of a worst-case scenario (where car ridership is the average for commuting to work) would see an increase of almost 100% emissions of CO_2, and in the best-case scenario, with an increased car ridership, Ithaca would see an increase of almost 40% of emissions.

As a final exercise, the hypothetical case for different driving distances and vehicle ridership was studied, assuming a possible increase or decrease of 20% in driving distance and increase of decrease in 0.5 passengers per vehicle, from the national average. The following matrices show the resulting emissions from those cases and percentage increase or reduction of CO_2 emissions.

		Driving Distance					Driving Distance		
		Low	Mid	High			Low	Mid	High
Car Occupancy		-20%	=	+20%	Car Occupancy		-20%	=	+20%
Optimist	2.1	8,232,473	10,290,591	12,348,709	Optimist	2.1	-17%	4%	25%
Mid	1.6	10,805,121	13,506,401	16,207,681	Mid	1.6	9%	37%	64%
Pessimist	1.1	15,716,539	19,645,674	23,574,809	Pessimist	1.1	59%	99%	139%

Table 22: Sensitivity Analysis on Passenger Vehicle Emissions

Conclusion

Total costs and emissions are calculated and compared among conventional diesel, diesel electric hybrid, hydrogen, CNG and biodiesel in this model. Based on the above analysis, we reach to the conclusions as follows.

1. Conversion to B20 of all the diesel buses in the fleet would result in a moderate decrease in CO_2 (15%) and other GHG emissions, and a small increase in the fuel consumed per year.
2. Environmental benefits of hydrogen buses can only be realized if capital and fuel costs go down. Currently, it is an infeasible option due to the high costs. This option can be suitable for larger cities with high levels of air pollution and higher ridership.
3. Diesel-hybrid buses could achieve significant cut in CO_2 emissions (36%) and other GHG emissions and pollutants. An estimated 10% fuel cost saving can be achieved in the hypothetical model. This option will continue to become more feasible as purchase cost of these buses decreases, which is an obvious trend.
4. The fuel cost savings of CNG buses do not cover the increased purchase and maintenance cost. The CO_2 emission reduction (19%) is much less than hybrid and marginally better than B20. These factors rule out CNG fuel option.
5. Our recommendation is to substitute biodiesel for conventional diesel, which is the most cost-efficient option, to achieve reduction in emissions.

IV. Buses with a High Level of Service

Introduction

Background Information

As of the year 2012, Tompkins County has a population of 102,554, among which at least one fifth are Cornell related staffs and students. Cornell University is arguably the largest source of trip generation as tens of thousands of students and staffs commute daily to and from campus. In fact, out of the ten largest TCAT stops by ridership, six are located on the Cornell campus (see Figure 31). When combined, Sage Hall, Statler Hall, and Uris Hall, all located on Cornell's central campus, have more ridership than any other TCAT stop (Tompkins Consolidated Area Transit 2012).

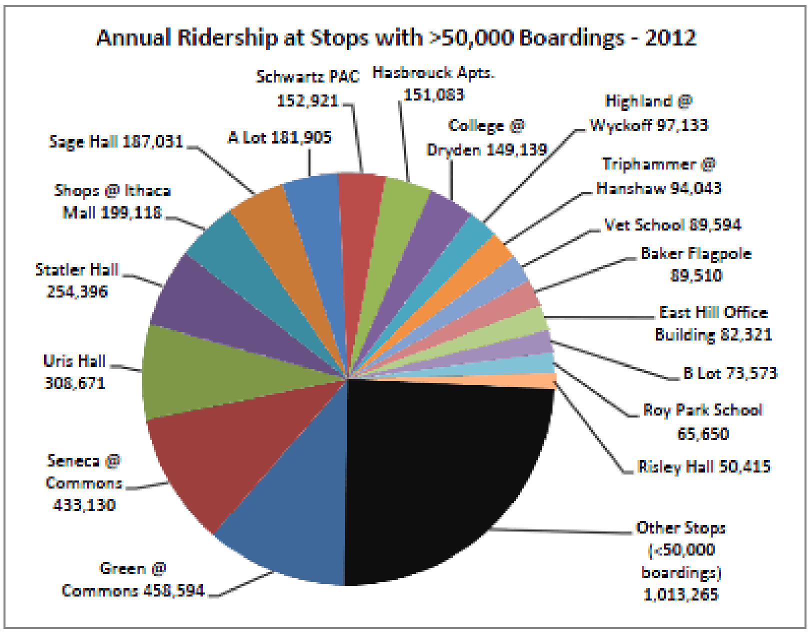


Figure 31: Annual Boardings per TCAT Stop

In addition, it can be seen that routes linking Cornell with locations where students and staff live, namely downtown Ithaca, Collegetown, and Cayuga Heights, are responsible for the majority of boardings on the TCAT system. Routes providing access to campus (Routes 10, 30, 81, and 82) account for more than 50% of the ridership on the system. Overall, more than 70% of the boarding on TCATs system were from members of the Cornell community (see Figure 32). Due to this high ridership, on-time performance along these routes has begun to suffer. For example, the Route 30 (Ithaca's busiest with 700,000 boardings per year) averages five to eight minutes late, even though it is running on only 15 minute headways.

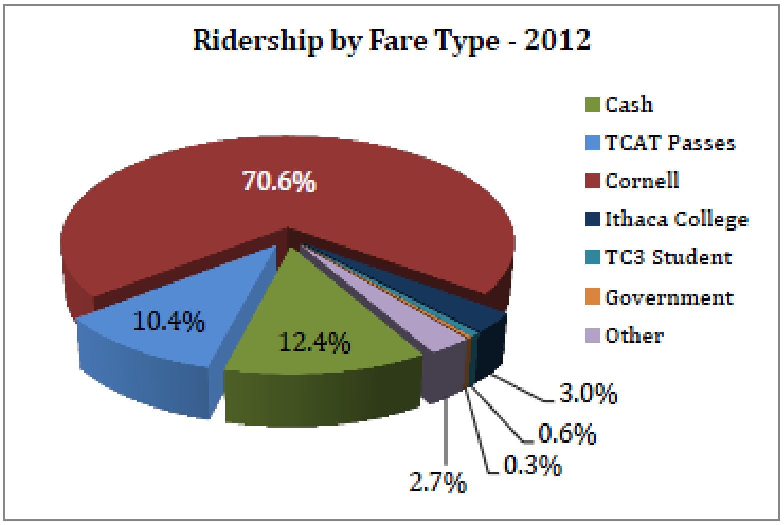


Figure 32: Proportions of Fare Type Use

The goal of this section is to analyze how applying buses with a high level of service (BHLS) technology could improve the quality of TCAT's service in the Ithaca area. For the aforementioned reason, our focus was on the Cornell community, as already high levels of ridership in this area will allow the technology to have the greatest impact on the community. In addition, with a large number of members of the current community already using the bus service for their daily commute, it is likely that this high ridership base would be more adaptable to use bus service for other trips. For example, the Collegetown area has only a few small grocery stores and limited services, so the most popular shopping areas are located near the Ithaca Mall and in the southwest portion of Ithaca near Wegmans and Walmart. Currently, bus service to these shopping areas is inefficient and thus has deterred many potential riders. In particular, to get to the southwest shopping area from Cornell campus, a bus must be taken to the Commons, and then the passenger must transfer to Route 15. TCAT previously operated Rotue 28 service directly from campus to the southwest area, but this was later discontinued in 2010 because of the need to best allocated limited resources. This was at the same time Routes 15 and 32 were redesigned to better fill the demand of the former Route 28. This route only runs once an hour and can take up to 30 minutes because it detours to serve other communities, including Titus Towers (senior citizen housing). In order to complete a feasibility study of a potential BHLS line, past implementation were compared and then potential ridership, time savings, marketing strategies, and cost of a proposed line were analyzed.

Case Studies

BusPlus in Albany, New York

The BusPlus system began operating in 2011 in Albany, New York. While this bus system is larger than the one in Ithaca, the two are close geographically and both have an area with an urban core surrounded by much more rural locations. Albany's bus system currently serves approximately 15 million riders per year, with 3.7 million of them using the BusPlus line (Capital District Transportation Authority 2013). While BusPlus is marketed as a bus rapid transit, the system lacks many of the standard BRT characteristics and is currently functioning more closely to a BHLS system. Another similar system is Metrobus in Quebec City, Canada.

The system was developed to resolve congestion and poor performance along the existing Route 5, which ran from Albany to Schenectady. This route ran approximately 17 miles and had 90 stops, carrying 25% of all the boardings on the system. Notably, the route links the communities of Colonie and Niskayuna that have 15% of the region’s population and 30% of the jobs. When developing the new line, the number of stops was reduced by 80% to just 18 stops, allowing for significantly faster service. In addition, all stops have a well-defined covered waiting area and are linked with park-and-ride facilities to allow better access for individuals not within walking distance of the service line. As with previous examples, real-time passenger information was included to increase convenience for users. All of the buses along the line were also replaced with diesel hybrid buses to help reduce emissions. In total, the cost of the project was $18 million, significantly less than a full BRT system (Capital District Transportation Authority 2013).

One aspect that the Capital District Transit Authority (CDTA) paid particular attention to was the branding of the new service. They recognized that an important aspect of BRT and BHLS is that individuals recognize that the service is something new and improved rather than just an addition to the existing bus system. This has had a significant impact on the system’s eligibility for federal grant money and on the public’s important first impression of the system. Albany accomplished this task by first changing the name of the system to BusPlus, and labeling the route as the Red Line as well as giving it a distinctive 900 series route number. To go along with its branding, the stops have similar color schemes and distinctive signage (see Figure 33).

Figure 33: Distinctive Branding of a BusPlus Stop

Since CDTA branded the BusPlus service as an improved premium system, they were able to increase the fare to $2, compared to the usual $1.50. The belief that people would be willing to pay more for the service has proven correct as evidenced by the fact that, in the two year period since its opening, ridership increased 17.6% compared to the previous Route 5. Similar to Lund, Sweden, BusPlus has shown that with a few small changes and proper marketing techniques, improved bus systems can quickly generate significant public support and experience growth much faster than one would normally expect. In fact, the system has been so successful at increasing ridership that CDTA is planning to spend an additional $40 million to lengthen the line and open two new BusPlus lines in the area. To go along with the existing branding scheme, each line will be distinguished by a unique color and all will be linked at a central hub in downtown Albany. The BusPlus system has also had a significant environmental impact. The hybrid vehicles save an estimated 2,193 gallons of diesel a year, totaling 25,000 over their 12 year lifespan. This not only greatly reduces emission, but also decreases operating costs.

Lundalänken in Lund, Sweden

Lund, Sweden provides an interesting comparison to Ithaca, NY as it is similar in size and has a similar demographic. The city itself is relatively small with 100,000 in the metropolitan area, of which the majority (42,000) is students or employees associated with the local university. The city is also closely linked with Copenhagen, which is only an hour away via high speed train. In 2003, the city opened its first BHLS line name Lundalänken, or “Lund Link.”

One challenge faced when seeking to improve the bus system in the city was that the city center was very constrained for space so operating a full scale bus rapid transit system was not possible. As a result, Lund turned to the European idea of BHLS to provide better service. New, improved service was provided along a six kilometer corridor that links Lund’s central station, its largest working district, the university, and new residential and developing areas. To improve service, the new BHLS system focused on providing the best operating conditions for the bus on the existing infrastructure (Finn, Heddebaut and Rabuel, et al. 2010). Buses run in bus-only lanes for large segments of the route and use signal prioritization. This means that the bus can signal when it is approaching a red light so that it will turn green, thereby saving the bus time and wasted energy in having to stop. In fact, a 600 meter bus-only road near the university was the only infrastructure that had to be constructed, giving the project a total cost of approximately 20 million euros (UITP 2009).

The biggest lesson learned from the Lundalänken is that even small improvements to existing bus systems can make them a more competitive form of transportation and cause significant modal shifts. While the system largely operates like a standard bus, improved operating conditions have helped to improve comfort, speed, and reliability along the corridor. Since opening in 2003, ridership along the corridor has doubled and it is estimated that 20% of the new riders have shifted away from commuting via cars (Finn, Heddebaut and Kerkhof, et al. 2011). Another aspect of the service was to extend it to the periphery of the city to some undeveloped agricultural land that was owned by the city (UITP 2009).

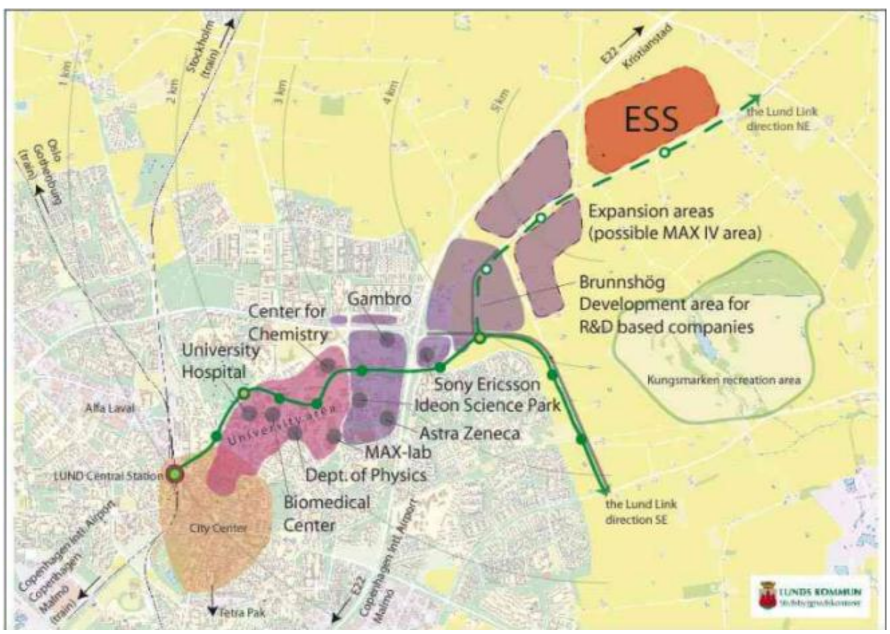


Figure 34: Lundalanken Layout and Extension to City Periphery

This extension has cause a significant increase in the value of this undeveloped land, increasing the economic feasibility of its development. Furthermore, since the land is being developed around a high performing transit service, it is likely to be developed in a manner that maximizes its use. This means that future development will likely be more sustainable and have a much higher transit share from the onset. This contrasts with many peripheral developments in the United States which often become reliant on automobiles due to underperforming transit service. Finally, Lund has seen a significant amount of money invested into rehabilitating communities along the BHLS line, particularly in the university and science park area.

Differences with Bus Rapid Transit

Buses with a high level of service (BHLS), is a term which originated in France to describe bus systems with more comprehensive and effective methods to improve bus priority. BHLS is based on improved operating environments, higher quality vehicles, infrastructure upgrades, customer service improvements, and marketing techniques (Finn, Heddebaut and Rabuel, et al. 2010). Whereas BRT systems normally try to provide a mass transit or rapid transit and thus are competitive with metro and light rail, BHLS tries to provide the best operating conditions for current bus systems to allow them to operate at their peak efficiency. This is normally coupled with improving customer service, marketing, vehicle quality, and system image. BHLS is often used in cities which have limited space and do not have the finances to build more expensive transit options. Features may include:

- Dedicated bus roads
- Bus priority lanes
- Short bus-only links
- Priority at traffic signals
- Network redesign
- Increased service levels, extended hours of operation, night services
- Advanced operations management and control (ITS-based)
- High quality bus shelters
- Park-and-ride facilities
- High quality buses
- Branding, marketing, and repositioning of the bus product
- Improved customer support services
- Advanced and integrated ticketing and fare collection
- Real-time passenger information

Area of Focus

For this feasibility study, this list of factors was simplified down to those that were reasonable for Ithaca. As a result of space constraints, installing bus-only roads and lanes was determined to be infeasible. Furthermore, TCAT does not have the funding to undertake a project the size of BusPlus. Thus, the proposed solution sought to minimize large scale infrastructure changes in order to minimize capital cost. Due to the small size of Ithaca and the majority of trips occurring during the morning and afternoon peaks it was determined that the proposed solution should aim toward reducing strain on the network and improving customer service. In the end it was determined that a BHLS solution for the Ithaca area should focus on express routing and route redesign, dwell time reduction techniques, and branding and marketing of the new improved service. A feasibility study of implementing some aspects of BRT systems on top of the proposed BHLS route is presented in the following section.

Express Routing

One of the major goals of BHLS systems is to improve the convenience and level of service of a bus system. The easiest and most logical method of doing this is to remove unnecessary stops to improve the overall efficiency of the route and reduce time lost stopping and picking up passengers at every stop. This technique was clearly used with BusPlus in Albany where 80% of the stops on the route were removed. Express routing is particularly suited for the Ithaca area as the vast majority of boarding and alightings occur at a handful of stop along each route. Ithaca bus system is also physically much smaller than many cities and many urban routes have stops located very close to each other. The Route 30, for example, has three stops within 0.4 miles, thus even with two of these stops removed riders would still not have to walk far to access the BHLS route. Also, the proposed BHLS route is not going to replace the local services buses, so riders will still have the their current option if they are not located close to a BHLS stop.

Rear Door Exiting

Figure 35: Rear Door Exiting in Portland, OR

Rear door exiting is a policy that has been implemented in many transit systems throughout the country. The idea behind the policy is to have everyone getting off a bus to exit out through the rear door, while people begin boarding through the front of the bus. This would save time as currently in Ithaca people normally have to wait to board while riders exit the bus. While a new policy can encourage passenger to exit the rear door there is no way to enforce that it is followed. By distinguishing a service as new and distinct from existing services it might make the public more willing to accept changes in generally accepted practices. Another alternative would be to allow boarding and exiting at both doors. However, this would require the installation of fare collection technology at both doors of the bus, which would reduce the room available for passengers. Also, a system would have to be set in place to ensure that everyone entering the rear door and not in view of the driver has paid the correct amount. As a result, this alternative was not considered. Instead, only suggested rear door exiting will be utilized for TCAT, while boardings will happen in the front of the bus.

Branding

Branding is how the bus is marketed as a new and improved service. As seen in Albany, branding can play an important role in how the public perceives a BHLS route. If the buses and the system simply resemble a normal transit bus, many users will expect that it will operate in the same manner and be turned off from the service when it doesn't. In particular, in most local buses, riders can signal to for the driver to stop at one of the non-standard bus stops to get off and they might expect a similar looking BHLS bus to perform the same service. Also, a well branded service can help to generate public support for the service, and even allow it to charge an increased fare.

Current Routes

Route 30

The current Route 30 links downtown Ithaca at the Commons with Cornell University and the Ithaca Mall. This route runs from the Green Street station, making stops along State Street and College Avenue as it approaches Cornell's campus. The route then stops on both Cornell's central and north campuses before continuing through Cayuga Heights to the Shops at Ithaca Mall. Stops include Green Street, Seneca Street, College and Dryden, Schwartz PAC, Sage Hall, Statler Hall, and the Shops at Ithaca Mall, all of which experience over 100,000 boardings per year. Upon return to the Commons, some of the buses loop around and start the route over again, while the majority continues on as a Route 11 bus. During the weekdays, the bus runs from 6 AM to 9 PM, with headways of 15 minutes during peak hours and 30 minutes during the rest of the day. Saturday and Sunday service is also provided at 30 minute headways. The route takes approximately 55 minutes to complete its loop with a five minute layover at the Ithaca Mall.

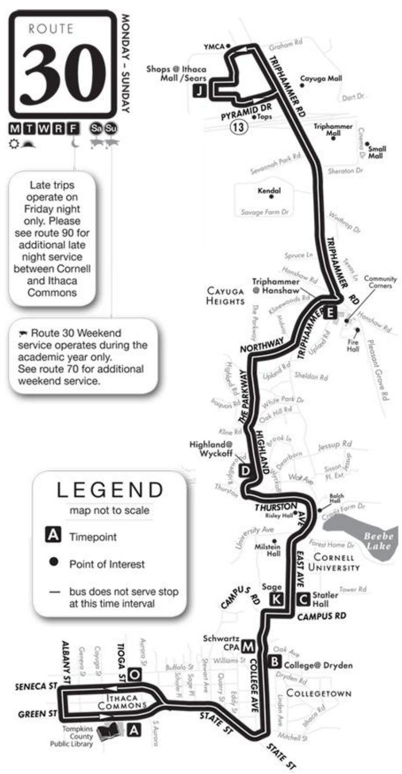


Figure 36: Route 30 Map

Overall, Route 30 is TCAT's busiest route with over 700,000 riders per year. This means that at peak hours, the route is operating very close to its capacity. In fact, the data from January to March 2014 shows that there were 39 reported cases where a bus became too full and had to leave passengers behind and during peak hours the bus is almost always standing room only.

Route 15

Route 15 currently runs from downtown Ithaca to a major shopping region southwest of the city. However, on the way to this shopping area, Route 15 takes a detour to serve a residential community and senior citizens (Titus Towers). After Titus Towers, the route continues to Wegmans and through to the Walmart area before return back via the same route to the Green Street station. The entire loop takes approximately 40 minutes. Following the Green Street station, the bus changes into Route 32 and proceeds along a different route. The route runs from 7:20 PM to 8:20 PM with hour headways for most of the day and 30 minute headways during the afternoon peak period (4:19 PM to 6:19 PM). In addition, the route runs hourly service on Saturday and Sunday. Overall in 2012, ridership on the route was 102,966, which was down by 1.3% from 2011 (Tompkins Consolidated Area Transit 2012).

Figure 37: Route 15 Map

While the current route provides important access to these communities, it is not efficient at carrying passengers who might already be transferring at the Commons. This fact makes an argument for providing an alternative route to better serve riders who are not located in these areas. It is important to note that regardless of what system improvement is installed, Route 15 should continue to run unchanged.

Proposed Route and Service

Taking into account the issues with Route 15 and 30, one possible application for BHLS in the Ithaca area would be creating a line that merges these two routes. This route would enable a single seat trip between the southwest shopping area, downtown Ithaca, Cornell, and the Ithaca Mall. In order to improve the efficiency of this route, the majority of the stops will be eliminated and for the most part the new route will only stop at the current TCAT time points. The one exception to this is that the time points of Highland and Wyckoff and Triphammer and Hanshaw will be replaced with a single stop between them at Lakeland Apartments. This is a large apartment complex that generates a significant number of trips on this segment. The stops will be Ithaca Mall, Lakeland Apartments, Risley/Balch Hall, Statler/Sage Hall, Schwartz/Collegetown, Green Street or Seneca Street in the Commons, Wegmans and Tops, and Walmart.

While the route will follow the path of the current Route 30, its path to the southwest shopping area has be change to allow faster service. Instead of detouring to access Titus Towers, the route will provide direct routing to Wegmans from the Commons via South Meadow Street. The reason for this is that this BHLS services seeks to maximize the number of people served while simultaneously reducing travel times. Because of the focus on the Cornell community, who are trying to reach these endpoint destinations, Titus Towers was omitted in order to more quickly serve the most number of people possible. The data showed that the Titus Towers time point represented a small proportion of the overall ridership. Titus Towers and the surrounding residential area will still be served by Route 15, as this community is still in need of bus services. In total, the route is approximately a 13 mile loop (from Walmart to Ithaca Mall and back).

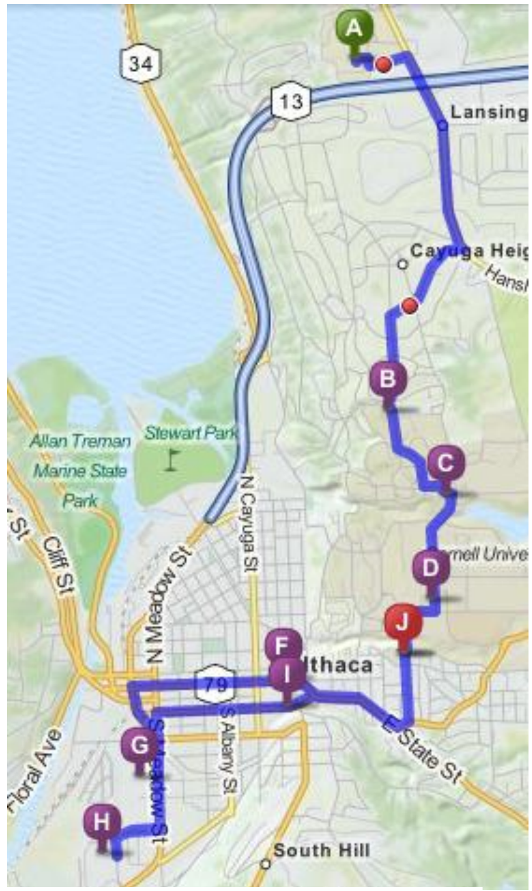


Figure 38: Proposed BHLS Route

Since the primary purpose of this proposed route is to provide more efficient transportation and a higher level of service during high demand periods, it is proposed that the route only be run during peak periods. Thus, the route should run for during the morning peak of 7 AM to 10 AM and afternoon peak of 3 PM to 7 PM. In addition, since the route serves shopping areas which are frequented on weekends, there is also high ridership during Saturday afternoons, so it is proposed that the route runs from 12 PM to 5 PM on Saturdays. Finally, since the route is only proposed as a supplement to the regular service, it should maintain headways of an hour. As we will see in later sections, this route takes approximately one hour to complete so only one bus will be needed. In our analysis it was also considered that by running the BHLS service, the demand along Route 30 could be met with one less bus per hour, since the BHLS take some of the ridership. This means the local service bus would only have to run three buses per hour during peak periods instead of four.

Ridership Calculations

Since it is impossible to predict the latent demand that the above proposed route, ridership calculations are based on predicting the proportion of current riders at each stop that would be willing to change over to the new service. One challenge to this method is that TCAT does not keep track of riders for each individual stop, but rather keeps track of the number of boarding between designated time points. These boarding are then counted as all occurring at the first time point. Thus, before ridership calculations could be completed, the boardings listed at each time point had to be distributed between all of the stops before the following time point on the route.

This was done by riding both Route 15 and 30 multiple times and keeping track of the number of people getting off at each stop. The results of this study were then analyzed and general proportions of alighting were developed for each segment. For example, on Route 30, the ridership at the Green Street station time point also includes boardings at State and Stewart, State and Quarry, and College and Mitchell. In this example, Green Street is by far the largest stop, thus 70% of the boardings on this segment were assumed to occur there, while 10% was assumed at each of the three other stops. A complete breakdown of how boardings were distributed can be found in the appendix.

After ridership had been distributed between different stops on the current bus service, an assumption was made about how many of these boardings would take the BHLS bus if it showed up instead of the normal Route 30. These assignments were based off of the Transit Capacity and Quality of Service Manual. According to studies, it is generally assumed that a passenger will be willing to walk 400 m (0.25 miles) to access improved transit service. At this distance on average 30% of riders will make this walk (Walker 2011). Using this information 30% of riders who would normally board at a neighboring stop (within 0.25 miles) were assumed to walk to get on the new BHLS service. For stops that match up exactly with the current service it was assumed 75% of riders would use it. This percentage was used rather than 100% as for some riders their destination may not be located close to a BHLS stop, so it may be faster overall to take the current service. In some cases, stops were located within 0.25 miles of two BHLS stops; in these cases, the 30% ridership was split between the two stops.

The percentages were then multiplied by the average hourly ridership for each time point during the hours that the BHLS operated. For the purpose of this study, only the average weekday ridership was used. It should be noted that the magnitude of these numbers and distribution among stops is slightly different on the weekend schedule. The result of these calculations is shown below.

BHLS Stop	Average Boardings per Bus
Walmart	1.8
Green St	7.4
College@Dryden	4.7
Statler Hall	3.9
Balch Hall	3.9
Lakeland Apt.	0.1
Ithaca Mall	5.4
Lakeland Apt.	1.5
Risley Hall	5.4
Sage Hall	1.8
Schwartz	1.2
Seneca	8.3
Wegmans/Tops	6.5
Total	**51.9**

Table 23: Estimated BHLS Ridership per Bus

Using the ridership values calculated above and the fact that 51 complete routes will be run per week gives and estimated yearly ridership of 140,000. While the estimates presented above are rough, they are very conservative, especially since they do not include latent demand. Even so, the BHLS route is would be one of the ten busiest routes on the TCAT system if it meets this estimate. Furthermore, the results suggest that the proposed route could have a significant impact on relieving the overcrowding on Route 30.

Time Savings

One significant advantage of express routing and encouraging rear door exiting is reducing the dwell time of a bus. This dwell time savings include the time for a bus to exit traffic, come to a stop, unload and load passengers, and reenter traffic. In order to better estimate the current dwell time of the system multiple rides of Route 30 were conducted at peak hours. At each stop, the number of people boarding and alighting was counted as well as the total dwell time. These data points were then used in a regression model to determine an equation for dwell time. The result of this regression is included in the appendix, but the generated equation is as follows.

$$\text{Dwell Time (s)} = 10.1 + 2.8 \times (\#\text{ boarding}) + 1.3 \times (\#\text{ alighting})$$

This time function was very consistent with observations made by various team members. There is additional dwell time (1.3 seconds) for every passenger alighting the bus because these people exit the bus through the front doors, which prevents passengers from boarding until the entry is clear. There will be some passengers who exit through the back door, but generally people will take whichever door is closer, and this will include the front. By suggesting everyone exit through the back door whenever possible, the dwell time associated with alighting passengers will be reduced to a negligible level because boarding and alighting will happen simultaneously.

$$\text{Dwell Time (s)} = 10.1 + 2.8 \times (\#\text{ boarding})$$

Monte Carlo Simulation

Monte Carlo simulation was used to assess the performance of this proposed BHLS route, and to determine whether a bus can complete the route (the full loop) in under an hour.

Base travel times were found for each segment of the route. Sub-team members rode the current Route 30 and 15 buses during peak hours and kept track of the time it took between stops, as well as the number of passengers. Using the dwell time model, the dwell time at each stop was subtracted, which gave an estimate for actual travel times along each segment. These were compared against a personal vehicle driving roughly 15 mph during peak hours, and these values were very similar. Travel times for each segment were rounded up to the next full minute in order to perform conservative calculations.

The boardings at each BHLS stop for this simulation were calculated by considering the maximum number of passengers at each time point throughout the day. Not every time point has the same peak hours, so in order to do a conservative estimation of travel times, the maximum was taken across the whole day, not for a single peak period. This incorporates the assumptions made previously about the shifts from normal bus services and about the people walking over from adjacent stops. These numbers are used as mean values for boardings. A standard deviation for each of these boardings per segment is assumed, based on the fluctuations in ridership of the segment.

The mean number of passengers and standard deviations were assumed to follow a normal distribution. The Monte Carlo simulation creates a number of boardings at each stop based on the distribution, which then is used to determine the dwell time. The total travel time includes the base travel time from before, and the dwell time for that scenario.

Segment	Start	End	Base Time (min)	Boardings	St. Dev
1	Walmart	Commons	6	10.88	2
2	Commons	Collegetown	5	20.56	5
3	Collegetown	Statler	2	9.78	3
4	Statler	Balch	3	8.21	2
5	Balch	Lakeland	2	8.21	2
6	Lakeland	Ithaca Mall	7	0.33	0.1
7	Ithaca Mall	Lakeland	7	9.37	3
8	Lakeland	Risley	2	3.99	1
9	Risley	Sage	2	9.33	2
10	Sage	Collegetown	2	3.66	1
11	Collegetown	Commons	5	2.79	1
12	Commons	Wegmans	4	29.25	4
13	Wegmans	Walmart	3	25.63	4
			50		

Table 24: BHLS Dwell Time Monte Carlo Simulation Base Values

Across all results, the average conservative travel time was around 58.77 minutes to complete a loop. The maximum travel time found through simulation was very close to an hour at 59.87 minutes, but it is important to note that these travel times are very conservative estimates. In reality, the travel times should be lower. Twenty samples from the simulation can be found in the appendix.

The results suggest that it is possible to use a single bus to operate the entire BHLS route. This bus can continuously run across the entire peak period. This will save TCAT in operational costs because only a single bus needs to be used. However, it is ideal to have a second bus in reserve for the BHLS service, in case the operating bus becomes inoperable. Alternatively, TCAT could choose to use extra local service buses to replace the BHLS bus if needed, as this reserve would be included in the 20% reserve buses they are required to maintain. However, due to unique branding on the BHLS bus, this substitution could cause some confusion.

Branding

As stated before, branding is essential to the success of a BHLS system. It is recommended that the proposed line follow the same branding strategy as BusPlus. This include painting the bus a distinctive color (different from the normal TCAT blue) and installing signs to mark which bus stops are also BHLS stops. One challenge in painting the buses differently from the normal fleet is that TCAT will essentially have to maintain two different fleets of buses that cannot be intermixed. As a result, while only one BHLS bus would be in use at a given time, at least one additional bus must be branded as a backup in case the usual bus breaks down or needs maintenance. In a small system like TCAT, this can pose a problem, as dedicating at least two buses for a route that is only run 51 hours a week is a significant capital investment for the actual usage time. However, since the buses themselves are the same, it might be possible for TCAT to simply retrofit two existing buses so entirely new vehicles do not have to be bought.

Cost Analysis

To calculate the cost of the proposed BHLS service, the hourly and per mile cost of operating a bus had to be calculated. This was done based off of TCAT's 2012 budget, which provided figures for revenue miles, revenue hours, wages and benefits, fuel cost, maintenance cost, and repair costs. These values were then used to calculate a direct hourly cost from wages and benefits of $42.53 per revenue hour and $1.50 per mile. The per mile cost includes fuel, fluids, maintenance and repairs.

Combining these values with the fact that the BHLS route is proposed to be run 51 times a week, taking one hour each time and totaling 13 miles we can calculate the total yearly operating cost as follows.

$$\begin{aligned}\text{Operating Cost} \\ &= [\$42.53(\text{per hour}) \times 51(\text{hours}) + \$1.50\ (\text{per mile}) \\ &\times 12.96\ (\text{miles per route}) \times 51\ \text{routes}] \times (52\ \text{weeks per year}) \\ &= \$\mathbf{164,334.44}\end{aligned}$$

As far as capital cost it was estimated that signage per stop would cost about $500, so for 13 stops, $6,500 was allocated. The cost of the bus depended on whether it was bought new or retrofitted; a new bus cost $390,000, while it would cost about $10,000 to paint an existing bus. All of these capital cost were discounted at the standard 7% over the 12 year life span of a bus (with no salvage value assumed).

Furthermore, the potential operating cost savings of running one less local Route 30 bus per hour were calculated. This operating cost was calculated similar to the above calculation but using a route length of 10.7 miles. As for hourly cost, running one less bus per hour equated to 51 hours of cost savings. Note that no savings are calculated for the Route 15. This is because since Route 15 runs on hourly headways for most of the day, one cannot reduce the number of buses without canceling the service.

$$\begin{aligned}\text{Operating Cost} \\ &= [\$42.53(\text{per hour}) \times 51(\text{hours}) + \$1.50\ (\text{per mile}) \\ &\times 10.72\ (\text{miles per route}) \times 51\ \text{routes}] \times (52\ \text{weeks per year}) \\ &= \$\mathbf{155,433.72}\end{aligned}$$

The result of the cost analysis is presented in the table below. The results are presented for three scenarios: buying two new buses, buying one and retrofitting one, and retrofitting two buses. The final row represents the increased yearly cost for TCAT if they institute the BHLS route and reduce Route 30 by one bus during peak hours ("potential savings").

	Buying 2 New Buses	Retrofitting 1 Bus, Buying 1 Bus	Retrofitting 2
Total Cost (per year)	$263,000	$216,000	$168,000
Potential Savings (per year)	$155,000	$155,000	$155,000
Additional Cost (per year)	$108,000	$61,000	$13,000

Table 25: Cost of BHLS Options

Benefits

Environmental Impact
Currently, TCAT has several hybrid diesel buses but they are not getting significantly more miles per gallon than the standard diesel buses. This is likely the result of hybrid buses lacking the power to be constantly starting and stopping on hills when run on urban routes in Ithaca. In contrast, if they are run on rural routes, they spend a larger portion at high speeds where they do not experience significant benefit over standard buses. Hybrid buses have proven effective on other BHLS system and could potentially be used more efficiently on the BHLS route.

Time Benefit
The most important benefit of a BHLS system is the travel time savings over regular service. In order to measure this travel time savings we must compute a monetary value. This can be done using the value of time for standard trips. According to a 2009 report, the US Department of Transportation (USDOT) estimates this value of time of the average trip in the country to be $12.50 (2009 USD), this value is equivalent to $13.77 2014 USD. Using the predicted yearly ridership calculated above and assuming that the average passenger saves five minutes we find the following.

$$\text{Time Benefit} = \$13.77 \times 137{,}658\ (\text{boardings}) \times 5 \left(\frac{\text{min}}{\text{boarding}}\right) \times \frac{\text{hour}}{60\ \text{min}}$$
$$= \$157{,}962(\text{per year})$$

This time savings can be further discounted over the 12 year life span of the capital investments to get a present value of future time savings of $1.25 million. This estimate in fact is very conservative as it assumes that ridership on the service will not increase due to improved performance and 10 minutes of time savings is lower than what will likely be realized. On some longer trips the time savings can be very dramatic. For example, on the current service, traveling from Balch Hall to Wegmans takes 37 minutes, but on the proposed BHLS system would take only 20 minutes (17 minutes time savings).

City Connectivity

In recent years there has been increasing vacancy at storefronts both in Collegetown and in the Ithaca Commons. A new BHLS will help to connect residential and commercial areas of Ithaca, thus making these locations more attractive for stores. As seen in Lund, Sweden, improved transit services can have a dramatic impact on the rehabilitation and development of economic centers.

Conclusion

From our analysis, it is easy to see that in the worst case cost scenario, if TCAT has to buy two new buses, the additional year cost on the system will be greatly exceeded by the benefit to the greater Ithaca community. Furthermore, the benefit could have long term benefits for TCAT in letting the system continue to grow, without being stifled by their current capacity. However, before a service would be implements there are a few challenges that TCAT would have to overcome. One would be getting the initial funding to pay for setup on the service. It is likely that the federal government would subsidize some of the capital cost, but a significant portion would have to be raised by TCAT. One option would be to try and foster public support and buy in to the system. For example, Cleveland, Ohio was able to sell the naming rights of their new BRT service, raising $6.25 million (Litt 2009). Another challenge will be public pushback of the service. Since the service is only being implemented on one specific line, many members of the public would be unlikely to support an expensive project that will not directly benefit them. This is a challenge faced in almost all transit projects and would have to be addressed through education of the public about the secondary benefits, which are not limited to just the riders of the BHLS line. Overall, BHLS is a feasible way for Ithaca to upgrade their current bus system, offering higher capacity and improved customer service for relatively little additional costs. If these initial challenges could be overcome, it is recommended the TCAT pursue this option.

V. Bus Rapid Transit

Introduction

Bus rapid transit (BRT) is an enhanced bus system that operates on bus lanes or other transit ways in order to combine the flexibility of buses with the efficiency of rail. A true BRT system generally has specialized design, services and infrastructure to improve system quality and remove the typical causes of delay. BRT operates at faster speeds, and provides greater service reliability and increased customer convenience. It also utilizes a combination of advanced technologies, infrastructure, and operational investments that provide significantly better service than traditional bus services.

Major Elements

There are six major elements of BRT systems, including running ways, stations, vehicles, fare collection, intelligent transportation systems (ITS), and service and operation plans (Federal Transit Administration 2009).

Running Way

Running ways are the most significant element in determining the speed and reliability of BRT services. The level of separation from other traffic affects the quality of BRT services. Options range from mixed flow lanes to fully grade-separated exclusive rights-of-way.

Stations

Stations are the important connections among passengers, BRT systems and other public transit services. The design of stations affects the accessibility, comfort and safety of the BRT services. Primary characteristics of stations include basic station type, platform height, platform layout, passing capacity and station access.

Vehicles

Vehicles have a direct impact on speed, capacity, environmental friendliness and comfort. The options of BRT vehicles range from standard buses to specialized BRT vehicles.

Fare Collection

Fare collection influences the convenience, accessibility, dwell time of vehicles, service reliability, and passenger security. Fare collection methods range from traditional pay-on-board methods to pre-payment methods.

Intelligent Transportation Systems

A wide variety of ITS technologies could be applied to improve the BRT services in terms of travel times, reliability, convenience, safety, and operational efficiency.

Service and Operation Plans

The design of service plans affects system capacity, service reliability and travel times. When designing service and operation plans, characteristics including route length, route structure, service span, service frequency, and station spacing should be taken into consideration.

Case Studies

Rede Integrada de Transporte

The Rede Integrada de Transporte (RIT) in Curitiba, Brazil is the first BRT system in the world. Curitiba has dedicated lanes for its BRT system on major streets. The buses are bi-articulated and stop at elevated tubes along its route, which provide handicapped access. The system is now used by five hundred thousand passengers every day.

There are 21 transit centers, where free transfers between routes can be made with great flexibility. The system uses alternative fuels, which help the local air quality. Additionally, the Brazilian economy relies on the production of soybeans and ethanol, so the increased use of alternative fuels helps with the generation of jobs.

However, the RIT has been facing problems recently because of its reduced fleet and lack of maintenance. Buses combine for only one percent of all vehicles in Curitiba. With 1.8 million residents in the city, demand is high for this limited amount of space, leading to overcrowding on buses. Additionally, with 1.2 million total vehicles on the road, traffic congestion greatly hinders the system. Because of these issues, the people of Curitiba now need to take alternative modes of transport because overcrowding on the buses prevents them from boarding.

Guangzhou Bus Rapid Transit

The Guangzhou Bus Rapid Transit (GBRT) is a BRT system in China. It began operation in February 2010 with daily 843,000 passengers, making it the second most used system in the world after TransMilenio in Bogota, Colombia. The route is 14 miles long and has an average bus frequency of 350 buses per hour during peak periods in a single direction. There are plans for two more extensions in the future.

Figure 39: BRT Lanes in Guangzhou

TransMilenio

TransMilenio is a BRT system in Bogotá, Colombia. It began operation in December 2000. As of 2012, there are over 70 miles of BRT lines running 12 routes, making it the largest BRT system in the world. The stations can be accessed by a bridge over the street to the center, where there are four dedicated lanes. There are regular buses which stop at every station, and express buses which stop at limited locations. These express buses can use the multiple lanes to bypass stopped buses. Passengers use a smart card to pay a fare of $0.90 USD to enter the station and can enter the bus through doors at platform level. The buses are articulated and could originally carry 160 passengers, but in 2007 they upgraded to larger buses with a capacity of 270. There were 1,400 buses in the BRT system as of October 2012.

The TransMilenio system accommodates the bicyclists in the city, which make five percent of the total trips. Bicycle parking facilities at terminal stations of lines have large facilities for storing bicycles.

According to a survey in 2005, the majority of respondents considered TransMilenio to be far superior to the previous bus service in the city. It is faster and more convenient than other transit modes. However, problems included overcrowding, pickpockets, and long wait times.

Figure 40: TransMilenio Image and System Map

Comparisons to Other Systems

BHLS vs. BRT

Many features of these two modes are similar. However, while BRT has the objective of rapid transit, BHLS does not. BHLS plays more of a complementary role to existing transportation systems, and aims to provide high quality service while still providing desired capacities. BHLS is a more suitable option for cities with road width limitations, as it would not require heavy construction work.

BRT vs. LRT

BRT is more flexible than light rail transit (LRT), and can be used as an interim system. Stations do not need to be completed before buses begin operation, and future expansions or improvements can be phased in without restricting current operations. BRT systems can respond to changes in land use or changes in community patterns. Buses can be rerouted because they are not restricted to rails. LRT, on the other hand, must have the necessary infrastructure in place before it can be used. It is also associated with a bias by local agencies to continue developing rail lines within the city instead of developing other modes. However, LRT is associated with increased economic development and a better community image. New businesses and residential developers are more likely to develop within proximity to LRT lines.

Applicability to Ithaca

Due to the limitations of space as well as budget, a standard BRT system, which includes elements such as busway alignment, dedicated right-of-way, and intersection treatments, cannot be implemented in Ithaca. Therefore, a "modified BRT system" that applies some of the BRT features to current transit system has been proposed to improve the service quality.

Running Ways

The most critical issue in planning BRT running ways is the availability of an exclusive right-of-way. Exclusive lanes are preferred for standard BRT system since they have the greatest level of separation. However, most roads in Ithaca do not meet the conditions to set exclusive lanes for BRT buses. Also, running ways are the most significant cost item in the entire BRT system. Based on these reasons, the modified BRT system would operate on current mixed flow lanes.

Stations

Most stations in Ithaca consist of a basic transit stop with a simple shelter to protect waiting passengers from the weather. The platform layouts of most stations are single vehicle length platforms. This is the shortest platform length necessary for the entry and exit of one bus at a time at a station. Platform-level boarding is an essential feature of BRT service. Having the bus station platform level with the bus floor is one of the most important ways of reducing boarding and alighting times per passenger and affecting the safety and convenience of service. Therefore, we would apply this feature to the modified BRT system.

Vehicles

Current buses are conventional standard vehicles that have two doors and a rapidly deployable ramp for wheelchair-bound and other mobility-impaired customers. Vehicle configuration would remain for the modified BRT system.

Fare Collection

Transit in Ithaca has a pay-on-board system. Passengers board through the front door and pay the fare by cash or smartcard as they enter. This fare collection process results in large dwell time on busy routes. Off-board fare collection, as another essential element of BRT service, is one of the most important factors in reducing travel time and improving the customer experience. This feature would be considered in the modified BRT system.

Off-Board Fare Collection

Fare payment aboard transit vehicles is often a source of delay for operators. For that reason, many transit providers find off-vehicle fare payment (sometimes called a proof of payment system) improves reliability and reduces dwell time at stops. Off-vehicle fare payment may take the form of pre-payment online or purchasing a ticket at a ticket vending machine. This practice is very common on North American light rail systems and has gained popularity as a way to improve service for many BRT systems. For this particular project, aiming to improve the bus system of TCAT in Ithaca, the long dwell time and crowded inflow of passengers could be solved by applying this BRT feature.

Comparison of Fare Collection Methods

In general, there are two generations of fare collection methods for buses. They can be grouped as traditional on-board fare collection and off-board fare collection.

On-Board Fare Collection

We can further group these by the types of machines they use.

- Mechanical, non-electrical
- Cashless fare boxes
- Full featured

Mechanical systems only use coins and bills. The advantages for this are that they are small, inexpensive, reliable, secure, easy to maintain, and well suited for their application, while the disadvantages are troublesome manual cash counting, limited amount of cash capacity, manual passenger counting, and no interfaces.

Figure 41: Fare Collection Types

Cashless fare boxes use smart cards and magnetic cards. The advantages are that they are easy to install, less expensive than full featured fare boxes, able to process all types of electronic fare media, able to interface to other devices, reliable, and configurable. Their disadvantages are that they require separate devices for accepting cash, and ridership or revenue reports are separate from cash counting and reporting.

Generally speaking, on board fare collection is simple to operate and straightforward to use. Most importantly, using this method can save capital cost. However, this system will not work as well in a busier condition. For the stops with frequent and a high level of ridership, this system can slow the inflow of passengers leading to serious delay of the bus. For a relatively mature bus transit system, the off-board fare collection system can optimize the boarding time.

Off-Board Fare Collection

This method refers to paying fares at the station instead of on the vehicle. Fare collection is accomplished with a smartcard reader and a turnstile at the station entrance. In some other systems, a “proof of payment” system is used. It could greatly speed up the boarding process by cutting down the time inflow passengers having trouble finding cash, coins or their smartcard, which would stop the flowing queue.

Figure 42: Example Off-Board Fare Collection

The primary benefit of off-vehicle fare payment is in reduced dwell time. These savings are derived from allowing people to board at all doors of vehicles, rather than only at the front, and reducing time waiting for people to pay aboard the vehicle. The Federal Transit Administration notes that moving all fare collection off the bus offers the greatest potential for reducing dwell time. Not only is fare payment time reduced to zero, but all doors of the bus can be used for both loading and unloading.

Off-vehicle fare payment is one of many strategies relating to boarding and alighting that can decrease end-to-end run time, and thus save money on operations. However, for the current TCAT buses, the front and back doors may not be big enough to do so. Simultaneous inflow and outflow may cause safety concerns.

In our plan, TCAT’s BRT will have a self-service, proof-of-payment fare collection system. Ticket vending machines will be located on BRT station platforms. Cornell IDs, transfer slips, and TCAT passes will still be acceptable forms of payment. Since we cannot achieve the full scale of BRT, we will not be able to install the boarding system with automatic ticket gates. Thus, it may be necessary for TCAT to check for passengers who have not actually paid. According to our team members’ observation in other cities like Paris and Boston, authorities usually assign a supervisor to randomly check the fare payment on board and impose a high fine on fare evasion. Fines must be high enough and enforcement frequent enough to produce a fare evasion level which is acceptable. The mechanism for paying the fine, or in some cases, a super-fare, must be administratively simple. The public must believe that inspections are random, and not prejudicially directed at certain types of people. For Ithaca, we recommend $100 as the fine for fare evasion.

Figure 43: Example BRT Stop in Collegetown

A limited way of introducing off-board fare collection is the free-fare zone. These are typically used in downtown areas with a high concentration of riders in a small area. Because the free-fare area is small, the trips served are inherently short, and tend to be off-peak (such as lunch trips and tourist trips). Since these trips do not contribute much to peak-hour demand, they usually cost little or nothing to serve. A free-fare policy in these small areas means that these trips do not increase dwell time much.

Time Savings

According to the experiment and observation data from BRT practice guide book, we can find that the pre-payment method takes the least time for boarding, while swiping or dipping card inversely take the longest time.

EXHIBIT 4-128 Passenger Service Times Associated with Different Payment Methods

Payment Method	Service Time (seconds/passenger)
Pre-payment	2.25 to 2.75
Single Ticket or Token	3.4 to 3.6
Exact Change	3.6 to 4.3
Swipe or Dip Card	4.2
Smart Card	3.0 to 3.7

SOURCE: *Transit Capacity and Quality of Service Manual* (*9*)

Table 26: Passenger Service Times Associated with Different Payment Methods

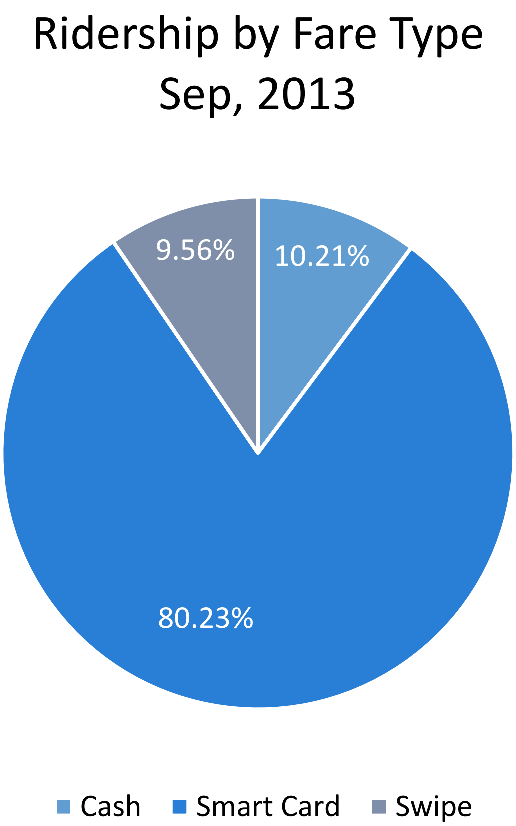


Figure 44: Ridership by Fare, September 2013

Based on the service time for each method, we can apply the percentage of each group in Ithaca to calculate the average boarding time for a passenger.

$$\text{Mean time per person} = 10.21\% \times 3.95\ \text{s} + 80.23\% \times 3.35\ \text{s} + 9.56\% \times 4.2\ \text{s} = 3.52\ \text{s}$$

$$\text{Mean time per person by off} - \text{board fare collection} = 2.25\ \text{s}$$

$$\text{Time saved} = 3.52 - 2.25 = 1.27\ \text{s per passenger}$$

Cost

With the BRT practice guide book, we can get the most conservative number for the cost of this system.

EXHIBIT 4-127 Fare Collection Equipment Capital and Maintenance Costs*

Capital Cost Elements (Bus-Related Fixed Costs per Unit)	Low	High
Mechanical farebox	$2,000	$3,000
Electronic registering farebox	$4,000	$5,000
Electronic registering farebox (with smart card reader)	$5,000	$8,000
Validating farebox (with magnetic card processing unit)	$10,000	$12,000
Validating farebox (with smart card reader)	$12,000	$14,000
Validating farebox (with magnetic & smart card reader)	$13,000	$17,500
Stand-alone smart card processing unit	$1,000	$7,000
Magnetic fare card processing unit (upgrade)	$4,000	$6,000
On-board probe equipment**	$500	$1,500
Garage probe equipment**	$2,500	$3,500
Application software (smart card units)	$0	$100,000
Garage hardware/software	$10,000	$20,000
Central hardware/software	$25,000	$75,000
Payment Media Costs	**Low**	**High**
Magnetic or capacitive cards	$0.01	$0.30
Contactless cards (plastic)	$2.00	$5.00
Contactless cards (paper)	$0.30	$1.00
Contact cards	$1.50	$4.00
Operation and Maintenance Costs	**Low**	**High**
Spare parts (% of equipment cost)	10%	15%
Support services include training, documentation, revenue testing, and warranties (% of equipment cost)	10%	15%
Installation (% of equipment cost)	3%	10%
Nonrecurring engineering & software costs (% of equipment cost)	0%	30%
Contingency (% of equipment/operating cost)	10%	15%
Equipment maintenance costs (% of equipment cost)	5%	7%
Software licenses/system support (% of systems/software cost)	15%	20%
Revenue handling costs (% of annual cash revenue)	5%	10%
Clearinghouse (e.g., card distribution, revenue allocation) *** (% of annual automatic fare collection revenue)	3%	6%

* Actual cost depends on functionality/specifications, quantity purchased, and specific manufacturer.

** In an integrated regional system, there is no additional cost for probe equipment.

*** This cost depends on the nature of the regional fare program, if any.

SOURCE: *TCRP Report 94* (*27*)

Table 27: Fare Collection Equipment Capital and Maintenance Costs

Based on the table above, we can calculate the cost of this system.

$$\begin{aligned}\text{Unit Fixed Cost} &= \text{Equipment Cost} + \text{Operation Cost} + \text{Maintenance Cost}\\ &= (100\% + 10\% + 10\% + 3\% + 10\% + 5\%) \times \text{Equipment Cost}\\ &= (138\%) \times \$5{,}000 = \$6{,}900\end{aligned}$$

$$\text{Unit Variable Cost} = \text{Contact Card Cost} = \$1.50$$

$$\begin{aligned}\text{Fixed Overhead} &= \text{Central System/Software Cost} + \text{Software License/System Support}\\ &= (100\% + 15\%) \times \$25{,}000 = \$28{,}750\end{aligned}$$

Platform-Level Boarding

Platform height refers to the vertical height of the station platform above the roadway or transit way. It affects the ability of passengers with mobility impairment or disabilities to board the vehicle. Traditionally, passengers step from a low curb up to the first step on the vehicle then climb the following steps to get on the bus. With the widespread adoption of low-floor buses, boarding and alighting have become easier and faster for passengers. On a low-floor bus, boarding times are reported to be saved from 0.2 to 0.7 second per passenger while alighting times are reported to be saved from 0.3 to 2.7 seconds per passenger. Matching platform height with vehicle floor height can enhance passenger experience and reduce station dwell time. As more agencies are considering BRT and low-floor buses, the need to address platform-level boarding issues, including how to achieve no-gap, no-step boarding and alighting, has increased.

Comparison of Curb Types

Three basic platform height options are available, including standard curb, raised curb, and level platform.

Standard Curb

A BRT station is installed on the existing curb that is six inches above the roadway (Figure 45). Although the application of a standard curb platform generally requires no incremental infrastructure, costs, and time, it causes a vertical gap between the curb and the vehicle floor and closely resembles local bus boarding. This option requires passengers to step up to enter the BRT vehicle and step down to exit the bus, even with low-floor coaches, which would increase station dwell times, especially for passengers who are handicapped, elderly, or traveling with small children. Standard ramps or lift deployment is necessary for passengers with disabilities to achieve accessing into the vehicle, the use of which would increase dwell time. Examples of BRT systems using standard curbs include Silver Line in Boston, Express in Chicago, and Metro Rapid in Los Angeles.

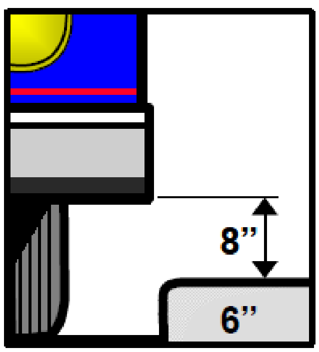


Figure 45: Standard Curb

Raised Curb

The raised curb reduces but does not eliminate the vertical gap between the platform and the vehicle floor with height between a standard curb and a level platform. With the average of U.S vehicles’ floor height of 14 inches and the optimal step distance for most people of five to seven inches, the optimal height for a raised curb should be nine to ten inches above the BRT running way (Figure 46).

Compared with a standard curb, the raised platform has benefits including easier boarding and alighting, enhanced passenger perception of BRT service and stronger branding and identity. This treatment is preferred over the standard curb. When contemplating a raised curb, the incremental infrastructure, costs and time for construction, as well as the sloped access from the level of sidewalk road to the end of the platform should be taken into consideration. Pittsburgh Busways is an example of BRT system using raised curb.

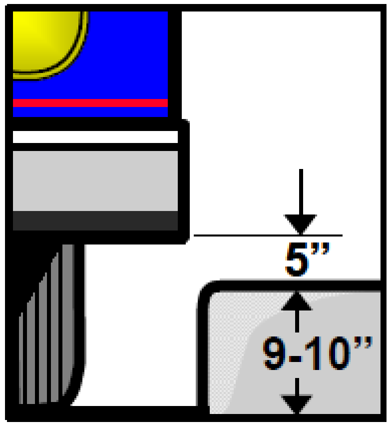


Figure 46: Raised Curb

Level Platform

This option places platforms on the same level as the floor of the vehicle. The height of a level platform is approximately 14 inches above the roadway for low-floor vehicles, which consistently eliminates the vertical gap between platform and vehicle floor (Figure 47). To provide easy access and enhance passenger safety of boarding and alighting, the horizontal gap between the bus and platform should be minimized. To address the horizontal gap and achieve level boarding, special devices and technologies, including intelligent transportation system (ITS), satellite-based technologies, and onboard bridge plates, are utilized to precisely dock vehicles.

The benefits of a level platform include reduced station dwell time, ease of passenger boarding and alighting, potentially the elimination of the need of standard ramps or lift deployment for passenger with disabilities, stronger branding and identity, enhanced passenger perception of BRT service, and greater similarity to rail-type services.

As with raised curb, factors such as the additional infrastructure, costs, and time for construction should be reviewed when contemplating a BRT system with level platforms. Examples of BRT systems using level platform include MAX in Las Vegas, and HealthLine in Cleveland.

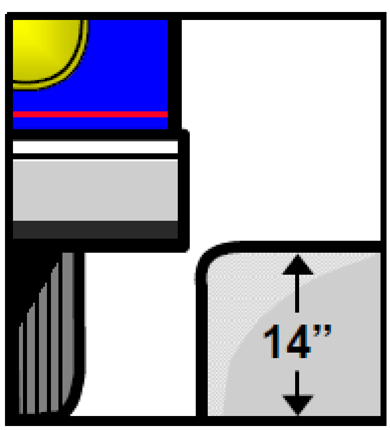


Figure 47: Level Platform

In summary, the standard curb is the easiest one to implement since no additional infrastructure, costs, and time is required, while raising the curb to a raised platform or level platform provide improvements in passenger convenience and safety.

Implementation for TCAT

To create a safe, easy, and efficient manner of passenger boarding and alighting, level platform is preferred compared to standard curb and raised curb. This treatment applies only to stations with high ridership due to the limitations of space and budget.

A few assumptions have been made to determine the construction area of each station. Since most stations in Ithaca are installed on the existing sidewalk and the minimum width of sidewalk is three feet, we assume the width of level platform is three feet.

The length of a platform consists of the lengths of entrance taper, deceleration lane, stopping area, acceleration lane, and exit taper (Figure 48). Since most passengers get on or get down the vehicle in the areas of deceleration lane, stopping area, and acceleration lane, we assume that the length of level platform only includes these three parts. The length of stopping area should be 50 feet for each standard 40 foot bus. Assuming that the through speed of vehicle is 35 miles per hour (mph) and the entering speed is 25 mph. Then, for the location and design of bus stops, the length of the acceleration lane is 250 feet while the length of the deceleration lane is 184 feet.

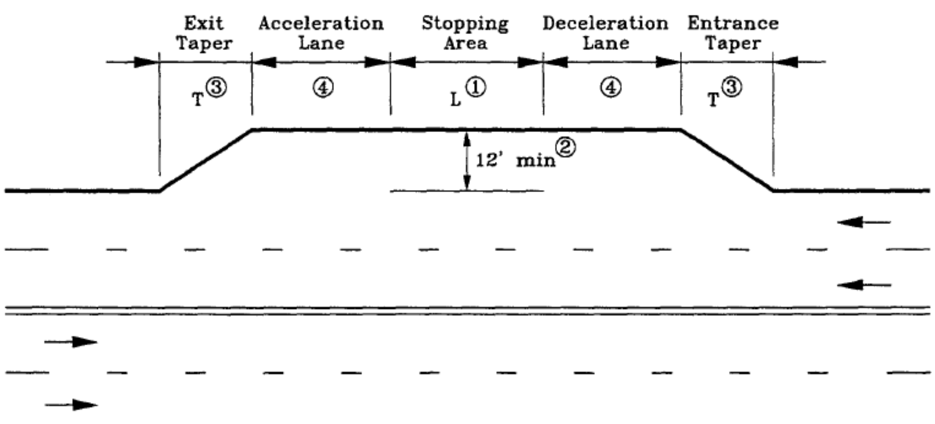


Figure 48: BRT Bus Stop Diagram

Based on above assumptions, the width of the level platform is 3 feet while the length of the level platform is 484 feet. The area of a level platform is 1,452 square feet.

Cost

Implementing a level platform requires an additional eight inches of concrete depth with additional infrastructure cost. According to Generic Cost Estimating Tool, the unit cost of concrete paving sidewalk (scored) is from $8 to $10 per square foot. We assume the unit cost of material is $9 per square foot. Given the area of a level platform of 1,452 square feet, the infrastructure cost of level platform is $13,068 per station.

Branding

Need for Branding

BRT systems are developed incrementally. Images and marketing are necessary for the success of BRT. A distinct identity is necessary for the promotion of BRT, e.g. distinct identity is a hallmark of Europe's BRT systems. It is necessary as a means to distinguish high-quality bus services from regular ones. In order to distinguish BRT in the public and media's perception, it is important to brand the system as different and as better than the existing system. This requires a strong communications and marketing plan leading up to system launch, as well as high quality branding that will touch all elements of the system, from communications products to signage to maps and the buses themselves.

First impressions can make or break a new BRT project. In Los Angeles and Las Vegas, both of which have already implemented BRT plans, the news media and the public's first impressions of the system at opening helped define the slant of subsequent coverage for months, if not years. In Las Vegas, the BRT system opened to great fanfare and praise, and benefited from the negative attention of the city's trouble-prone monorail project. Los Angeles's BRT system opened late, over budget, had a series of collisions with automobiles, and brought with it a batch of service cuts on parallel bus routes. High ridership volumes and free rides were not enough to overcome the Orange Line's troubled start.

Future BRT lines and networks can build on initial successes. The consistent use of certain messages, particularly early on, can help shape long-term public perception of a project.

There should be strong positioning of BRT as much more than a regular bus service. The system should be sold as modern and efficient, something locals could be proud of and as groundbreaking and cost-effective.

Results of Developing Branding

There will be great public support and enthusiasm. Public buy-in to the system can be achieved by various means, such as naming contests. Las Vegas officials used a contest as a way to build public awareness and interest. Although that did open the door to the publication of critical names like The Bust, it did engage the community members early on in the development process. The pride that this kind of early buy-in engendered was fostered through the opening weeks of the system.

Strong business and political can also be achieved. Seeing the popularity of the system, the business and political community tend to lend support to it. This is an important step towards federal grant eligibility. Branding can also lead to positive media, which leads to more people using the system, potentially increasing the ridership by 15 to 20%.

Improved and new-generation transit systems like BRT act as a catalyst for economic development. The brand helps in increase in property values around the new system. BRT branding also increases ridership, which help generate more revenue for the transit authorities.

Features of Branding

Branding should be applied system-wide and should include the following items

- Branding stations and terminal features such as bus and BRT stop signs, passenger information boards, fare collection equipment, and media
- Giving vehicles a special styling, unique livery, added passenger amenities, and marketing panels
- Branding running ways by using special paving materials, colors, and markings
- Branding marketing materials such as route maps, route schedules, websites, and media information
- Special signs at bus stops
- Pamphlets and flyers advertising the BRT system
- A special timetable or poster showing the stops along the BRT route
- A BRT brand name is necessary, e.g. Fastline, MetroRapid, Express
- Transit agencies can post interior ads on its buses to announce the new BRT service
- Catchy logos, distinct color schemes, and other visual elements should be used to convey BRT's unique identification, distinguishing them from regular buses. Las Vegas's BRT buses and stations, for example, feature old casino signs that reflect the city's iconic identity and history
- Differentiation techniques like pavement marking and signs should be done on BRT bus stops, such as "bus only" markings
- Running way marking supplement brand identity. It can be done by paving running ways in a unique color (e.g. maroon in Europe, green in New Zealand, yellow in Nagoya).

Figure 49: BRT Bus Stop Signs

Figure 50: BRT Name Examples

For example, the New York Select Bus Service uses distinctive graphics. Strip maps on the bus, akin to a rapid transit vehicle, improve the availability of information to customers. A number of elements were also included to ensure a successful program launch, such as customer ambassadors. For the first few weeks, staff was on the ground to educate riders, which was a very successful and necessary strategy.

Cautions

If transit authorities really want to distinguish BRT from the regular buses, then they have to get "bus" out of the name of the transit system. Names like "BRT-Lite" should also be avoided. The transit authority should not promote the BRT brand at the expense of the existing bus system. They should be careful not to devalue the already existing services and riders. BRT experts warn against promoting BRT public transportation projects by price. BRT's relative low cost can be misconstrued as evidence of a lower value system. People generally do not like new systems which are marketed as low priced. That is why cost-intensive transit systems like rail are desired by the public. However, BRT is a low cost but high value and efficient transit system. Drivers need to be trained by the transit authority about the brand and how to explain the brand or service to the customer. They should always speak highly of the transit system to the public, and any complaints should be directed to the transit authorities.

Branding in Ithaca

Full-scale implementation of BRT is not possible in Ithaca due to space and budget constraints. Limited features of branding can be implemented.

- Special signs at bus stops, with Green Street and the Seneca Street stations in the Commons as the focus

- A special timetable showing the stops on the BRT route to be affixed on the off-board fare collection machines
- Due to the limited availability of buses with TCAT, we do not suggest special livery or logos to be painted on the buses
- Buses will have electronic sign boards with special route numbers to indicate BRT service
- Pamphlets and flyers advertising the BRT system, especially on stops on proposed express Route 30
- Painting running ways with a unique color at bus stops with the stops of Green Street and Seneca Street in the Common and at Ithaca Mall
- "BRT Only" markings on the pavement at bus stops
- Logo and BRT names will be decided by the citizens of Ithaca

Cost of Branding

The population of Cleveland is 390,928. In Cleveland, the money spent for branding is $1.2 million. In Santa Clara, California for the Valley Transportation Authority 522 Rapid, the cost of branding is $135,000. For the Los Angeles BRT, the transit authority started the advertising budget at approximately $80,000. After deciding to have an in-house public relations unit, the budget rose to close to $3.5 million but currently it has shrank to $1.5 – 2 million. Considering that the population of Ithaca is 30,331, we expect the cost of branding for the proposed BRT system is $80,000.

Monte Carlo Simulation

The Monte Carlo simulation was carried out for the ridership for certain stops which we chose to apply the off-board fare collection feature. We can use the ridership data to calculate the time spent at these stops compared to the original time spent to see how much time a passenger can save by applying the BRT features.

In our simulation process, we used @Risk as our analysis tool. We used the fitted distribution function to analyze the original data of each stop to fit the ridership distribution. We ran 500 iterations for each stop to get the simulated ridership distribution. By applying the percentage and the standard time spent at each fare payment method, we can get the time using the distribution. We will be able to calculate the mean time spent at each stop and the mean time saving from off-board fare collection.

There are differences in the effects of features at different peak periods. We considered fitting the distribution and running the simulation by different time periods. We divided a weekday into three parts: morning rush hour, afternoon rush hour, and others, while for weekends, the day can be divided into rush hour and others.

The following figures show the results for the boarding times from the stop at College and Dryden at different times of the day.

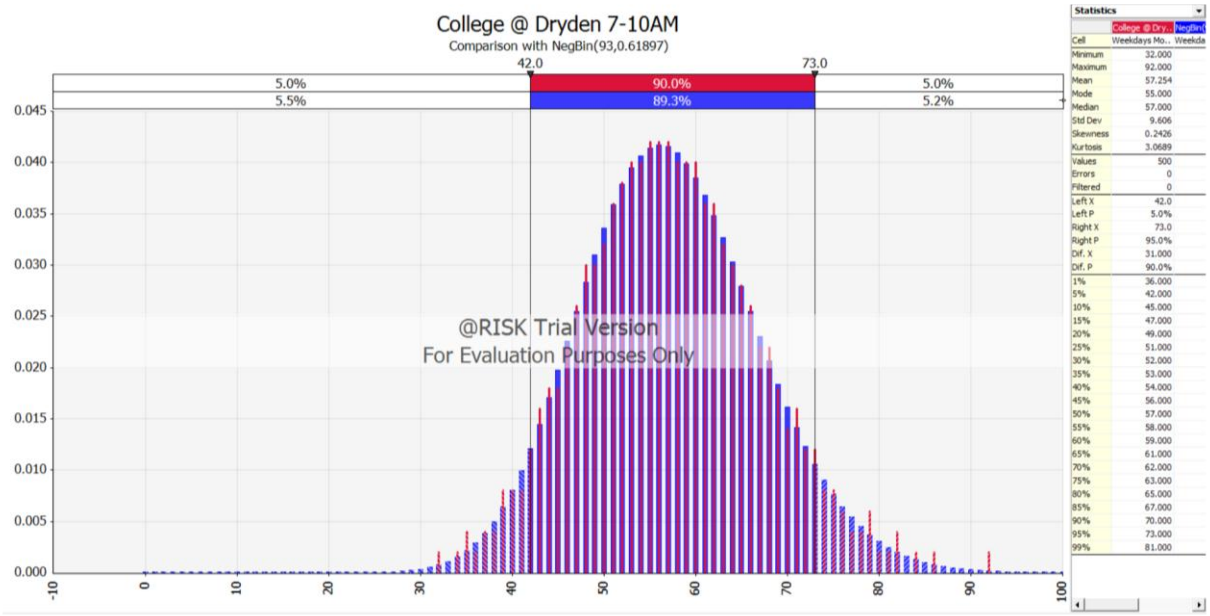


Figure 51: College and Dryden, Weekdays 7 AM - 10 AM

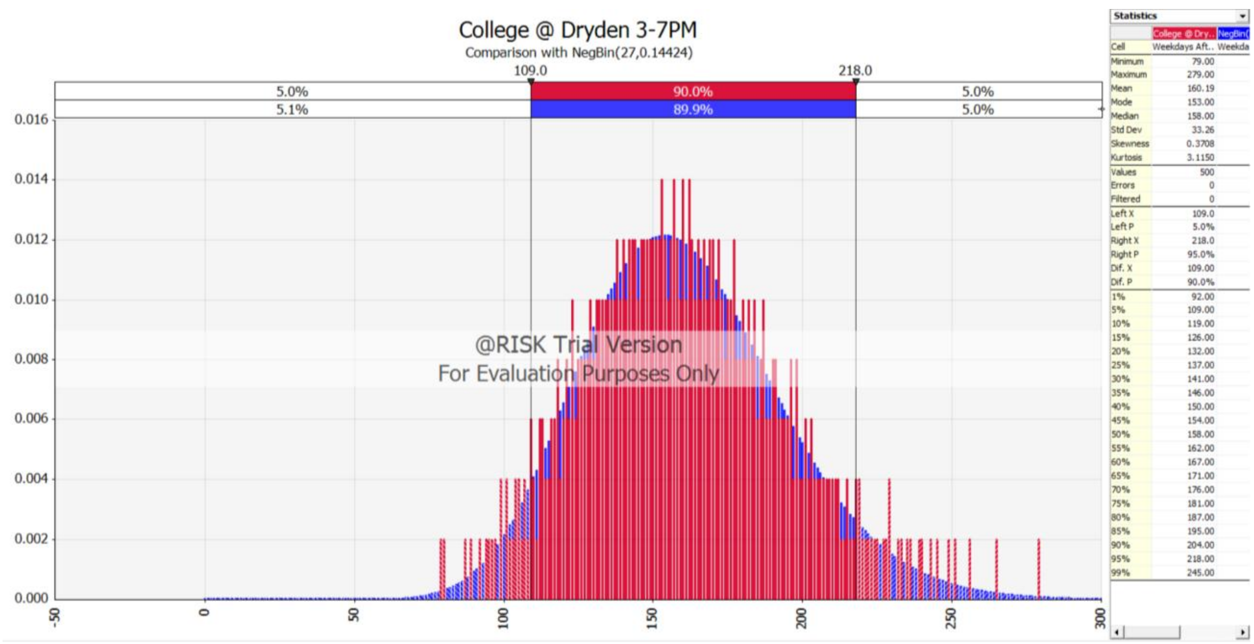


Figure 52: College and Dryden, Weekdays 3 PM to 7 PM

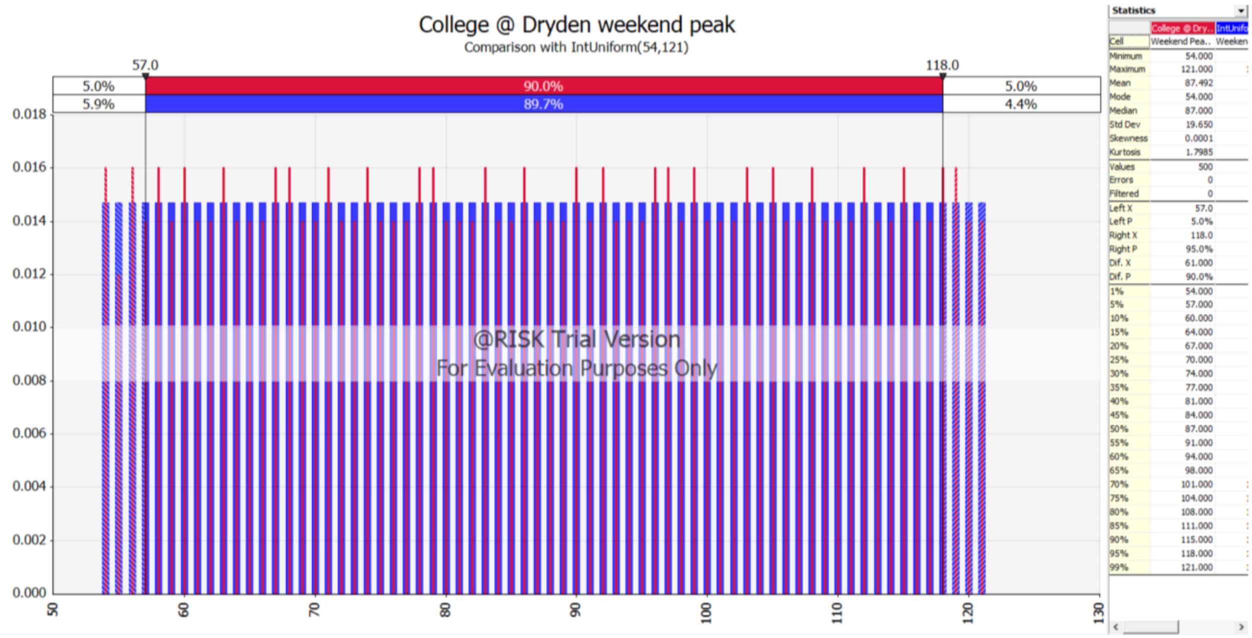


Figure 53: College and Dryden, Weekends 12 PM to 4 PM

The following table is a summary of time savings for all of the stops of Route 30 through weekdays and weekends using BRT features.

Total Time Saving during the period at the stop						
Stop	Weekdays			Weekend		Total Time Saving (hours)
	Peak Hour		others	Peak Hour	others	
	7-10AM	3-7PM		12-4PM		
Green @ Commons	419.4	140.6	338.8	126.9	110.6	1.380219
Seneca @ Commons	53.1	101.3	101.9	56.9	29.5	0.403983
College @ Dryden	71.6	200.3	204.0	109.4	79.1	0.765618
Schwartz PAC	4.2	52.3	80.0	34.4	13.1	0.21591
Sage Hall	7.5	111.7	151.9	32.5	5.6	0.397666
Shops at Ithaca Mall @ Sears	250.0	237.8	336.5	122.5	119.4	1.279194
Statler Hall	36.2	446.3	320.4	160.6	83.8	1.250927
Total for each period (mins)	7	22	26	11	7	-
Total Time Saving for Route 30 (hours)	5.11					

Table 28: Total Time Savings Using Off-Board Fare Collection

From the results above, we find by applying the BRT features, it does save time for each stop, but it is far less than other improvement methods. However, considering the other effects like branding and rider experience, it may be considered a convenient and time-saving experience.

Total Cost

Among stops that have annual ridership of more than 50,000 boardings in 2012, nine of the eighteen stops belong to Route 30. Along Route 30, stops with annual ridership of more than 100,000 boardings are selected to implement BRT features. That is, we would apply off-board fare collection and level platform features to seven stops, including Green at Commons, Seneca at Commons, Statler Hall, Ithaca Mall, Sage Hall, Schwartz PAC, and College and Dryden.

The unit cost of implementing off-board fare collection is $28,750 per stop. The unit cost of implementing level-platform is $13,068 per stop. The total cost of apply these two features is $292,726. Combined with the cost of branding, the cost for implementing BRT services in Ithaca will be $372,726.

Conclusion

In summary, we reach the following conclusions. A standard BRT system cannot be implemented due to the limitations of space and budget. Instead, a “modified BRT system” has been proposed, which applies limited BRT features including off-board fare collection, level platform, and branding, to current transit system. For off-board fare collection, a self-service, proof-of-payment fare collection method would be recommended. Ticket vending machines would be located on station platforms. Current forms of payment, including paying with Cornell IDs, transfer slips, and TCAT passes, would be kept. A supervisor would be assigned to randomly check the fare payment on board. A penalty of $100 would be charged for skipping the ticketing. For platform height, a level platform is preferred compared to standard curbs and raised curbs. The area of a level platform would be 1,452 square feet based on assumptions of the width and length of the platform. For branding, we suggest to have special signs at stops of Green Street and Seneca Street in the Commons, and a BRT route timetable to be affixed on the ticket vending machine. Buses with electronic signboards would display the BRT service with special route numbers. Running ways of stops of Green Street Station and Seneca Street in the Commons and Ithaca Mall would be painted with a unique color. Also, “BRT Bus Only” would be marked on the pavement at BRT bus stations.

These features would be applied to seven stops along Route 30. The combined cost of all features would be $372,726. Through implementation of these features, it will be possible for users to save time and find the BRT experience to be an improvement over existing services.

VI. Articulated Buses

Introduction

TCAT has experienced an increasing number of full buses during peak-hour services. Full buses incur an opportunity cost associated with the unserved demand, and lower passenger satisfaction. One among numerous options to improve the quality of transit service on high-demand routes is the use of high-capacity transit vehicles. The goal of this study is to evaluate the feasibility of operating articulated buses on high-demand routes. The fixed-routes with high current demands, upward demand trends, and are frequently reported full during peak services are the focus of the analysis. Two representative routes are chosen accordingly.

Background Information

Articulated buses have a long history in North America. In 1938, Twin Coach Company manufactured the first articulated bus for Baltimore, Maryland. However, at that time, the articulated bus was not successful due to the large turning radius. On the west coast, AC Transit in California started operating the experimental commuter coach named XMC 77 in the mid-1960s. During the early stages, articulated buses were eventually withdrawn from service due to the expensive maintenance. Nowadays, thanks to the high passenger capacity, articulated buses are used as part of BRT systems.

In addition to BRT, other applications include peak-only services on trunk routes, commuter express services to park-and-ride lots, trippers that experience overloads, replacement service for rail shutdowns, and high-demand special events.

Technologies

Typical articulated buses are approximately 59 feet in length, with a standard rigid-construction from 36 to 46 feet. Some variations include the bi-articulated bus and the double-decker articulated bus. The bus capacity is usually about 200 passengers. Articulated buses come in two configurations – pusher or puller. In the pusher configuration, because rear-mounted engine powers the rear axle of the bus while the longitudinal stability is maintained by hydraulics, the buses can be built without steps. With this configuration, the pushers can be built with low floors and without steps, which enhance the accessibility of the passengers. The pullers, on the other hand, have the engines mounted in the front area, preventing lower floors and creating discomfort to the passengers because of the noise and the vibration. However, the pullers outperform the pushers in low temperature or freezing conditions. Diesel engines are common among articulated buses. Nevertheless, there are also diesel-electric hybrids and others that are propelled by compressed natural gas.

Advantages, Disadvantages, and Current Issues

Articulated buses have a few attractive features. Aside from their high capacity, articulated buses enable more rapid, simultaneous boarding and disembarkation through more and larger doors. The bus dimensions translate to a lower center of gravity and, therefore, more stability. The lower center of gravity also allows the bus to turn at a smaller turning radius. Unlike the double-decker buses, the smaller frontal area of the articulated one results in less air resistance and, thus, higher maximum service speed. In addition, the low-floor articulated buses benefit passengers with limited accessibility.

On the downside, however, the older-model articulated buses have inefficient and ineffective motive power (i.e. lower speed and acceleration in comparison to traditional 40 foot buses). Numerous stalling and on-board fires have been reported as a result of the overheating engines. When operating in highly populated areas, articulated buses are more likely to be involved in road accidents due to the complexity of operating such long buses.

The potential tradeoffs associated with utilizing articulated buses are the following.

Pros	Cons
• 3 or 4 doors available for exiting. Also for boarding if pre-paid fare collection is used. Shorter dwell times. • Turning radius comparable to 40 foot buses. • Available in low-floor design, which facilitates boarding and exiting • Wheelchair access and transport similar to 40 foot buses	• Larger roadway footprint. • Longer bus stop zones required. • May have slower acceleration capacity. • Low-floor results in higher passenger compartment road noise. • Some passengers do not like the articulated joint to ride in—cannot see out and it moves. • State regulations on length may be an impediment

Table 29: Pros and Cons of Articulated Buses

In a 2008 report, the Transit Cooperative Research Program (TCRP) discussed the experiences with higher capacity buses. The findings were based on the survey among transit agencies owning high capacity buses. There are two general findings: the introduction of high capacity buses need not affect the ridership, and that the experience with high capacity buses is generally positive (Hemily and King 2008). For articulated buses, however, the feedbacks were mixed. While all the respondents agreed that the articulated bus was superior to standard bus in terms of the turning maneuverability, about half of them perceived the performance of articulated buses to be inferior in three areas: fuel economy, grade climbing and acceleration. On the other hand, the issue with acceleration is likely to be relieved thanks to the deployment of hybrid-articulated bus.

Another consideration is the modification to be made to the existing infrastructure, should the articulated buses be deployed. For instance, the bus operator may need to make changes to the concrete pads at bus stops. Because of the lengths, articulated buses may require modifications to garage, parking spots, maintenance decks, etc. Articulated buses will also require a rescheduling due to the effects on the dwell time and the running time. The use of articulated buses is expected to have a mixed effect on running time. First, there is a helpful effect as a result of the decline in dwell times (El-Geneidy and Vijayakumar 2011). Second, there is a positive effect due to the size of the bus and the time associated to acceleration, deceleration, and merger with regular traffic. In terms of the operation, specially-trained drivers may be required, even though many parts of the US allow drivers with rigid bus license to operate the articulated buses.

Around the World

Articulated buses are common in the English-speaking countries, and some parts of Asia including Singapore, China, etc. In the UK, particularly in London, articulated buses and their double-decker counterparts have replaced the old double decker AEC Routemasters on most routes. Elsewhere in the UK, they are generally operated on particular routes in order to increase passenger numbers, rather than across entire networks. With unsupervised "open boarding" through three doors and the requirement for pre-purchase of tickets, levels of fare-dodging on the new vehicles were found to be at least three times higher than on conventional buses where entry of passengers is monitored by the driver or conductor. In 2007, Transport for London surveys showed 12-month fare dodging on the articulated buses at 9.3%, as opposed to 3.18% on the double-decker and traditional buses.

Articulated buses have also been operated in Israel since the mid-1970s. In Hungary – the buses' origin – articulated buses are popular modes of transit. Articulated buses also serve as a solution to the space issues (i.e. the land-use problems) in Singapore.

Forecasted Demand

Cornell students, faculty and staff comprise a significant share of the total ridership. This study assumes that the campus demand is an indicator of the overall demand for bus transit. To assess the current and the speculative demand, student enrollments, and the faculty and staff statistics are investigated.

Cornell Enrollments, and Faculty & Staff Statistics

Year	Undergrads	Grads	Total Enrollment	Staff	Faculty	Total Staff-Faculty
2011-2012	14,158	6,964	21,424	8,081	1,564	9,645
2012-2013	14,393	5,023	21,593	8,103	1,628	9,731
2013-2014*			**21,712**			**9,818**

* = Projected

Table 30: Cornell Enrollment, Staff, and Faculty Statistics

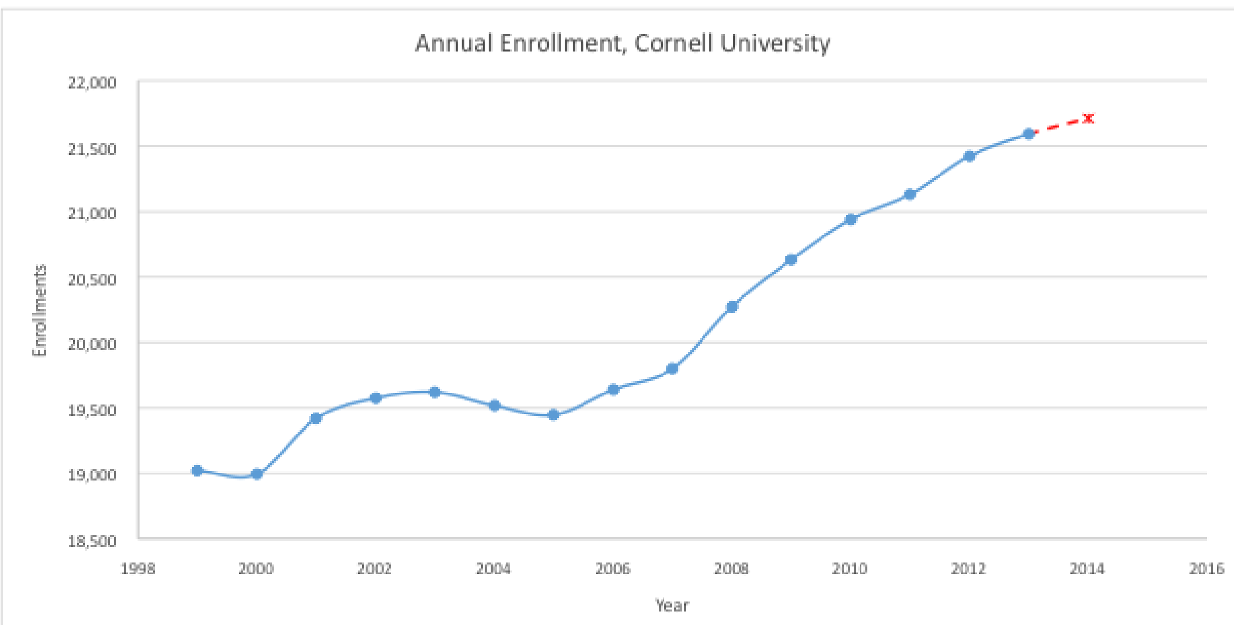


Table 31: Cornell Annual Enrollment Trend

In summary, the total campus ridership is expected to increase for the next year.

Full Bus Report

Figure 54 demonstrates the distributions of full buses across a three-month period from January 2014 to March 2014, during each hour from 8 AM to 6 PM. Note that the chart includes only the top four routes with most frequent reports. From Figure 54 below, Route 30 and Route 81 constitute the largest fractions of the total full buses during the peak morning and the peak afternoon services. Evaluations and analyses are conducted on these two representative routes.

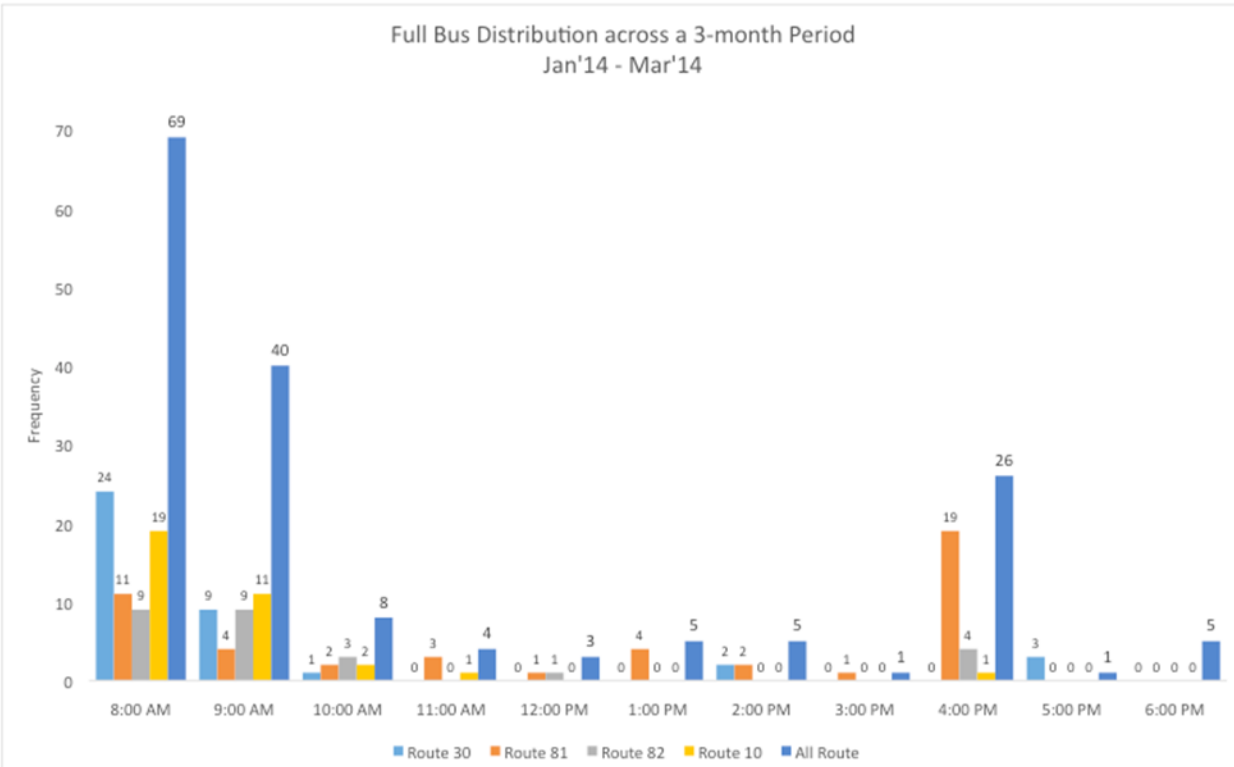


Figure 54: Full Bus Distribution of Four Most-Frequently Reported Routes, Jan '14 - Mar '14

Route-by-Route Ridership

Another indication of a need for higher capacity services is the trend in ridership. Table 32 shows the percentage change in annual ridership from 2012 to 2013 for Routes 10, 81, 82, 83, 90, 92, 93, 30, and 32.

Annual Ridership

Route	Route Description	2013	2012	Δ	% Change
10	CU-Commons	479,132	440,588	38,544	8.0%
81	CU Weekday	567,562	548,821	18,741	3.3%
82	CU Weekday	404,614	394,393	10,221	2.5%
83	CU Weekday	55,241	51,894	3,347	6.1%
90	Commons-CU Night	56,871	44,631	12,240	21.5%
92	CU Night	129,039	116,019	13,020	10.1%
93	CU Night	58,108	46,258	11,850	20.4%
30	Commons-Mall	763,418	707,786	55,632	7.3%
32	Airport	278,064	256,010	22,054	7.9%

Table 32: Ridership Changes from 2012-2013

The figures associated with Route 30 and Route 81 contradict what would have been expected based on the full-bus findings. Since both routes have high demands during peak hours, the increase in ridership from 2012 to 2013 should have been more aggressive. However, both routes experienced mediocre increases—7.3% for Route 30, and 3.3% for Route 81. The observation implies that the increase in ridership is limited by the service capacity constraint.

Route-by-Route Findings

Since the perceived quality of service depends upon passenger's perception, the performance is evaluated subject to the following measures:

1. Passenger loads
2. Reliability performance
3. Current and speculative transit vehicle occupancy

The first measure, passenger loads, follows the guideline stated in Transit Capacity and Quality of Service Manual (TCQSM). Since the passenger's comfort is the main concern, TCQSM uses seating capacity, instead of total bus capacity, in calculating the load factor. For the purpose of the analysis, 38 seating and 28 standing spaces per bus, totaling 66 passengers per bus, is assumed.

Reliability performance for Route 81 is different from that of Route 30—the on-time performance. Because Route 81 operates on ten minute headway, on-time performance is not appropriate for assessing its reliability performance. Instead, headway evenness is a more indicative measure for services with headways less than or equal to 10 minutes.

Finally, the current occupancy indicates how actively the service is utilized. The speculative occupancy assumes that the NOVA articulated bus replaces the existing 40 foot model. The articulated bus has a total capacity of 120 passengers per bus (or 101 with 20% spare ratio). The speculative occupancy is a rough estimation of whether the articulated fleet will be effectively utilized.

Route 81

Reliability Performance – Headway Adherence

The Goldwin Smith Hall time point is selected for assessing the headway evenness, as the stop at Goldwin Smith Hall is the busiest stop during peak hours. From the time stamps during September 2013, the latitude-longitude coordination at Goldwin Smith Hall is identified. The data is narrowed down to include only the peak-AM boardings. The underlying assumption is that the long elapse time between any two boardings is an approximation of the actual headway.

After the data is extracted, the aberration from the scheduled headway is calculated by subtracting the mean scheduled headway of 10 minutes from the observed headway. To use the TCQSM reliability measure, the coefficient of headway deviation is calculated according to the following equation:

$$c_{v,h} = \frac{\text{standard deviation of headway aberration}}{\text{mean scheduled headway}}$$

The study finds that a trip is on average 7 minutes and 20 seconds deviated from the scheduled headway, with a standard deviation of 4 minutes and 37 seconds, resulting in a $c_{v,h}$ of 0.46. TCQSM provides the guideline—demonstrated in Table 3—for the corresponding level of service (LOS).

LOS	c_{vh}	Comments
A	0.00-0.21	Service provided like clockwork
B	0.22-0.30	Vehicles slightly off headway
C	0.31-0.39	Vehicles often off headway
D	0.40-0.52	Irregular headways, with some bunching
E	0.53-0.74	Frequent bunching
F	⩾0.75	Most vehicles bunched

Table 33: TCQSM Headway Adherence LOS

Thus, the service at Goldwin Smith Hall has the headway evenness LOS D. The irregular headways imply the followings:

1. If the headway is longer than 10 minutes, the subsequent bus needs to pick up both its regular passengers and those arriving early but are kept waiting. This bus will be more crowded.
2. As a result of the first point, some buses will carry lighter-than-normal loads and therefore arrive ahead of the schedule. This results in bunching.

Passenger Comfort – Passenger-Load LOS

Manual rider checks during peak-morning operations were conducted on April 17, 2014, for Route 81 outbound that departs from A Lot to B Lot. The average number of passengers on board is summarized in Table 34. The TCQSM guideline for passenger-load LOS is demonstrated in Table 35.

Stop No.	Stop Name	Next Stop	Boarding	Alighting	Passengers on Board
1	A-Lot	Tennis Court	22	0	22
2	Tennis Court	Jessup @Triphammer	27	0	49
3	Jessup @Triphammer	Risley Hall	3	0	52
4	Risley Hall	Goldwin Smith Hall	5	1	56
5	Goldwin Smith Hall	Uris	10	30	36
6	Uris	Corson/Mudd	8	22	22
7	Corson/Mudd	Bradfield	13	12	23
8	Bradfield	Dairy Bar	3	0	26
9	Dairy Bar	BTI	0	20	6
10	BTI	B-Lot	0	5	1
11	B-Lot		0	1	0

Table 34: Manual Rider Check, Route 81

LOS	Passenger-Load Range Low	High	Comments
A	0	0.5	No passenger need to sit next to another
B	0.51	0.75	Passengers can choose where to sit
C	0.76	1	All passengers can sit
D	1.01	1.25	Comfortable standee load for design
E	1.26	1.5	Maximum schedule load
F	1.51		Crush loads

Table 35: Passenger-Load LOS

40-ft Capacity	Required Spaces[1]	Articulated Capacity	Expected Occupancy
66	72	120	60%
66	71	120	59%
66	71	120	59%
66	80	120	67%
66	72	120	60%
66	91	120	76%
66	78	120	65%
66	151	120	126%
66	72	120	60%
66	146	120	122%
66	136	120	113%
66	78	120	65%
66	141	120	118%
66	131	120	109%
66	96	120	80%
66	126	120	105%
66	87	120	73%
66	96	120	80%
66	86	120	72%
66	81	120	68%
66	86	120	72%
66	78	120	65%
66	91	120	76%
66	116	120	97%
66	91	120	76%
66	93	120	78%
66	91	120	76%
66	106	120	88%
66	76	120	63%
66	81	120	68%
66	104	120	87%
66	86	120	72%
66	79	120	66%
66	96	120	80%
66	106	120	88%
66	106	120	88%
66	96	120	80%
66	126	120	105%
66	86	120	72%
66	71	120	59%
66	69	120	58%
66	78	120	65%
66	76	120	63%
66	86	120	72%
66	86	120	72%
66	74	120	62%
66	86	120	72%
66	96	120	80%
66	72	120	60%
Average	**93**		**77%**
Max	**151**		**126%**
Min	**69**		**58%**
Range	**82**		**68%**

Table 36: Estimation of Speculative Occupancy on an Articulated Bus

The services along the critical sections, which include stops 2, 3, and 4, reached the maximum schedule load, or LOS E. Overall, the space-averaged passenger load approached the crushed load, LOS F, during the peak morning service. Since the recommended design level is LOS D, the peak AM service on 81 fails the standard, higher capacity is recommended.

Speculative Occupancy on an Articulated Bus

The full-bus reports during January 2014 to March 2014 also include the approximated number of boardings denied. Suppose the articulated buses are operated on Route 81 during the peak services. The estimate of the speculative occupancy is calculated by simply adding the number of boardings denied to the capacity of a 40 foot bus. The sum is then divided by the capacity of an articulated bus. Table 36 shows the formulation, as well as the results found. In the table, the capacity of 66 is the nameplate capacity of the 40 foot bus, though in practice it is more likely to be 50 to 55. Similarly, the capacity of 120 passengers is optimistic for the articulated buses, and a lower capacity would change the table. On average, the articulated bus will likely be effectively utilized, as the expected occupancy is 77%.

Route 30

Reliability Performance- On-Time Level of Service

TCAT provided the data for this timing study, conducted in September 2013 for weekday operations. The on-time performances among the time points of Route 30 were investigated. According to TCQSM standards, a late transit service is, by definition, more than five minutes behind the schedule. Table 37 shows TCQSM guideline for on-time LOS.

The on-time LOS was assessed for both the inbound and the outbound directions. The percentage of late buses at each time point was obtained from dividing the number of late trips by the total number of trips counted during the timing study. The findings are presented in Table 38 and 39.

LOS	On-Time Percentage	Comments
A	95.0% - 100.0%	1 late transit vehicle every 2 weeks (no transfer)
B	90.0% - 94.9%	1 late transit vehicle every week (no transfer)
C	85.0% - 89.9%	3 late transit vehicles every 2 weeks (no transfer)
D	80.0% - 84.9%	2 late transit vehicles every week (no transfer)
E	75.0% - 79.9%	1 late transit vehicle every day (with a transfer)
F	< 75.0%	1 late transit vehicle at least daily (with a transfer)

Table 37: TCQSM On-Time LOS

The findings suggest that the Friday outbound services at Highland and Wyckoff and at Triphammer and Hanshaw, and the other weekday outbound services at Triphammer and Hanshaw have a below-standard reliability performance.

Route 3000 Outbound	Seneca @ Commons	Green @ Commons	College @ Dryden	Statler Hall	Highland @ Wyckoff	Triphammer @ Hanshaw	Shops at Ithaca Mall @ Sears	Highland @ Wyckoff - Fridays	Triphammer @ Hanshaw - Fridays
	Stop								
1	0	0	1	0	0	0		0	0
2	0	0	1	0	2	1		3	2
3	0	0	1	0	1	1		1	1
4	2	0	2	1	2	2		2	2
5	0	0	1	0	2	1		2	1
6	1	0	2	1	2	2		2	2
7	2	0	2	2	4	3		2	1
8	2	0	2	3	4	4		4	3
9	2	0	2	2	4	3		3	2
10	2	0	1	1	2	1		2	1
40	1	0	1	1	4	4		4	5
41	5	0	2	2	5	6		5	5
42	3	0	2	1	3	8		5	5
43	2	0	1	1	4	4		4	3
44	2	0	1	1	4	3		5	3
45	3	0	1	1	5	5		6	4
46	0	2	2	0	4	3		4	3
47	1	0	1	0	2	2		2	2
Late Buses	0	0	1	0	9	10		18	15
Total Buses	47	47	47	47	47	47		47	47
Percentage on-time	**100%**	**100%**	**98%**	**100%**	**81%**	**79%**		**62%**	**68%**
On-time LOS	A	A	A	A	D	E		F	F

Table 38: On-Time Performance of Route 30 Outbound

Route 3010 Inbound	Shops at Ithaca Mall @ Sears	Triphammer @ Hanshaw	Highland @ Wyckoff	Sage Hall	Schwartz PAC	Seneca @ Commons	Schwartz PAC - Fridays	Seneca @ Commons - Fridays
	Stop							
1	-	2	2	2	1		2	1
2	-	2	2	2	1		3	2
3	-	2	3	4	3		3	2
4	-	3	3	4	3		3	2
5	-	3	3	4	3		3	2
6	-	2	3	4	4		2	2
7	-	3	4	5	4		6	5
8	-	1	4	6	5		6	5
9	-	2	3	4	3		4	3
10	-	1	2	2	2		3	2
40	-	1	2	3	3		4	4
41	-	2	2	3	3		4	3
42	-	1	1	2	1		2	2
43	-	2	2	3	2		4	3
44	-	2	2	4	4		4	4
45	-	0	2	2	4		4	3
46	-	0	2	3	3		5	4
47	-	1	2	4	3		4	3
48	-	2	1	2	1		2	1
Late Buses		0	0	4	2		9	3
Total Buses		48	48	48	48		48	48
Percentage on-time		**100%**	**100%**	**92%**	**96%**		**81%**	**94%**
On-time LOS		A	A	B	A		D	B

Table 39: On-Time Performance of Route 30 Inbound

Figures 55 and 56 show the total number of boardings in September 2013 at each time point along Route 30 across different hours of the day. The lines representing Highland and Wyckoff and Triphammer and Hanshaw lie flat along the x-axis, implying that only small numbers of boarding occur at such stops despite the sub-standard levels of service. This implies that the transit arrival times at these stops are affected by the lateness at preceding stops. For instance, during the peak-morning outbound services, the largest number of boarding occurs at Green and Commons. The dwell time is exceptionally longer as the passengers try to get on the bus. Time is required for swiping the card, paying the fare, and finding a seat. Based on the observation, the majority of the passengers get off at Cornell campus. Extra time is required for alighting since the bus is crowded. People waiting to get on the bus at the campus stops may also have to wait for passengers on the bus who attempt to exit from the front doors.

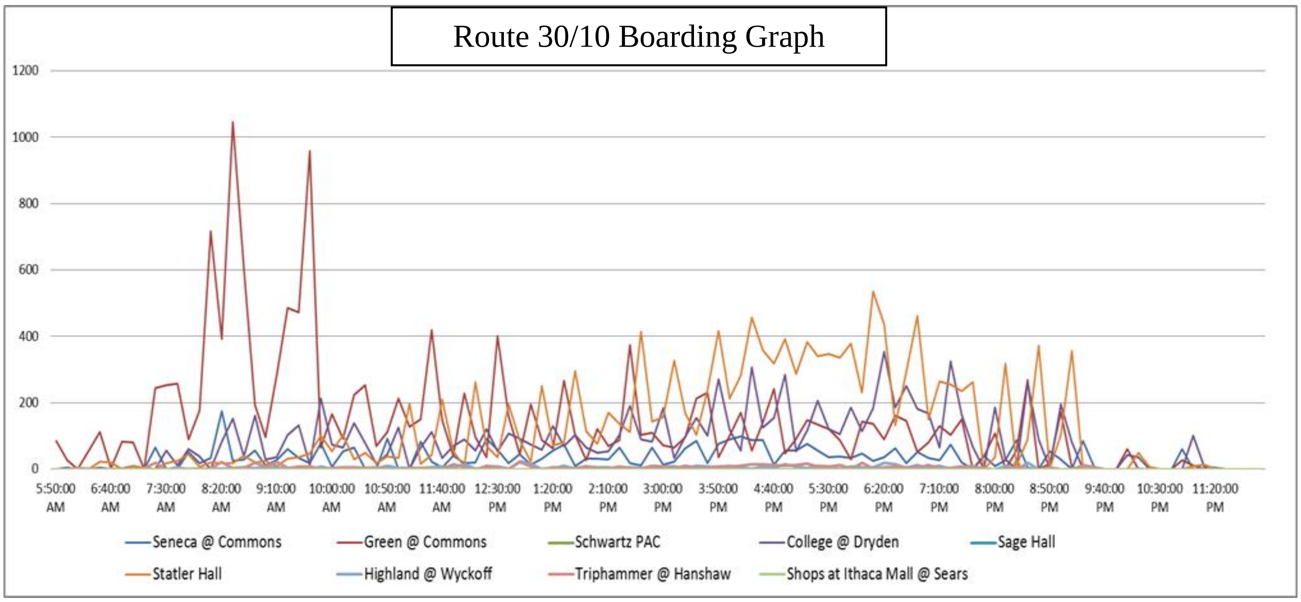


Figure 55: Total Boardings from Route 30 Outbound, September 2013

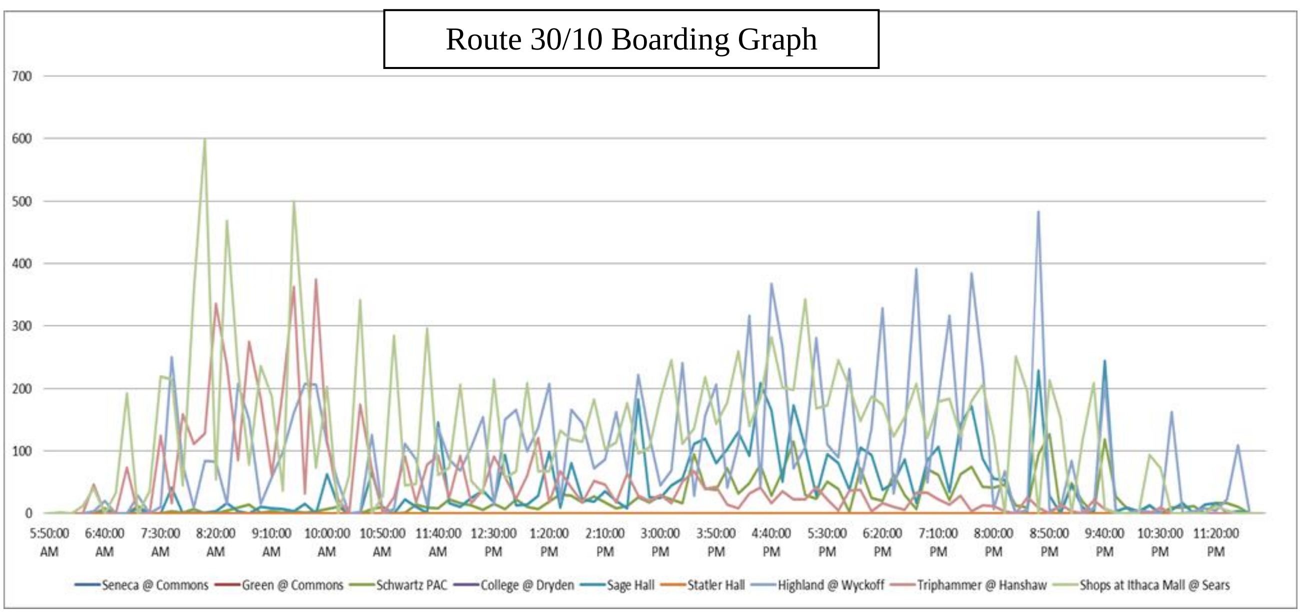


Figure 56: Total Boardings from Route 30 Inbound, September 2013

Operating the articulated buses during the peak hours can address these issues, since an articulated bus has additional two or three doors, allowing the boarding and the alighting to be shorter.

Passenger Comfort

The analysis was based on the manual rider check by one of the sub-teams. The passenger boarding and alighting was observed for both the inbound and the outbound directions on Friday March 21, 2014 during 9AM to 9:30AM. However, the data obtained was not representative of the actual performance during the peak services. Please refer to the appendix for the findings.

Speculative Occupancy on an Articulated Bus

40-ft Bus Capacity	Required Spaces[2]	Articulated Bus Capacity	Expected Occupancy
66	106	112	95%
66	78	112	70%
66	90	112	80%
66	76	112	68%
66	86	112	77%
66	74	112	66%
66	91	112	81%
66	77	112	69%
66	79	112	71%
66	78	112	70%
66	83	112	74%
66	71	112	63%
66	96	112	86%
66	82	112	73%
66	71	112	63%
66	91	112	81%
66	96	112	86%
66	79	112	71%
66	76	112	68%
66	116	112	104%
66	76	112	68%
66	70	112	63%
66	78	112	70%
66	74	112	66%
66	69	112	62%
66	76	112	68%
66	84	112	75%
66	91	112	81%
66	86	112	77%
66	91	112	81%
66	74	112	66%
66	78	112	70%
66	96	112	86%
66	101	112	90%
Average	**84**		**75%**
Max	**116**		**104%**
Min	**69**		**62%**

[2]The required spaces are estimated from the driver-report number of boarding denied

Table 40: Speculative Occupancy for an Articulated Bus on Route 30

The full-bus reports during January 2014 to March 2014 also include the approximated number of boardings denied. Suppose the articulated buses are operated on Route 30 during the peak services. The estimate of the speculative occupancy is calculated by simply adding the number of boardings denied to the capacity of a 40 foot bus. The sum is then divided by the capacity of an articulated bus. Table 40 shows the formulation, as well as the results found. On average, the articulated bus will likely be effectively utilized, as the expected occupancy is 75%.

Applicability to Ithaca

Demand Calculations

Cornell University currently has over 22,400 students and faculties working on campus. Route 30 and Route 81 both operate through Cornell campus, thus we will consider the two routes for applications of articulated buses. The current data only reflects the demand in September, which is not representative for the full ridership pattern throughout the year because of a drop in the number of students during winter and summer breaks.

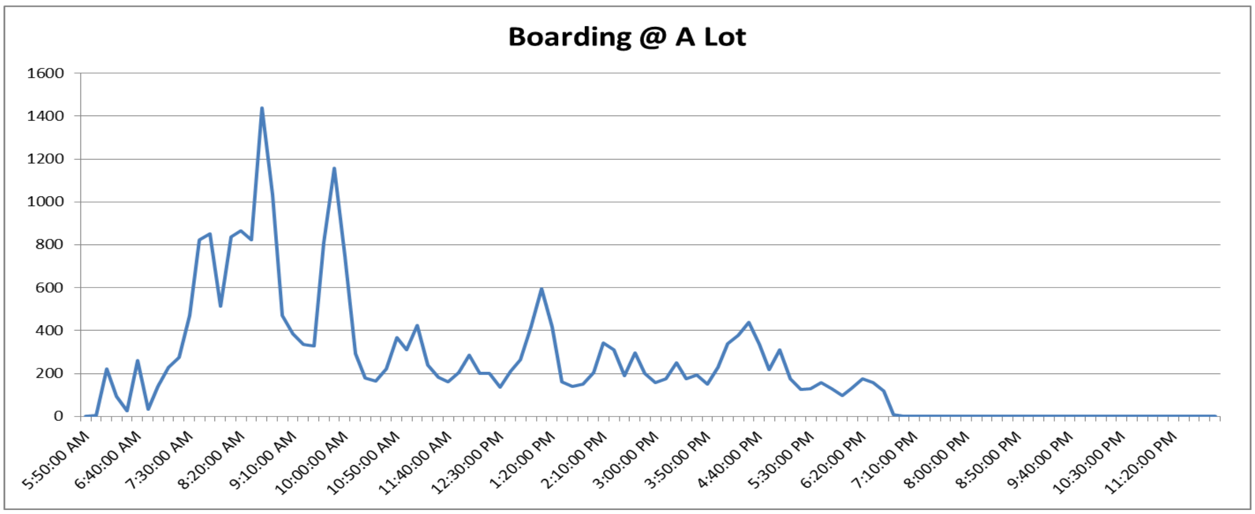


Figure 57: Total Boardings from A Lot, September 2013

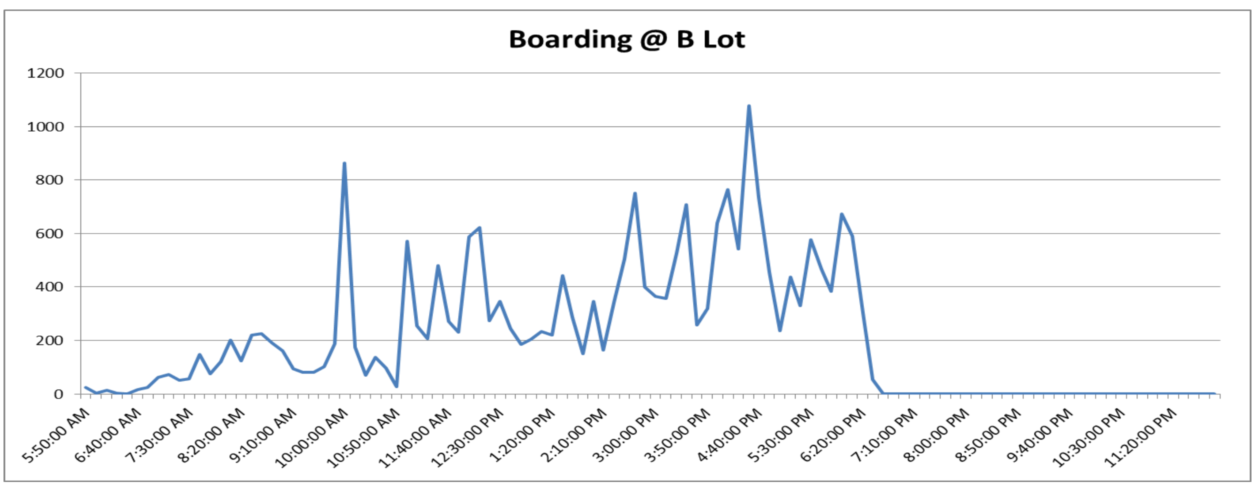


Figure 58: Total Boardings from B Lot, September 2013

From Figures 55, 56, 57, and 58, we can observe peaks in demand during the morning hours from 8 AM to 1 PM and evening peak hours from 6 PM to 9 PM for Routes 30 and 81. Based on the TCAT time stamp data in September, peak demand for Route 30 and Route 81 are 1,045 passengers and 1,439 passengers respectively. The peaks for both routes occurred in the morning rush hours. Peak hour headway and numbers of buses on roads are calculated based on peak demand and capacity of the bus.

Assuming an 80% spare ratio, the calculations for the number of buses of each type (standard 40 foot or articulated 60 foot) required to satisfy peak demand on each route are detailed below in Table 41.

Data\Route	30	80
Peak passenger demand in Sept.	1045	1439
Peak passenger demand in 10 mins per day	34.83	48
Actual bus capacity (20% spare ratio) – Standard	101	101
Actual bus capacity (20% spare ratio) – Articulated	53	53
Number of buses on road		
Standard	**4**	**5**
Articulated	**2**	**3**

Table 41: Calculation of Number of Required Buses

Thus, we conclude that for Route 30, TCAT needs to operate four standard buses or two articulated buses in order to satisfy passenger demand. For Route 81, TCAT needs to operate five standard buses or three articulated buses in order to satisfy passenger demand. Regular buses have a peak headway of 13 minutes with 6.14 miles between each bus. Articulated buses have a peak headway of 25 minutes with 3.05 miles between each bus. When increasing the capacity of articulated buses to 120 passengers per bus (5% spare ratio) and keeping peak headway of 25 minutes, TCAT can handle peak passenger demand of 1,245 people. In order to decrease the spare ratio of the bus, passengers need to be educated and cautious to board to the end of the bus in order to create more space for incoming passengers.

Bus Models Considered

The details of the current bus fleet of TCAT are provided in the 2013 Yearbook, shown in Table 42. Buses with a replacement year after 2014 are extracted to compute total fleet numbers and capacities for comparison's sake so that "newer" bus models are used (Table 43). Currently, TCAT has 31 new buses, which consist of 23 diesel buses and eight hybrid buses, not including the bus manufactured by the International Company. The average capacity for a transit bus is 67.14 and the actual capacity with 20% spare ratio is 53.71 or 54 passengers.

2012 Fleet Summary

As of 12/31/2012

Bus Nos.	Year	Total #	Age	Replace-ment Year	Type of Vehicle	Seats	Stands	Body Manufacturer	Power	Length (ft.)	Width (in.)
914	1991	1	21	2003	Transit Bus	38	20	Orion	Diesel	35	96
73	2001	1	11	2013	Trolley	28	21	Chance	Diesel	30	96
101 - 108	2001	8	11	2013	Transit Bus	37	41	Nova	Diesel	40	102
201-204, 206-209	2002	8	10	2014	Transit Bus	39	38	New Flyer	Diesel	40	102
601-608	2006	8	6	2018	Transit Bus	38	28	Gillig	Diesel	40	102
609-612	2006	4	6	2013	Mini-Bus	16	6	Ford	Gas	23	93
613-615	2006	3	6	2018	Transit Bus	38	28	Gillig	Hybrid	40	102
701-703	2007	3	5	2019	Transit Bus	38	28	Gillig	Hybrid	40	102
704	2007	1	5	2014	Transit Bus	22	11	International	Diesel	30	96
901-902	2009	2	3	2021	Transit Bus	38	28	Gillig	Diesel	40	102
1102-1103	2011	2	1	2023	Transit Bus	38	25	Gillig	Hybrid	40	102
1104-1108	2011	6	1	2023	Transit Bus	38	28	Gillig	Diesel	40	102
1110-1116	2011	7	1	2023	Transit Bus	36	41	Orion	Diesel	40	102

Table 42: TCAT 2012 Fleet Summary

Bus Nos.	Year	Total #	Age	Replacement Year	Type of Vehicle	Seats	Stands	Body Manufacturer	Power	Length	Width
601-608	2006	8	6	2018	Transit Bus	38	28	Gillig	Diesel	40	102
613-615	2006	3	6	2018	Transit Bus	38	28	Gillig	Hybrid	40	102
701-703	2007	3	5	2019	Transit Bus	38	28	Gillig	Hybrid	40	102
901-902	2009	2	3	2021	Transit Bus	38	28	Gillig	Diesel	40	102
1102-1103	2011	2	1	2023	Transit Bus	38	25	Gillig	Hybrid	40	102
1104-1108	2011	6	1	2023	Transit Bus	38	28	Gillig	Diesel	40	102
1110-1116	2011	7	1	2023	Transit Bus	36	41	Orion	Diesel	40	102
		Average Capacity (seats+standing)				67.14					
		Actual Capacity with 20% spare ratio				53.71					

Table 43: Selected Buses for Comparison

We researched the base numbers for articulated buses based on the King Metro in Washington State, the Miami Dade Transit System, and the public transit system of Urbana-Champaign in Illinois. These numbers are further used in our economic analysis and environmental emission analysis for different types of articulated buses. The base numbers should be adjusted based on geological conditions, weather conditions, ridership patterns, etc. The fixed assumptions for the buses are 12 years useful life, and 7% discount rate per year.

Table 44 lists the different models and manufacturers of articulated buses studied in three cases stated above. These models will be used as a basis for comparison with TCAT's average fleet numbers.

Manufacturer	Model
NABI	60FLW
New Flyer	D60LF
New Flyer	XD60
New Flyer	DE60LF
Van Hool	AG300

Table 44: List of Different Articulated Bus Models

Table 45 shows the key assumptions used in comparing average findings for TCAT's fleet and the case studies' findings.

	40 ft Standard Bus (TCAT's)	60 ft Articulated Bus (Case Study Avg)	
	Diesel	Diesel	Hybrid
Fuel Economy (mpg)	3.85	2.55	3.21
Fuel Cost ($/gal)	3.60	3.60	3.60
Maintenance Cost ($/mi)	0.54	0.46	0.47
Cost of Bus	390,000	600,000	800,000
Useful Life (yrs)	12	12	12
Discount Rate (%)	7	7	7
Capacity (Seat + Stand) with 20% spare ratio	53	101	101

Table 45: Key Assumptions for Comparisons

Due to the size of the articulated bus, both the diesel and the hybrid model of an articulated bus are less fuel-efficient. Regular diesel transit bus has an average fuel-efficiency of 3.85 mpg, comparing to 2.55 mpg and 3.21 mpg for diesel articulated and hybrid articulated respectively. Articulated buses have lower maintenance cost per mile compared to regular buses. The cost of articulated bus is almost twice of regular bus, but the capacity is also twice of regular bus. An important note to consider is that no 40 foot standard buses were mentioned in the case studies, so there is a possibility for some differences in results due to differences in road conditions in Ithaca.

Economic Analysis

All costs are evaluated using the discounted cash flow method in 12 years with a 7% discount rate. The major costs of operating articulated buses in Ithaca are broken down to four categories that include fuel cost, capital cost, maintenance cost, and labor cost.

Tables 46 and 47 show the details for cost calculations and a comparison between each type of bus for Routes 30 and 81, respectively.

	Standard 40-ft Bus			60-ft Articulated Bus	
	Diesel	Hybrid	CNG/LNG	Diesel	Hybrid
Average Fuel Economy - mpg -	3.85	4.31	3.14	2.55	3.21
Average Fuel cost - $/g -	$ 3.60	$ 3.60	$ 2.10	$ 3.60	$ 3.60
Maintenance Cost -$/mile-	$ 0.54	$ 0.40	$ 0.80	$ 0.46	$ 0.47
Total number of boardings per year for the route	707,786	707,786	707,786	707,786	707,786
Average Bus Cost - $ -	$ 390,000	$ 530,000	$ 470,000	$ 600,000	$800,000
Discounted Rate -%-	7	7	7	7	7
Average Operating Life of Bus - yrs -	12	12	12	12	12
Number of buses for Route	**4**	**4**	**4**	**2**	**2**
Total Operating Hrs/yr	12,805.00	12,805.00	12,805.00	12,805.00	12,805.00
Total Operating Labor Cost/yr -$50/hr-	**$ 640,250.00**	**$ 640,250.00**	**$ 640,250.00**	**$ 640,250.00**	**$ 640,250.00**
Total Maintenance Cost/yr	**$ 74,102.69**	**$ 54,890.88**	**$ 109,781.76**	**$ 63,124.97**	**$ 64,497.72**
Total Revenue Miles/yr -from yrbook-	137,227.20	137,227.20	137,227.20	137,228.20	137,229.20
Total Fuel Cost/yr	**$ 128,316.34**	**$ 114,621.33**	**$ 91,776.15**	**$ 193,733.93**	**$ 153,901.91**
Annual installment cost per year per bus	$ 49,101.78	$ 66,728.05	$ 59,173.93	$ 75,541.19	$ 100,721.59
Capital Cost for the buses/yr	**$ 196,407.10**	**$ 266,912.22**	**$ 236,695.74**	**$ 151,082.39**	**$ 201,443.18**
Total Cost per year - $/yr -	**$ 1,039,076.13**	**$ 1,076,674.42**	**$ 1,078,503.65**	**$ 1,048,191.29**	**$ 1,060,092.81**
Average cost per boarding	$ 1.47	$ 1.52	$ 1.52	$ 1.48	$ 1.50
Operating Expense per Revenue mile	$ 7.57	$ 7.85	$ 7.86	$ 7.64	$ 7.72
Gallons of Fuel Consumed/yr	35,643.43	31,839.26	43,702.93	53,814.98	42,750.53
Annual Fuel Cost saving compared to Diesel	-	13,695.02	36,540.19	-	39,832.02
Annual % Fuel Cost saving compared to Diesel	-	10.67%	28.48%	-	20.56%

Table 46: Cost Comparison of 4 Standard Buses vs. 2 Articulated Buses on Route 30

	Standard 40-ft Bus			60-ft Articulated Bus	
	Diesel	Hybrid	CNG/LNG	Diesel	Hybrid
Average Fuel Economy - mpg -	3.85	4.31	3.14	2.55	3.21
Average Fuel cost - $/g -	$ 3.60	$ 3.60	$ 2.10	$ 3.60	$ 3.60
Maintenance Cost -$/mile-	$ 0.54	$ 0.40	$ 0.80	$ 0.46	$ 0.47
Total number of boardings per year for the route	548,907	548,907	548,907	548,907	548,907
Average Bus Cost - $ -	$ 390,000	$ 530,000	$ 470,000	$ 600,000	$800,000
Discounted Rate -%-	7	7	7	7	7
Average Operating Life of Bus - yrs -	12	12	12	12	12
Number of buses for Route	5	5	5	**3**	**3**
Total Operating Hrs/yr	12,571.00	12,571.00	12,571.00	12,571.00	12,571.00
Total Operating Labor Cost/yr -$50/hr-	**$ 628,550.00**	**$ 628,550.00**	**$ 628,550.00**	**$ 628,550.00**	**$ 628,550.00**
Total Maintenance Cost/yr	**$ 48,753.90**	**$ 36,114.00**	**$ 72,228.00**	**$ 41,531.10**	**$ 42,433.95**
Total Revenue Miles/yr -from yrbook-	90,285	90,285	90,285	90,285	90,285
Total Fuel Cost/yr	**$ 84,422.34**	**$ 75,412.06**	**$ 60,381.69**	**$ 127,461.18**	**$ 101,254.21**
Annual installment cost per year per bus	$ 49,101.78	$ 66,728.05	$ 59,173.93	$ 75,541.19	$ 100,721.59
Capital Cost for the buses/yr	**$ 245,508.88**	**$ 333,640.27**	**$ 295,869.67**	**$ 226,623.58**	**$ 302,164.77**
Total Cost per year - $/yr -	**$ 1,007,235.12**	**$ 1,073,716.33**	**$ 1,057,029.36**	**$ 1,024,165.86**	**$ 1,074,402.93**
Average cost per boarding	$ 1.83	$ 1.96	$ 1.93	$ 1.87	$ 1.96
Operating Expense per Revenue mile	$ 11.16	$ 11.89	$ 11.71	$ 11.34	$ 11.90
Gallons of Fuel Consumed/yr	23,450.65	20,947.80	28,753.18	35,405.88	28,126.17
Annual Fuel Cost saving compared to Diesel	-	9,010.27	24,040.65	-	26,206.97
Annual % Fuel Cost saving compared to Diesel	-	10.67%	28.48%	-	20.56%

Table 47: Cost Comparison of 5 Standard Buses vs. 3 Articulated Buses on Route 81

The following equations were used in determining the values in the tables above.

$$\text{Total Annual Cost} = \text{Fuel Costs} + \text{Capital Costs} + \text{Maintenance Costs} + \text{Labor Costs}$$

$$\text{Fuel Costs} = \frac{\text{Total Revenue Miles per Year}}{\text{Average Fuel Economy}} \times \text{Average Fuel Cost}$$

$$\text{Capital Costs} = \text{Number of Buses} \times \text{PMT}(12\%, 7\ \text{Years}, \text{Average Bus Cost})$$

$$\text{Maintenance Costs} = \text{Total Revenue Miles per Year} \times \text{Average Maintenance Cost}$$

$$\text{Labor Costs} = \text{Total Operating Hours per Year} \times \$50\ \text{per Hour}$$

Figure 59 below shows the cost of different types of buses for Route 30 and Route 81. We can conclude that there is no single type of bus that has an absolute cost advantage. Regular diesel buses have low fuel cost, but have high maintenance cost. Diesel articulated buses have high fuel cost, but have low in maintenance cost. Hybrid articulated buses have high capital cost, but low maintenance cost.

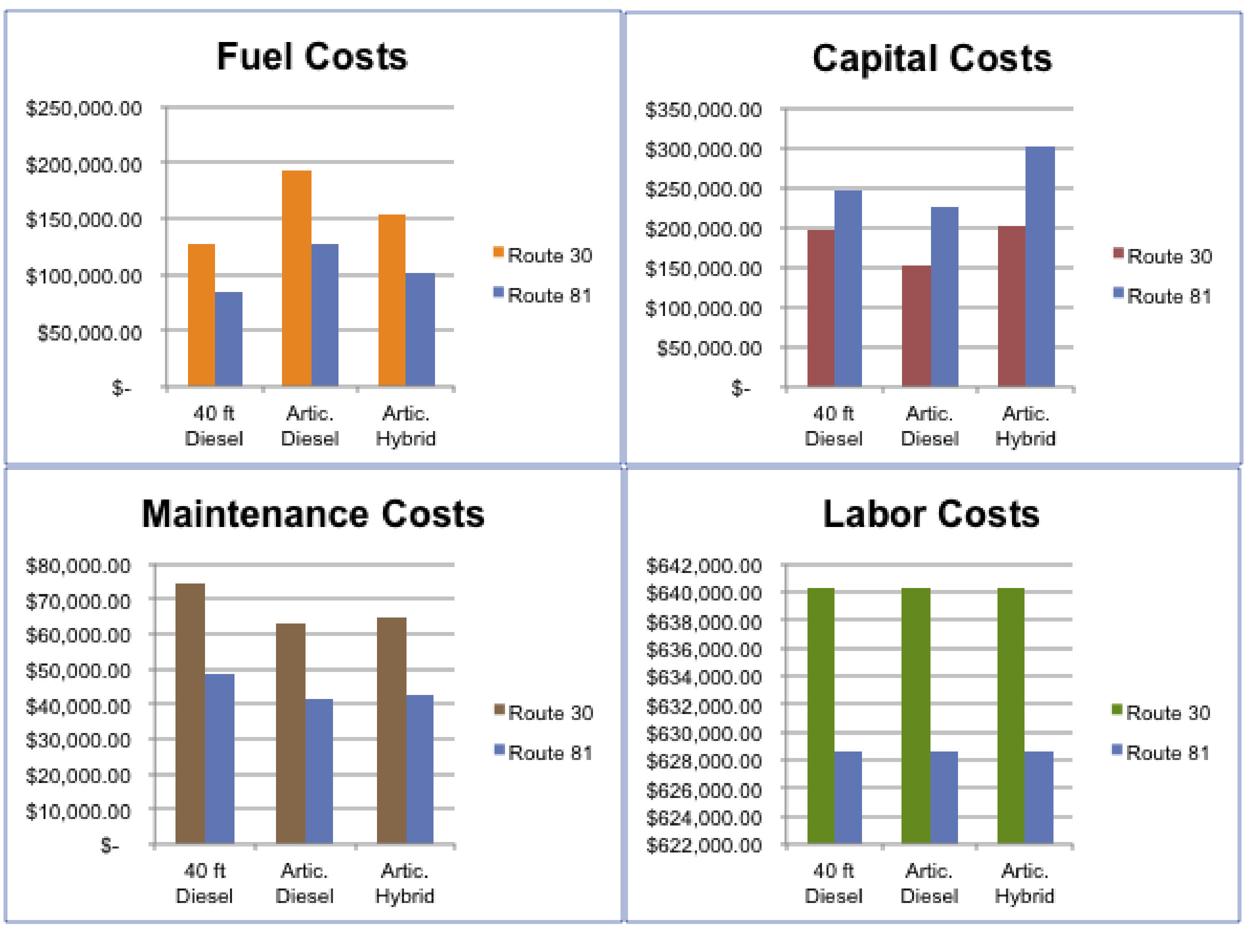
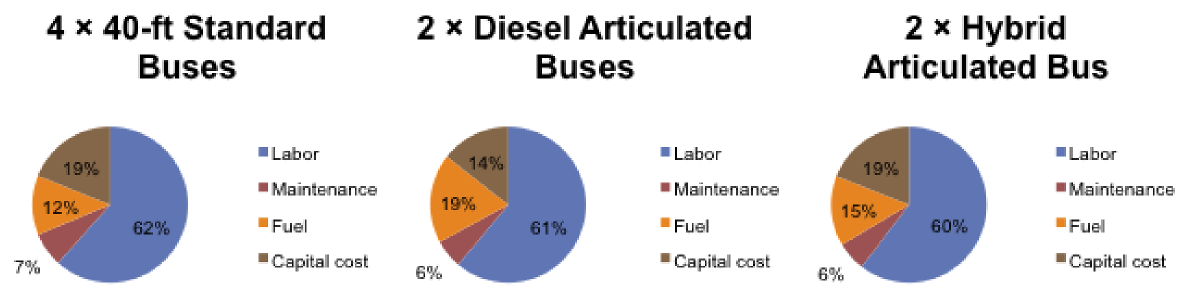


Figure 59: Different Costs for Routes 30 and 81

After analyzing the characteristics of each type of cost, we concluded that capital cost and labor cost, which are indicated in the blue and brown sections in the pie charts on Figure 60, contribute over 80% of the total operating cost for both regular buses and articulated buses. Capital cost of the buses is a fixed cost that is paid at initial purchasing. On the other hand, labor cost is a variable cost that depends on various factors such as seasonal demand. When demand increases, labor cost will also increase.

Route 30



Route 81

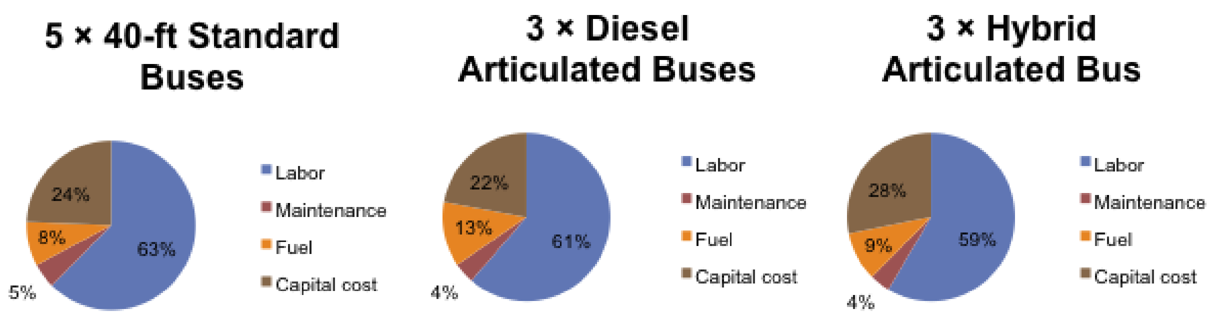


Figure 60: Cost Breakdown Charts

The annual cost for 40 foot standard buses is used as the base for cost comparison. For Route 30, the annual cost for a diesel articulated bus is 0.88% more and for a hybrid articulated bus is 2.02% more compared to standard buses. For Route 81, the annual cost for a diesel articulated bus is 1.68% more and for a hybrid articulated bus is 6.67% more compared to standard buses. We conclude that hybrid articulated buses for Route 81 has the highest price difference.

Route	Option	Annual Cost	% Difference
30	4 Standard 40-ft Buses	$1,039,076.13	-
	2 Standard 60-ft Artic. Buses	$1,048,191.29	0.88%
	2 Hybrid 60-ft Artic. Buses	$1,060,092.81	2.02%
81	5 Standard 40-ft Buses	$1,007,235.12	-
	3 Standard 60-ft Artic. Buses	$1,024,165.86	1.68%
	3 Hybrid 60-ft Artic. Buses	$1,074,402.93	**6.67%**

Table 48: Total Annual Cost Comparison Between Options

Environmental Considerations

Emissions of greenhouse gases (GHG) and pollution have also been considered with the application of articulated buses to Ithaca. It would be beneficial to the communities that TCAT serve to run buses that provide cleaner air, which is why we believe environmental assessments of articulated buses are also important. Diesel and diesel-electric hybrid articulated buses are the two types of buses that will be compared.

Five major pollutants are analyzed in the emission analysis between diesel articulated buses and hybrid articulated buses. From the Emission Comparison Table (Table 49), we observe that CO, NMHC, and PM are reduced by over 50%. NO_X and CO_2 are reduced by over 15%.

Emissions (g/mi)	Diesel	Hybrid	% Reduction
CO	0.66	0.27	**59.09**
NMHC	0.04	0.02	**50.00**
NOx	14.74	12.11	17.84
PM	0.16	0.05	**68.75**
CO2	3446	2614	24.14

Table 49: Emissions Comparison Table

We can clearly see that hybrid articulated buses provide significant emission reduction of GHG and pollutants compared to the diesel-only model. Though the hybrid option provides reductions, there are higher capital costs which may also be significantly different. The tradeoff between cost and emission is significant. However, the hybrid buses have a better fuel economy, which translates into a costs savings in terms of fuel as illustrated in Table 15 and 16 where fuel costs for Route 30 and 81 are less. Together with lower emissions, we feel that using hybrid articulated buses instead of regular diesel buses align more closely to TCAT's objective of providing better and cleaner service to the communities they serve, thus justifying the higher capital costs.

Conclusion

We recommend TCAT replace the 40 foot standard buses with 60 foot hybrid articulated buses for Route 30 and Route 81. Route 30 requires two articulated buses to operate daily while Route 81 requires three articulated buses. Our decision is made based on the following criteria.

1. Direct cost: Capital cost, labor cost, fuel cost, and maintenance cost. Estimated direct operating cost for a 60 foot hybrid articulated bus is $1.06 million for Route 30 and $1.07 million for Route 81.
2. Bus LOS and passengers' perception of comfort level: Operating articulated buses will increase the LOS of the current route. Passengers perceive articulated buses to be more comfortable.
3. Time saved during boarding and alighting: Articulated buses have more exit doors, so passenger inflow and outflow will be less chaotic.
4. Environmental impact: Hybrid articulated buses significantly reduce emission to the environment. In order to operate sustainably, hybrid buses are preferred.

In our research for Route 81, we learned that the bus is often fully loaded in the north campus area because all freshmen live there, and take free bus to get to central campus for class in the morning peak hours. Leftover passengers occur often at stations after residential areas. The bus carries fewer passengers from central campus to B Lot. Future research could focus on bridging Route 81 with lower-occupancy routes and reduce the turnaround time for Route 81. One other focus could be potentially allowing Route 81 to turn around and pick up left behind passengers.

An important note to consider regarding deploying articulated buses is that the public might not welcome the idea, given high capital costs, changes in level of service, and perceived negative consequences of large buses on other traffic, pedestrians, and neighborhoods. This study on community acceptance was not directly addressed as part of the feasibility study. Further studies can be conducted to convince the community that articulated buses are not only worth their costs, but also lead to better levels of service.

VII. Simulation

Introduction

Background Information

Simulation modeling is the discipline of developing a model of an actual or theoretical physical system, executing the model on a computer and analyzing the execution output. This enables us to see how the system would behave in the same way as the real process. In short, it is the imitation of a real phenomenon with a set of mathematical formulas or testing new theories or operation of a real world system over time.

Today, simulation is used widely to reduce the probability of failure of a project, such as simulating new technologies for performance optimization, safety engineering, testing, training and many more. Simulation can easily illustrate the eventual real causes of alternative conditions and courses of action, even though many constraints are assumed negligible. Furthermore, simulations are used when the real system cannot be engaged because it is inaccessible, dangerous, inexistent, or unacceptable to engage.

The key problem today with simulation is that in many situations, it is difficult or impossible to acquire valid sources of data and information of relevant characteristics and behaviors. This is because most natural phenomena are subject to an infinite number of influences. Thus, the use of assumptions and approximations are often made within simulation for reliability and validity of the simulation. Ultimately, in simulations, designers usually determine which factors are the most important and take them into account meaningfully.

Comparison of Software

There is an extensive availability of software for discrete event simulation. We have tried our hands on various open source software:

JaamSim: Java based open-source simulation with drag-drop UI and interactive 3-D graphics. However, entity options are very limited but can be added as it is open-source.

SimPy: Simulation software written in Python. It is based on Simula, a simulation programming language concept. The complexity of the software makes it not very usable for the current project.

SystemC: A set of C++ classes and macros which provide an event-driven simulation kernel in C++. The complexity of the software makes it not very usable for the current project.

We have also considered commercial software: Arena, FlexSim, and ProModel.

In the process of studying these software, we realized that open source software, although available for free, requires much time modifying or coding as per our requirements. Instead, we decided to use commercial software where we can focus more on adding additional constraints and conditions to our problem in hand and making the model more realistic. For this project, we have chosen to use ProModel.

Why ProModel?

We used ProModel as it is one of the leading commercial software for discrete event simulation and is also used as the simulation software for a class at Cornell University. This made it easy to get the required licenses and the installation support. We planned to use modeling software rather than program the model from the scratch, as software makes it easier to model the problem which would leave us with more time to develop the model and add more constraints.

The simulation team used the existing entities available in ProModel to build the model and see its fit for the simulation requirements of the project. One of the main reasons for us to use ProModel is its ability to replicate real-world TCAT and transportation models with their inherent variability and interdependency and to conduct performance analysis which would help optimize the system.

Assumptions

Due to the complex nature of reality, we are forced to make several key assumptions for the process of building a simulation model for TCAT Route 30. In this section, we discuss in detail the necessary assumptions that are incorporated to complete the design.

First, on the TCAT program, only the schedule for key bus stops is given. Therefore, all of the stops in between these key stops are not given in the program. To be consistent with the TCAT data, our team decided to accumulate all the passengers arriving at the sub-stops to the key bus stops adjacent from them and simulate only the key bus stops as provided in the TCAT program.

Our team has carried out an investigation to see the average time for a person to enter and exit the bus. To make the data consistent with the route that we are simulating, we took the bus on Route 30 at peak hours, 8 AM to 10 AM. From our observations, it shows that, on average, it takes about four seconds per person to enter the bus. The predicted time may sound quite long; however, considering the person to step up onto the bus, to swipe the card and some people looking for cash, four seconds per person on average is ideal to be used in the simulation. Furthermore, from our observations for people getting off the bus, we estimated an average of 0.5 seconds per person. The estimated time may sound short, but incorporating the time people exiting from the front and back while people are waiting to get on the bus, this time is considered conservative for the model. Note that the estimation of dwell time is slightly different from that on page 73, as this model does not account for the time it takes to pull in and out of the stop, and accounts for an overlap in passengers alighting at both exits.

For the distances from one bus stop to another, there are no accurate distances provided by TCAT. Since the route of the bus is constant, we used the aid of Google Maps to attain the distances between each bus stop for our simulation model.

Our team believes that the speed TCAT provides in its yearbook for the average speed of a bus is unsuitable for our model because Route 30 runs on the hills, and the speed varies significantly. Therefore, our team decided to manipulate the arrival times found in the TCAT bus program.

With the distance found from Google Maps and the time stamps from one station to another, we could derive a better estimation of the speed of the bus for each segment of the path.

TCAT states that the average capacity for transit buses that they run for their routes is 67.14 passengers; on average, 38 passenger seats and 28 standing. At many occurrences, passengers do not move to the end of the buses, which leads to an inability of reaching the maximum capacity of the bus. To be conservative, and through observations, it is ideal for use around 80% of the stated bus capacity as a less optimistic value. Hence, we have used a maximum capacity of 54 passengers per bus for the simulation model.

There was no data provided from TCAT about the number of passengers on the bus that exits at each bus stop. From our investigation data, we have made close assumptions of the number of passengers who would exit at each bus stop. One key point is that we decided to use a percentage of passengers on the bus that exit at each bus stop; the details of the percentages used are illustrated in the table below:

Bus Stop (0 – outbound, 1- inbound)	**Percentage of passengers on the bus that exit**
0/1 Ithaca Mall	100%
0 Triphammer @ Hanshaw	15%
0 Highland @ Wyckoff	20%
0 Sage	50%
0 Schwartz CPA	30%
0 Tioga St	90%
0 Tompkins County	100%
1 College @ Dryden	60%
1 Statler Hall	90%
1 Highland @ Wyckoff	20%
1 Triphammer @ Hanshaw	15%

Table 50: Percentage of Passengers Disembarking at Each Stop

Ultimately, it is important to note that the collected results from the investigation were from the spring semester and during the day with good weather conditions. Therefore, the calculations may not be adaptable for different weather condition or a different season due to varying demand.

Model

Elements

To build a complete simulation model, the system must contain various building blocks called elements. In the section, we discuss the different options of elements that could be used to create a simulation model in the ProModel software, and we give a summary of what elements were implemented in the final design.

Entities

An entity is described as an object of interest in the system. These are usually dynamic objects in the model that get created, moved around, changes status, affect and are affected by other entities and may get destroyed in the system. Furthermore, entities usually have multiple realizations floating around and can have different types of entities concurrently.

Resources

Resources are what entities compete for in a system. An entity seizes a resource, uses it, and releases it. A resource is usually a person or equipment used with set functions. Resources usually transport entities and perform operations and maintenance on entities at locations. Moreover, resources may have downtimes and could move along a path network or stay static.

Locations

Locations in the system are entities designed for processing, storage, or activities for decision making. Usually locations represent the important areas in the design where something happens. Locations can be queues, conveyors, or other work locations; typically location elements are used to model elements such as delivery locations or warehouse locations.

Variables

Variables are used to keep track of information that is not tied to entities. There are two types of variables: global variables and local variables. Global variables are tags defined to represent the changing numeric values. Local variables are tags used that are available only within the logic that declared them. These variables can be designed to be either real numbers or integers to be used for recording information. For the implementation of the design, we will use the global variables to identify characteristics of the system as a whole and use the global variables for entities to communicate with each other.

Processing

Processing defines the operations that take place at each location they enter and routing of entities through the system. Subsequently, whenever entities enter the simulation model, as defined in the arrivals modeling, the process logic specifies what happens to them until they exit the system.

Arrivals

Arrivals could be implemented whenever new entities are introduced into the simulation model. An arrival record is defined by the number and frequency of new entities per arrival, the time and place of arrival, and the total occurrences of the arrival. Furthermore, an entity could be designed to arrive at a particular location, and the frequency of the arrival elements can be fitted to the distribution pattern that repeats over time.

Incorporated Simulation Elements

The summary table of the elements used to build our final simulation model is displayed below.

Element	Functionality
Entities	1. Bus to carry the passengers 2. Passengers who are generated at every bus stop
Location	1. A location stop for each bus stop 2. A queue for each bus stop 3. A conveyor from point A to point B for every path to let the bus move
Processing	1. Incrementing the amount of passengers at the stop whenever a passenger is generated at a queue 2. Moving the bus from station to station in a loop 3. Processing logic explained in detail in the next section
Arrivals	1. Bus starts from bus stop #1 2. Passengers arriving at each queue at a frequency of the fitted distribution functions
Variables (global)	1. Number of passengers at each stop 2. Occupancy of the bus 3. Maximum capacity of the bus 4. Number of passengers left over at each bus stop 5. Total number of leftover passengers in the route

Table 51: Elements of the Model

Simulation Logic - Algorithm

The main purpose of the logic is to keep track of all the variables and data established for data collection.

For our simulation, the logic starts whenever a bus arrives at the next stop. Once the bus arrives, as mentioned in our assumptions, we allow a set percentage of the people on the bus to get off at that bus stop. Subsequently, we allow the bus to wait 0.5 seconds per person to get off the bus. When all of the people that were assigned to get off the bus exit, the logic decides if the bus could hold all of the people waiting at the bus stop. If the bus loaded all the passengers waiting at the station, we will add the number of passengers waiting at the bus stop to the current bus occupancy. The bus will wait four seconds per passenger to board and load these passengers onto the bus with no delay. Lastly, we must reset, or re-zero the number of passengers waiting at the bus stop.

However, if the bus cannot carry all the passengers, we increase an external counter to keep track of how many times the bus is full. We set the bus to its full occupancy and have an additional counter to keep track of the number of passengers who are left over at the stop. Moreover, we load all of the passengers onto the bus until the bus is full, and this process would wait four seconds per passenger to enter the bus. Then, we total the number of passengers left over throughout the route. Last, the algorithm resets the number of passengers waiting at the stop.

Ultimately, this logic allows us to capture the data needed to analyze the bus route to see if the supply of buses meets the required demands. This simulation logic could be used to optimize the releases of buses for the route simulated.

Arrivals Distribution

We need the arrival frequencies of passengers at various stops to model the passenger arrivals. These frequencies determine how many people are waiting at each stop for the bus.

TCAT provided an Excel file containing September 2013 ridership data. September 2013 had over 200,000 boardings, but due to the enormous size of the Excel file, and Excel's limited computational capabilities, we decided to import the data into a MySQL database.

We have queried the database for the number of passengers in each stop who have taken Route 30 between 8 AM and 10 AM each day in the month of September using the following query. The following is the example used for the stop at Highland and Wyckoff. A similar query was used for the remaining stops in the route.

```
SELECT DISTINCT `ride_time` , Count( * )
FROM `table 1`
WHERE route2 =30
AND (time LIKE '8% AM' OR time LIKE '9% AM')
AND stop_name = "Highland @ Wycoff"
AND route = 3000
GROUP BY `ride_time`
ORDER BY `table 1`.`ride_time` ASC
```

The following is the result set from the above query.

Ride Time	Count
9/10/2013	99
9/11/2013	75
9/12/2013	78
9/13/2013	76
9/16/2013	63
9/17/2013	82
9/18/2013	46
9/19/2013	75
9/2/2013	7
9/20/2013	77
9/23/2013	56
9/24/2013	72
9/25/2013	52
9/26/2013	76
9/27/2013	56
9/3/2013	72
9/30/2013	63
9/4/2013	61
9/5/2013	50
9/6/2013	61
9/9/2013	37

Table 52: Query Results

Using this data we then tried to fit distribution to estimate the Poisson parameter for the passenger arrivals.

Fitting Distributions

For fitting distributions, the Excel add-in @Risk was used. The following is the result summary for each of the stops.

Stop name	Arrival Frequency
Greens @ Commons	Poisson (271.57)
College @ Dryden	Poisson (47.905)
Statler Hotel	Poisson (18.524)
Highland @ Wyckoff (Outbound)	Poisson (2.4375)
Triphammer @ Hanshaw (Outbound)	Poisson (5.35)
Ithaca Mall	Poisson (149.43)
Highland @ Wyckoff (Inbound)	Poisson (63.57)
Triphammer @ Hanshaw (Inbound)	Poisson (123.19)
Sage Hall	Poisson (4.278)
Schwartz PAC	Poisson (3.276)
Seneca @ Commons	Poisson (27.333)

Table 53: Arrival Frequencies at Each Stop

Graphs of the distribution fits are provided in the appendix. These distribution values have been used in the model to generate passenger arrivals at each stop.

Limitations

The model that was developed is very powerful in simulating TCAT Route 30 but has its own set of limitations.

1. Weather conditions: Ithaca is known to have very unpredictable weather, which could be a key factor in determining the speed of the buses. This model does not take into consideration the weather conditions and other factors that determine the speed of the buses. In the current model the speed of the buses is determined by the TCAT schedule. We have calculated the speed as distance from one stop to another over time taken for one stop to another.

2. TCAT bus stops: The model does not account for all of the stops on the route. The stops that were incorporated into the model were based on TCAT's tiem points in the route. The data provided by TCAT was based on the time points on the route, so we built our model to alight with TCAT's data.
3. Passengers disembarking the bus: Due to the limited information about the number of passengers disembarking at each stop, the model is built on an estimate of the number of passengers disembarking the bus.
4. Non-peak hours: The model only addresses the simulation of peak hour operations of Route 30. However, we have tried to build the model in a flexible manner and it would thus work for non-peak hours by simply making changes to the arrival frequencies of the model to fit the non-peak hour distributions.
5. Limited data: For the purposes of this project, only September 2013 data provided by TCAT has been used. Due to the lack of data for other months of the year, this model is not scalable throughout the year. However, the data can be incorporated into the arrival distributions section of the model when available and the model will analyze the operation scenario of the complete year.
6. Cumulating capacities: In the process of simplifying the model for simulation, only one bus has been modeled to move through the route per hour. In reality, Route 30 operates with a headway of 15 minutes during peak hours, and to accommodate this into the model, we increased the capacity of the single bus by a factor of four. This might smoothen some of the peaks in the output. As the analysis is only on the average values of the output, cumulating the capacities will not heavily impact the model.

Results

We explained previously that we used cumulating capacities depending on the number of buses we assume are running in an hour. Using cumulative capacities, we have run our model making an assumption of 15 minute headway between buses, 20 minute headway, and 30 minute headway, and have analyzed each of these situations to make better recommendations to TCAT.

ProModel gives detailed output summary statistics upon running each of these models and we will discuss the results observed in each case.

Case 1 – Two Buses per Hour

In this case, TCAT runs only two buses an hour during peak hours, i.e. the headway between buses is 30 minutes. Maximum capacity of the bus in this case will be 108 (assuming a single bus capacity of 54) and we assume a simulation run time of 20 hours.

Name	Total Changes	Avg Time Per Change (Min)	Minimum Value	Maximum Value	Current Value	Average Value
Occupancy	438	2.73	0	108	13	49.59
Total Leftover Passengers	58	20.44	0	894	894	418.80
Max Capacity	0	0	108	108	108	108
Bus Full Counter	58	20.44	0	58	58	28.03

Table 54: Simulation Case 1 Results

From the above table we observe that once every 20.44 min the bus becomes full and there are leftover passengers on the route. The bus was full 58 times in 20 hours, which means it was full almost three times an hour. In the 20 hours that the simulation was run, there were about 894 passengers who were denied boarding into the bus as the bus was full. This clearly indicates a poor level of service for TCAT.

Case 2 – Three Buses per Hour

In this case, TCAT runs only three buses an hour during peak hours, i.e. the headway between buses is 20 minutes. Maximum capacity of the bus in this case will be 162 (assuming a single bus capacity of 54) and we assume a simulation run time of 20 hours.

Name	Total Changes	Avg Time Per Change (Min)	Minimum Value	Maximum Value	Current Value	Average Value
Occupancy	334	3.58	0	162	152	84.82
Total Leftover Passengers	12	94.14	0	18	18	8.36
Max Capacity	0	0	162	162	162	162
Bus Full Counter	12	94.14	0	12	12	5.52

Table 55: Simulation Case 2 Results

From the above table we observe that once every 94.14 min the bus becomes full and there are leftover passengers on the route. The bus was full 12 times in 20 hours, which means it was full around 0.6 times an hour, each time denying boarding to only one to two passengers. In the 20 hours that the simulation was run, there were 18 passengers who were denied boarding into the bus as the bus was full. This indicates a substantial improvement over running just two buses an hour.

Case 3 – Four Buses per Hour

In this case, TCAT runs four buses an hour during peak hours like the current real-time scenario, i.e. the headway between buses is 15 minutes. Maximum capacity of the bus in this case will be 216 (assuming a single bus capacity of 54) and we assume a simulation run time of 20 hours.

Name	Total Changes	Avg Time Per Change (Min)	Minimum Value	Maximum Value	Current Value	Average Value
Occupancy	320	3.74	0	171	23	91.47
Total Leftover Passengers	0	0	0	0	0	0
Max Capacity	0	0	216	216	216	216
Bus Full Counter	0	0	0	0	0	0

Table 56: Simulation Case 3 Results

From the above table we observe that the bus never gets full when there are four buses running an hour and there are no leftover passengers on the route. In the 20 hours that the simulation was run, the average occupancy of the bus was 91.47, which is almost 42% of the maximum capacity of the bus. This is a very ideal way of running the bus, where absolutely no passenger is ever denied boarding.

Comparison

The following tables and graphs show the number of times the bus is full and leaves behind passengers in each of the simulated cases.

Case	Number of Buses	Maximum Capacity	Bus Full Counter per Hour
1	2	108	3
2	3	162	0.6
3	4	216	0

Table 57: Simulated Bus-Full Report

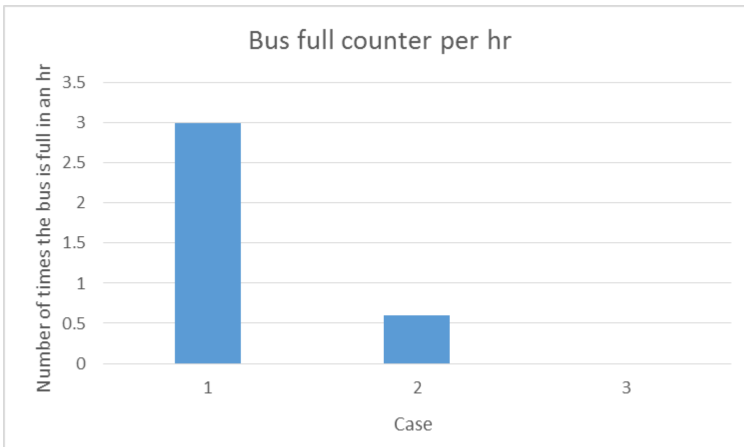


Figure 61: Simulated Bus-Full Report

Case	Number of Buses	Maximum Capacity	Number of Leftover Passengers per Hour
1	2	108	44.7
2	3	162	1.5
3	4	216	0

Table 58: Simulated Leftover Passengers Report

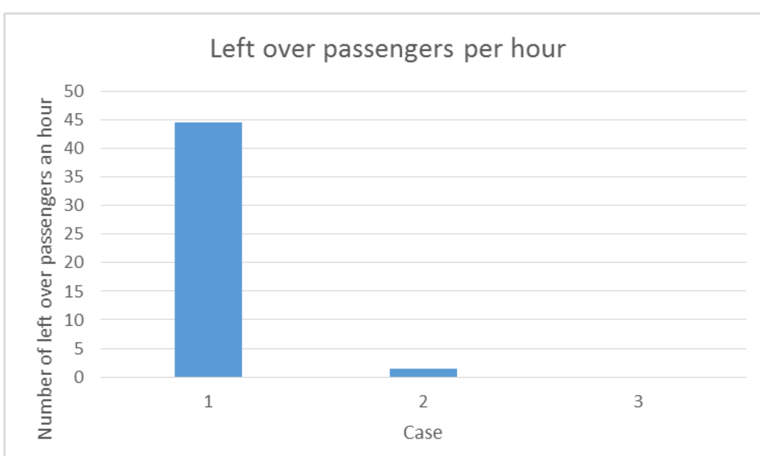


Figure 62: Simulated Leftover Passengers Report

Case	Number of Buses	Maximum Capacity	Average % Occupancy of the Bus
1	2	108	46%
2	3	162	52%
3	4	216	42.3%

Table 59: Average Percentage Occupancy Report

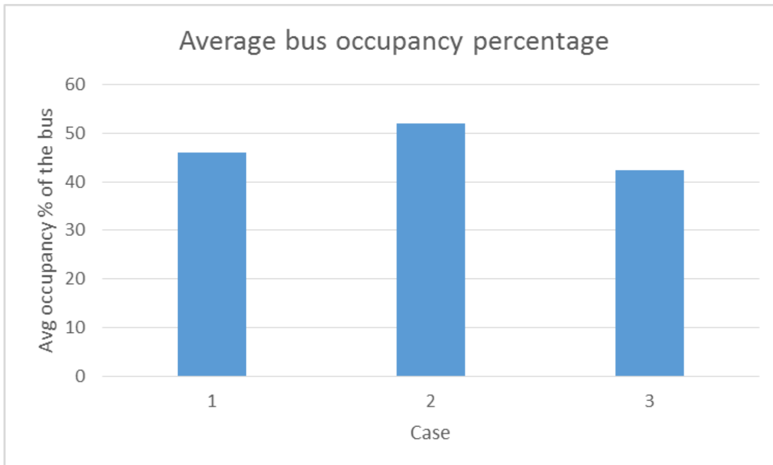


Figure 63: Average Percentage Occupancy Report

Conclusion

Having observed the above mentioned results we conclude that in the given scenario it would be profitable for TCAT if they run only three buses an hour during the morning peak hours of 8 AM to 10 AM, given the very small number of passengers left over on the route and the very small number of times the bus gets full when there are three buses running in an hour. Running four buses an hour like the current operation scenario of TCAT would lead to the most ideal service, as seen in the simulation results where there are no left over passengers and the bus never becomes full, but an extra bus per hour would result in increased operational and fuel costs and increased CO_2 emissions. However, as specified in the model limitations, this result is only based of September 2013 data and is thus not scalable for the entire year.

We believe that a model of this sort could help TCAT analyze their weekly, monthly, and annual operational efficiency by plugging into the model relative arrival frequency distribution values and keeping the rest of the elements constant. We thus recommend that TCAT uses this model as a framework for any simulation models that they would like to run in the future. The model has been built in a flexible and easily modifiable fashion for this purpose.

VIII. Conclusion

As TCAT is growing steadily every year, already exceeding four million riders per year, it is important for TCAT to always look for ways to better serve their community. In this paper we have presented various methods that TCAT could approach to improving its current bus system. We have taken several different perspectives to improve TCAT services: analyzing current practices, conducting feasibility studies on buses with high levels of service, bus rapid transit, articulated buses, and environmentally-friendly buses, and using simulation identify profitable scenarios. These suggested improvements can help make TCAT’s system more efficient, decrease its emissions to the local environment, increase customer service, and provided better analyses of service performance. Overall, TCAT’s current system has been effectively handling Ithaca’s demand, but to maintain this performance and to allow the system to continue to grow, significant investment and changes will have to be made in the coming years. Furthermore, Ithaca has always been a forward-thinking community, with TCAT often at the head of that progress. This makes the region ideal to implement and demonstrate the advantages and feasibility of new technology.

Despite the benefits detailed in this feasibility study, TCAT must be ready to overcome significant challenges. First and foremost is obtaining the funding required for projects of this scale. This is particularly a challenge as transit projects often require significant investment in a short period of time, yet the true impact of this investment can take many years to realize. Furthermore, being a non-profit agency in a small town makes receiving funding even more difficult and it is likely that TCAT will have to find creative ideas and methods of funding future projects. Second, before any project is implemented and for that project to be successful, TCAT must generate public support and buy-in to the proposal. Public backlash against improper or unfair development of transportation services such as TCAT is always expected to happen. This will require education of the public and communal input in order to make the system provide the greatest benefit for the greatest number of people in the community.

Future Studies

This feasibility study discussed many options which TCAT may pursue in order to improve its services. However, TCAT and Ithaca are not limited to the projects discussed in this report. Around the world, other bus systems have proved effective, such as light rail transit, airport shuttles, flexible routing, double-decker buses, and cable cars. Flexible routing may be effective on the north side of Ithaca where demand is lower, as well as along the perimeters of the city, away from the universities and commercial areas. Express buses to the airport could also be used for travel to the business park adjacent to it in order to provide those employees faster service to that area. While some of these are not appropriate options for Ithaca given its geographical and financial constraints, they are options which can be explored further in addition to the ones analyzed in this study.

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Appendix

Literature Review of Unconsidered Service Options

Light Rail Transit

Light rail transit (LRT) is an alternative transit mode evolved from streetcar technology, and emerged in North America in the 1970s. Many regions around the world are considering developing an LRT system. Current systems can be classified into two types: “first generation” systems, which were transformed from earlier trolley and tramway lines; and “second generation” systems that were built afresh, utilizing parts of abandoned trolley or railroad lines occasionally (Boorse 2000).

LRT, according to the American Public Transportation Association (APTA), is defined as “an electric railway system characterized by its ability to operate single or multiple cars, runs along exclusive rights-of-way at ground level, on aerial structures, in subways or in streets, able to board and discharge passengers at station platforms or at street, track, or car-floor level and normally powered by overhead electrical wires” (Transportation Research Board 2012). To make both the definition and the functionality of LRT more flexible, the system can be categorized into three types (C. D. Higgins 2012):

- Streetcars, with all or most tracks in mixed-traffic lanes
- Classic LRT lines using a mix of at-grade and separated alignments
- LRT routes that offer rapid transit service through private right-of-ways with no more than a handful of streets crossing the tracks at grade.

Features

The following are advantages of LRT.

- Attracts more riders who leave cars at home (discretionary riders).
- Provides superior service quality, including great comfort due to large space per passenger and a smooth and quiet ride.
- Greater capacity.
- Relatively low operating costs per passenger-mile compared with other modes when transit demand is high.
- Has positive impact on land use.
- Increases property values near transit stations.
- Less air and noise pollution, particularly when electric-powered.
- Rail stations tend to be more pleasant than bus stations, so rail is preferred where many transit vehicles congregate.
- Helps preserve and revitalize downtown areas of major U.S. cities.
- More investment in LRT.
- Great travel speed and reliability.
- Improves community image.

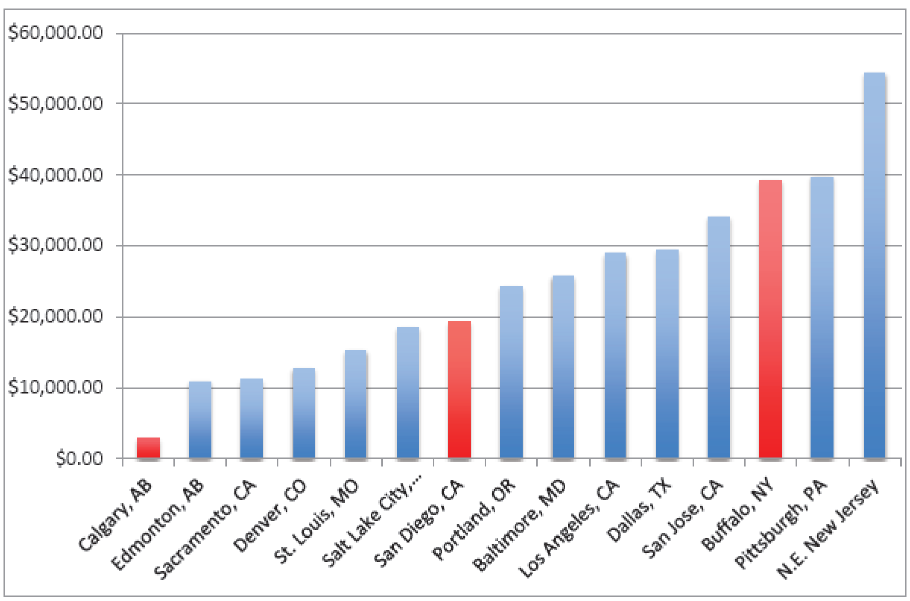
However, LRT has the following disadvantages.

- High initial costs, including high infrastructure costs.
- Declining federal support.
- LRT primarily benefit higher-income people and drain funding from basic bus service used by lower-income people, so LRT's benefits are skewed.
- More stops and longer trips.

In summary, although only a limited number of stations can be served by LRT system, these stations can stimulate intense development with increased density (residents, employees and business activity per acre), higher per capita transit ridership and walking trips, and lower per capita vehicle ownership and trips.

Costs

LRT systems from various cities in the United States and Canada cost several million dollars (see Figure 64). This figure presents a metric for the total cost per passenger. Generally, light rail does not cover costs. One of the main reasons for LRT is the low ridership. Another reason is overruns in original versus actual construction costs.



(McKendrick, Colquhoun, Charles, & Hubbell, 2006)

Figure 64: Total Cost per Weekday Passenger

Case Study: Calgary C-Train

Calgary is a rapidly growing Canadian city with a population of 1,096,833. The transit system of Calgary, C-Train, which is highly supported by three LRT lines: the South Line, the Northwest Line and the Northeast Line, turns out to be efficient and effective for the city. The LRT system in Calgary is successful because its ridership is the highest among all LRT cities in North America and the costs per weekday passenger of C-Train are the lowest.

Calgary C-Train began operating in 1981 with the opening of the eight mile-long South LRT line. It now stretches 30 miles and consists of 36 stations on three lines that share the 7th Avenue transit mall downtown and separate into two routes. The C-Train system has 36 stations, among which 25 of them are located in the suburban area and are spaced approximately every mile. Stations range from simple platforms to large structures. Most stations have bus terminals and park & ride lots. As the Northwest line leaves the downtown area, it runs along a residential street and passes through a college campus, and then enters an expressway. The following figure shows the annual LRT Ridership in Calgary from 1995 to 2010.

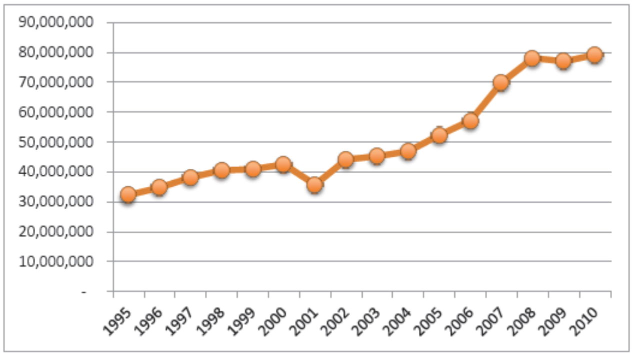


Figure 65: Annual LRT Ridership in Calgary

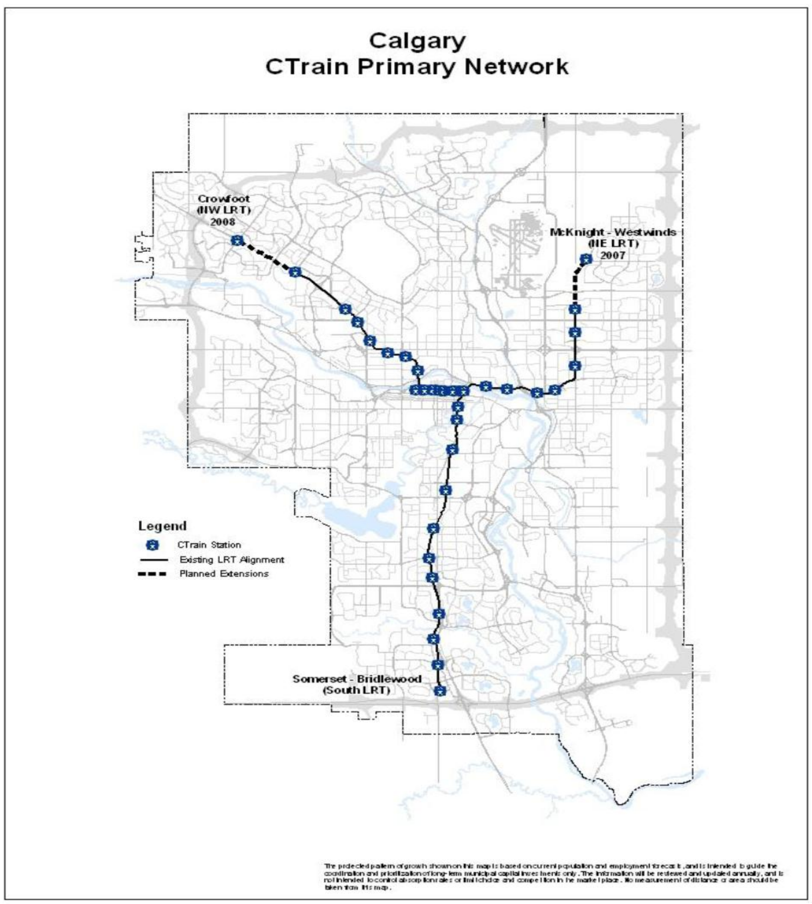


Figure 66: C-Train Primary Network

C-Train has a high level of ridership, which indicates its success. Based on data from 2005, daily ridership was over 220,000 and averaged over 600 boardings per operating hour, and passenger boardings ranged from 720 to 780 per operating hour during peak periods. The main principles that Calgary adopted to minimize costs and maximize effectiveness of service and investment returns include strategic location of LRT lines, designing stations to reflect the local environment and expected passenger volumes, providing LRT with priority over traffic outside of downtown areas, protecting the right-of-way to maximize travel speed, minimizing construction of new infrastructure by using a downtown surface transit mall instead of a subway, providing priority access to stations, implementing a self-serve fare system, and managing park & ride supply (McKendrick 2005).

Conclusions

LRT provides high quality transportation service with comfort and speed. However, LRT requires high cost, both investment and operation. It also demands high infrastructure requirement. Thus, the adoption of LRT system depends greatly on the support of government.

Double Decker Buses

Double decker buses have been in use all around the world for many purposes including mass transit and touring. The double decker buses were first developed as early as the late 1800s. Thousands of double decker buses are used as mass transit in the UK and the rest of Europe, as well as in Asia. The US also has a history of use with double decker buses. New York City has been using the double decker buses for transit as early as 1912 until 1950s, and the open-top style double decker buses were the icons of Fifth Avenue at the time. However, after the 1950s, use of double decker buses did not regain interest for more than 40 years, with few exceptions, until the 1990s when BC Transit of Canada decided to use double decker buses in Victoria. With hundreds of double decker buses in locations like Victoria and Las Vegas, the double decker buses now see growing interest in possibly being the choice for many other cities in North America.

Technologies

Typical dimensions for a double decker bus are from 40 to 45 feet in length, 14 feet tall, and 7.5 to 8.8 feet in width. Variations of the double decker buses are closed top, open top, and double decker articulated buses. Capacity for the typical double decker bus ranges from 80 to 87 passengers. Engines used for double decker buses are mostly diesel engines. Other engines are CNG propellers and hybrid diesel-electric engines (Transport NSW 2010).

Advantages, Disadvantages, and Barriers

Double decker buses offer a few advantages over conventional buses and articulated buses. They have a higher capacity than conventional buses and take up less road space than articulated buses. In times of traffic congestion and limited road space, a higher capacity within limited space can be very important. In addition, passengers may appreciate higher and unobstructed views when sitting on the top deck, leading to more preference towards double decker buses.

On the other hand, there are a number of disadvantages with double decker buses. First, there may be restrictions in routes due to the vertical height of the buses, limiting the route design process. The design of the buses requires that all passengers on the top deck must be seated for safety reasons, thus limiting the total capacity of the bus. Higher capacity comes with increased loading and unloading. The buses will require a staircase to connect the decks, which are not accessible for passengers with physical disabilities and can deter passengers from climbing up the stairs. More frontal area of the buses means that there is more air resistance when traveling.

Combined with a higher center of gravity from the height, double-decker buses operating in winter conditions and high winds can be an important concern.

The 2008 TCRP report on double decker buses show that the issue with vertical clearance can be resolved with modifications in infrastructure given the conditions of most roads in the US. In addition, a review of regulations reveals that double decker buses satisfy the height limits of 21 states.

A possible barrier to obtaining double decker buses in the US is the Buy America Act, which, according to the Department of Transportation, dictates that transportation infrastructure projects with federal funding are all constructed with products made in the US. Major manufacturers of high quality and mass numbers of double decker buses are located in Europe, such as Alexander Dennis and AEC of Leyland Motors in the UK and Van Hool in Belgium. However, the Enviro500 model from Alexander Dennis is assembled in the US and is compliant with Buy America, indicating that it is possible to have international brands assembled within the US to ensure compliance with the Buy America Act.

Economic Aspects

Based on the TCRP report, the cost of a typical double decker bus from Alexander Dennis with capacity of 81 costs $600,000 while the cost of an articulated double decker from Van Hool is in the low $600,000s as of January 2007 (Hemily and King 2008). Other sources suggest that a double decker bus can cost around $500,000, which leads to the estimate that a typical double decker bus has a cost that ranges from $500,000 to $650,000. Based on the Transport for New South Wales' specifications of its new set of double decker buses, each bus is expected to last up to 25 years, more than the expected useful life of current TCAT buses.

Another major cost to consider for double decker buses is the cost to modify facilities and infrastructure. Removal of overhead obstructions, larger door openings, portable lifts purchases, modifications to garage and washing facilities are some extra costs with double decker buses. The TCRP's sample modification cost calculation from a bus agency sums up to be around $700,000.

Environmental Impacts

Transport for London's new set of iconic red AEC Routemaster double decker buses is reported to have a fuel efficiency of 6.1 mpg for hybrid buses and 5.3 mpg for diesel buses (Transport for London 2013). Measurements of eight prototypes of the new Routemasters for eight months show a significant improvement in bus emissions: 2.048g/km of nitrogen oxide, 690.23 g/km of CO_2, and 0.012 g/km of particulate matter. The levels of nitrogen oxide and particulate matter are 75% less than that of the current fleet average for hybrid and diesel double decker buses, while the level of CO_2 emission is less than half.

Applicability to Ithaca

Double decker buses can certainly be considered for serving the Ithaca and Tompkins County area. The extra capacity can prove to be useful in satisfying the demand level during rush hours. In addition, the extra height of the buses should not prove to be prohibitive because there are minor road obstructions within the areas of service, especially those that had seen high demand.

It is important, though, to note the severe winter conditions and the steepness of roads in the Tompkins County that may affect the safety factor of using double decker buses.

Flexible Routing

Flexible transit routes combine fixed route transit service and demand-responsive service. Flexible route vehicles travel on a general route with stops determined by prior passenger request or when flagged by a pedestrian, or they may serve fixed stops, with periodic deviations to pick up or drop off a passenger on a demand-response basis. Flexible routes can be a way to serve both paratransit passengers and the general public. Flexible route services may extend the reach of general transit service into areas where fixed route service would not be as efficient. As transit agencies search for ways to improve efficiency and to serve new rider markets, flexible routing may be a possible solution. Flexible transit service provides easier access than fixed route transit, as well as provides transit in lower-density areas where fixed routes would not be possible.

Historical Background

Public transportation systems have historically operated as fixed routes, predetermined stops, and collecting passengers at scheduled times. The fixed route transit system works most efficiently where there are high concentrations of residential areas and common destinations. For rural and suburban areas with low population density, fixed route service is not as efficient compared to metropolitan areas.

In order to understand flexible route services better, the Transportation Research Board conducted a series of online surveys which indicated that the implementation of flexible public transportation service is on a demand rise. According to the survey, different people have different customization for flex route service. Of the respondents, 56.1% believe the service operates route deviation for general public, 45.1% believe the service operates route deviation for people with disabilities, and around 30% of respondents believe the service operates demand responsive corrector, requested stops and zone routes. The major parts of the passenger base that requires flexible route service are senior citizens and people with disabilities. They contribute to 56% of total passenger demand (Higgins and Cherrington 2005).

Services

The transit demand was identified using GIS. The GIS determines the population rate, household densities, elderly populations, youth populations, household income, and households without automobiles. Information from census block groups is also combined into the overall database for transit demand. There are also many other factors put into consideration when identifying the demand for service and planning of the service. These factors include unbuilt and impassible streets, location of common destination such as downtown areas, financial district, shopping centers, and employment centers, location of schools and hospitals, and social service and government centers.

The routing corridors were further refined based on public surveys and comments. Operational considerations includes running times, operating cost, vehicle requirements, and pulse point transfer requirements. There are also two planning strategies often acquired by agencies providing flexible route service. The two planning strategies are

1. Buses serve all stops in the corridor on each run, and deviate when there is a passenger required point to pick up or drop off.

2. Buses deviate from its main route without returning to point of departure, as long as all passengers are served along the route.

Manually dispatched flexible route services involve trip requests, taking orders, scheduling trips, and vehicle dispatching. Flexible route services are accessible at bus stops or by calling 24 to 48 hours in advance to schedule a round trip. Riders may establish a subscription for regular services.

Advantages and Disadvantages

The following are the advantages of flexible routing.

- Whether or not flexible transit is cost-effective for a given transit provider depends on the purpose of the program and the cost of the alternative transit service. Flexible transit can be cost effective when comparing total costs to provide transit service.
- Total cost to provide flexible service in a specific service area, such as a low-density residential neighborhood, may be lower than the cost to provide adequate fixed route services for the same area.
- Flexible service can be less expensive than fixed route service when the flexible service can meet specific customer needs with fewer hours or miles of service. Total cost for flexible route can be lower than the cost of complementary ADA paratransit, if the flexible service meets ADA requirements for paratransit.

However, flexible routing has its disadvantages.

- Dispatching issues: vehicle capacity limitations, transferring, and schedule adherence.
- Conveying the working of flexible routes to the public can be difficult. It requires clear illustration of service corridor, location of time points, bus stops, landmarks, and schedule.
- Driver training is difficult.
- Flexible route passengers require an adjustment period before becoming comfortable with the concept of a bus not following a regular route.

Economic Feasibility

In terms of cost per hour, the direct cost of providing flexible services may be lower if operated by a private contractor, but total costs may be similar. Total costs include the expense of the transit agency for contract administration and managing the service to for customer satisfaction and service quality. It is reasonable to assume the flexible service cost per hour is similar to fixed route cost per hour if the transit agency administration, management, and indirect costs are not allocated, which may show small differences. Analysis of examples showed both higher and lower flexible costs per hour than for fixed routes. The differences may be explained the assumptions for the allocation variables.

Cost per mile for flexible route services is higher than for fixed route services because flexible services operate fewer miles per hour. Flexible services also carry fewer passengers per hour, so cost per passenger is higher. As a result, cost per passenger for flexible transit is higher than for fixed routes. Although flex-route services are less productive and efficient than fixed route services, in lower density suburban environments, flexible route services may be the best way to provide transit services. Omnilink flexible route service requires eight vehicles, 78 service hours per day and cost $688,000 annually. The same level of service, if operated as fixed route services with the ADA required complementary paratransit service would require 14 vehicles, 130 service hours per day, and cost $1,150,000 annually (Farwell 2003).

Applicability to Ithaca

Ithaca is the home to Cornell University, Ithaca College, and nearby, the Tompkins Cortland Community College. The seasonal population of Ithaca is highly influenced by these three colleges. Most students aggregate around the campus areas. From the above analysis of flexible routing public transportation, the system is most suitable for 1) rural, urban peripheral, and lower density areas where fixed route service would not be as effective, and 2) people in need for mobility when demand is low. As a result, applying flexible routing to the outskirt regions of Ithaca, where demand is too low to effectively operate a fixed route service for residences should be considered. The most commonly served stations in Ithaca are downtown, university campuses, and the Pyramid Mall. Developing flexible routes that could provide transits to these hubs may also be considered.

Additional Calculations

Calculations for Economic and Environmental Analysis

Fuel Cost Comparison (Route 84 vs Route 13) :

< Proposed new Cornell Campus Route 84 >

Estimate of daily ridership : $250\ passengers\ /_{day}$

Total Miles run (From RPCC to Swartz PAC and back to RPCC, The Loop) : 2.92 miles

2.92 miles x $\frac{8\ runs}{day} = 23.36\ miles/_{day}$

Total gallons consumed :

$= \frac{23.36\ miles}{day} \text{x} \frac{1\ gal}{3.94\ miles} = 5.93\ gallons/_{day}$

Total (Daily)Fuel Cost :

= 5.93 gal x $\frac{\$\ 3.6}{gal} = \$\ 21.6\ /_{day}$

Total (annual)**Fuel** Cost = $\frac{\$\ 21.6}{day} \text{ x } \frac{52(weeks)\ x\ 5(weekdays)}{year} = \$\ \mathbf{5,616}\ /_{\mathbf{year}}$

Total (annual) **Maintenance/Repair** cost :

$= \frac{23.36\ miles}{day} \text{ x } \frac{52(weeks) x\ 5(weekdays)}{year}\ x\ \frac{\$\ 1.5}{mile} = \$9{,}110/_{year}$

Total (annual) **Wage** :

$= \frac{4\ hour}{day} \text{ x } \frac{52(weeks) x\ 5(weekday)S}{year} \text{ x } \frac{\$\ 42.53}{hr} = \$\ 44{,}231/_{year}$

Total annual costs = $ 5,616 + $ 9,100 + % 44,231 = $ 58,947

Total (annual) Revenue = $\frac{250\ passengers}{day} \text{ x } \frac{52(weekes) x\ 5(weekdays)}{year} \text{ x } \frac{\$\ 1.5}{ride} = \$\ \mathbf{97,000}\ /_{\mathbf{year}}$

Total (annual) Profit = $ 97,000 - $5,616 $= \$\,\mathbf{91,884}/_{\boldsymbol{year}}$ **(considering only fuel cost)**

< Existing Route 13 >

Annual Ridership from 2012 data table : $\mathbf{56,862}\ \boldsymbol{passengers}/_{\boldsymbol{year}}$

Total Miles run :

Weekday : $\frac{11.5\ miles}{trip}$ x $\frac{11\ runs}{day}$ x 2(round trips) = $253\ miles/_{day}$

Saturday : $\frac{11.5\ miles}{trip}$ x $\frac{13\ runs}{day}$ x 2 (round trips) = $299\ miles/_{day}$

Gallons consumed :

Weekday : $\frac{253\ miles}{day}$ x $\frac{1\ gal}{3.94\ miles}$ = $64.21\ gallons/_{day}$

Saturday : $\frac{299\ miles}{day}$ x $\frac{1\ gal}{3.94\ miles}$ = $75.72\ gallons\ /_{day}$

Daily Cost (considered Fuel cost only for comparison) :

Weekday : $\frac{64.2\ gal}{day}$ x $\frac{\$\ 3.6}{gal}$ = $\$\ 231.12/_{day}$

Saturday : $\frac{75.7\ gal}{day}$ x $\frac{\$\ 3.6}{gal}$ = $\$\ 272.88/_{day}$

Annual Fuel Cost :

Weekday : $\frac{\$\ 231.12}{day}$ x $\frac{52(weeks)\ x\ 5(weekday)}{year}$ = $\$\ 600{,}91/_{year}$

Saturday : $\frac{\$\ 272.88}{day}$ x $\frac{52(weeks)\ x\ 1(day)}{year}$ = $\$\ 141{,}90/_{year}$

Total Annual **Fuel** Cost : $ 600,91 + $ 141,90 = $\$\ \mathbf{74,281}\ /_{\boldsymbol{year}}$

Total Annual **Maintenance/Repair** Cost :

Weekday :

= $\frac{253\ miles}{day}$ x $\frac{52(weeks)\ \ x\ 5(weekdays)}{year}$ x $\frac{\$\ 1.5}{mile}$ = $\$\ 98{,}670/_{year}$

Saturday :

= $\frac{299\ miles}{day}$ x $\frac{52(weeks)x\ 1\ (Saturday)}{year}$ x $\frac{\$1.5}{miles}$ = $\$\ 23{,}322/_{year}$

Total Annual **Wage** :

Weekday :

= $\frac{11\ hour}{day}$ x $\frac{52(weeks)\ x\ 5(weekdays)}{year}$ x $\frac{\$\ 42.53}{hr}$ = $\$\ 121{,}636/_{year}$

Saturday :

$= \frac{13\ hour}{day}$ x $\frac{52\ (weeks) x\ 1\ (saturday)}{year}$ x $\frac{\$\ 42.53}{hr}$ = $\$\ 28{,}750 / year$

Total Annual Cost = $ 74,281 + $ 98,670 + $ 23,322 + $ 121,636 + $ 28,750 = $ 346,659

Total Annual Revenue: $\frac{56{,}682\ passengers}{year}$ x $\frac{\$\ 1.5}{ride}$ = $\$\ \mathbf{85{,}293} / \mathbf{year}$

Total Annual Profit : $ 85,293 -$ 74,281 = $\$\ \mathbf{11{,}012}\ / \mathbf{year}$ **(Considering only fuel cost)**

CO_2 Emission Comparison (Route 84 vs Route 13) :

< Proposed new Cornell Campus Route 84 >

Annual CO_2 emission : $\frac{5.93\ gal}{day}$ x $\frac{52(weeks)\ x\ 5(weekdays)}{year}$ x $\frac{22.4\ lbs\ CO_2}{gal}$ = $34536\ lbs\ CO_2 / year$

< Existing Route 13 >

Weekday : $\frac{64.2\ gal}{day}$ x $\frac{52(weeks)\ \ x\ 5(weekdays)}{year}$ x $\frac{22.4\ lbs\ \ CO_2}{gal}$ = $373900\ lbs\ \ CO_2 / year$

Saturday : $\frac{75.8\ gal}{day}$ x $\frac{52(weeks) x\ 1(day)}{year}$ x $\frac{22.4\ lbs\ \ CO_2}{gal}$ = $88292\ lbs\ \ CO_2 / year$

Total : 373900 + 88292 = $462192\ lbs\ \ CO_2 / year$

Annual Saving in CO_2 Emission : 462192 – 34536 = $\mathbf{427656\ lbs\ \ CO_2 / year}$

BHLS Ridership Assumptions

Stop	% of ridership
Green@Commons	70
State@Stewart	10
State@Quarry	10
College@Mitchell	10
College@Dryden	70
Carpenter	30
Statler	40
Rockerfeller	20
Balch	40
Highland@Wychoff	60
Lakeland Apartments	40
Triphammer@Hanshaw	20

Triphammer@Winthrop	20
Triphammer Mall	20
Triphammer@Cayuga	20
YMCA	20
Ithaca Mall	50
Tops	20
Lansing West	20
Triphammer@Spruce	10
Triphammer@Hanshaw	70
Lakeland Apartments	30
Highland@Wychoff	10
Risley	80
Goldwinsmith	10
Sage	50
Anabel Taylor	50
Schwartz	70
College@Mitchell	10
State@Quarry	10
State@Stewart	10
State@Commons	90
Albany St	10

* each color represents a different time point segment

BHLS Dwell Time Regression Model

```
# Read the data
mydata <- read.csv("route30.csv")
attach(mydata)

# GLM results

GLM.estimates <- glm(time ~ Boarding + Leaving)
summary(GLM.estimates)
```

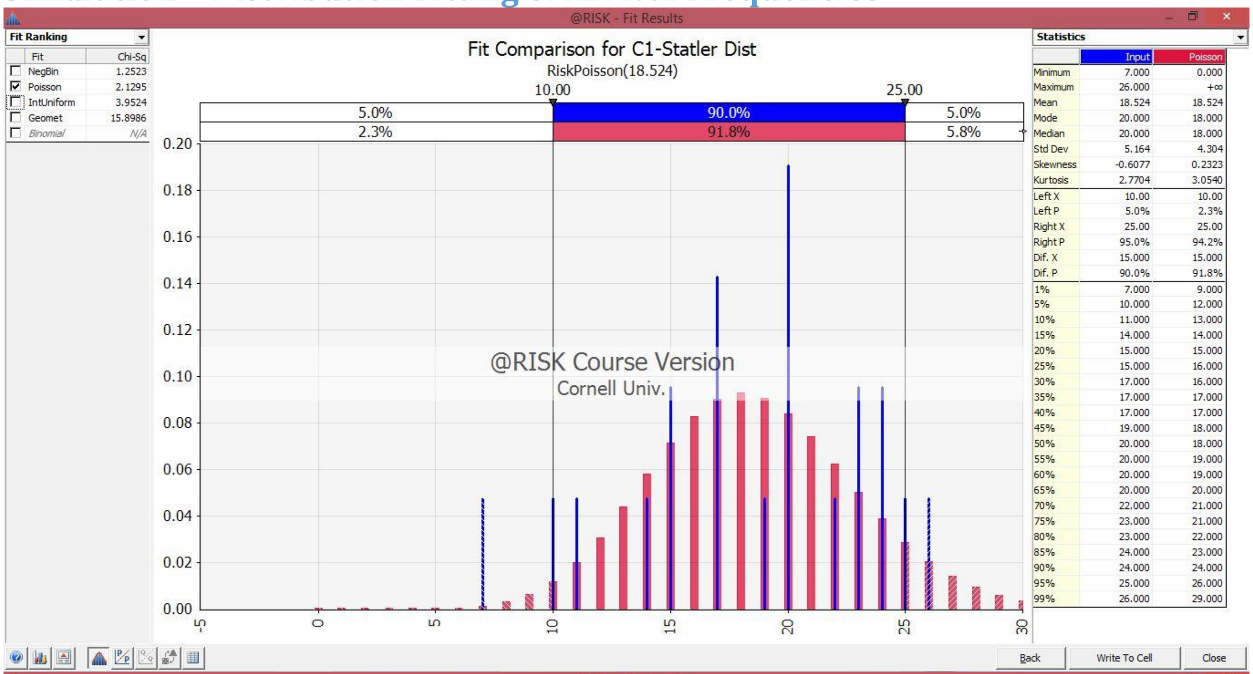
```
Call:
glm(formula = time ~ Boarding + Leaving)

Deviance Residuals:
    Min       1Q    Median      3Q      Max
-18.962   -4.108   -0.958    5.055   15.707

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   10.067      1.408    7.15  3.9e-09 ***
Boarding       2.832      0.251   11.26  3.4e-15 ***
Leaving        1.316      0.206    6.38  6.1e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 56.11)

    Null deviance: 12246.7  on 51  degrees of freedom
Residual deviance:  2749.5  on 49  degrees of freedom
AIC: 361.9

Number of Fisher Scoring iterations: 2
```

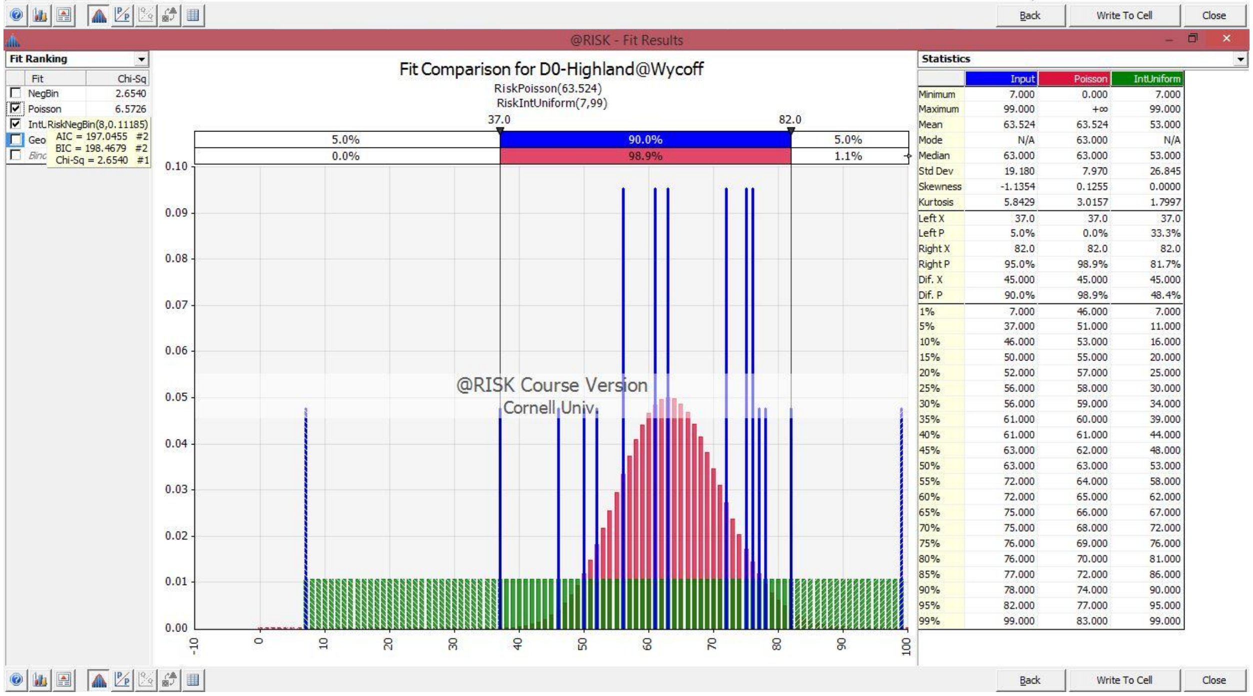
BHLS Monte Carlo Sample

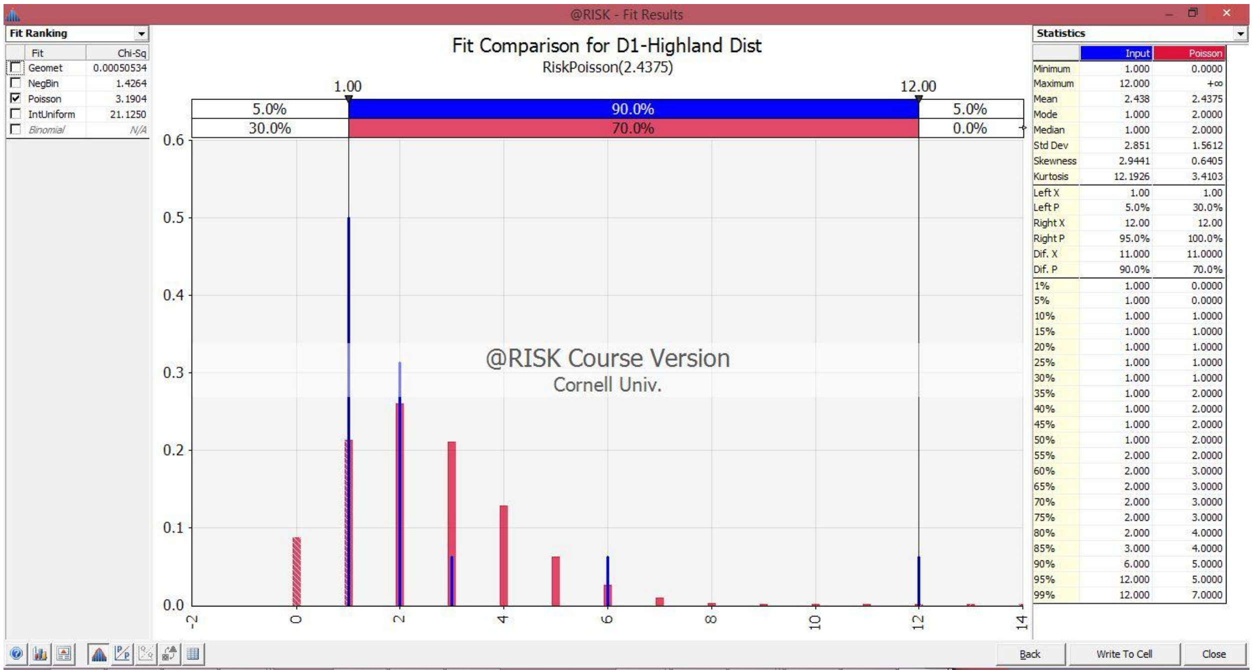
RUN	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL (min)
1	13	19	11	5	11	0	4	3	9	4	3	24	31	58.56
2	10	24	8	6	7	0	9	4	13	4	3	26	20	58.42
3	9	13	9	11	12	1	7	5	9	4	3	21	21	58.00
4	11	15	9	7	10	0	11	2	10	4	3	28	24	58.42
5	10	19	9	6	6	0	6	5	7	3	1	24	28	57.95
6	11	26	13	8	8	0	11	4	11	2	3	24	19	58.70
7	11	19	12	7	6	0	12	5	9	5	3	33	27	59.12
8	13	21	13	9	11	0	8	4	6	4	2	35	23	59.12
9	12	19	16	10	9	0	10	6	10	7	2	29	30	59.63
10	12	23	9	7	10	1	12	6	7	2	2	29	24	58.89
11	13	12	8	8	9	0	7	4	11	4	2	32	23	58.37
12	13	16	8	8	5	0	15	2	8	4	2	30	28	58.65
13	9	35	9	8	6	0	9	5	13	1	4	23	32	59.35
14	9	22	10	11	8	0	11	7	9	4	1	23	26	58.75
15	12	18	12	7	7	0	9	5	7	5	3	32	26	58.84
16	15	19	14	6	9	0	5	2	8	2	2	31	29	58.79
17	5	21	8	10	8	0	5	4	10	3	4	22	30	58.23
18	12	27	7	12	8	0	11	4	7	3	2	31	22	58.98
19	12	31	9	8	8	1	6	4	8	1	3	33	27	59.21

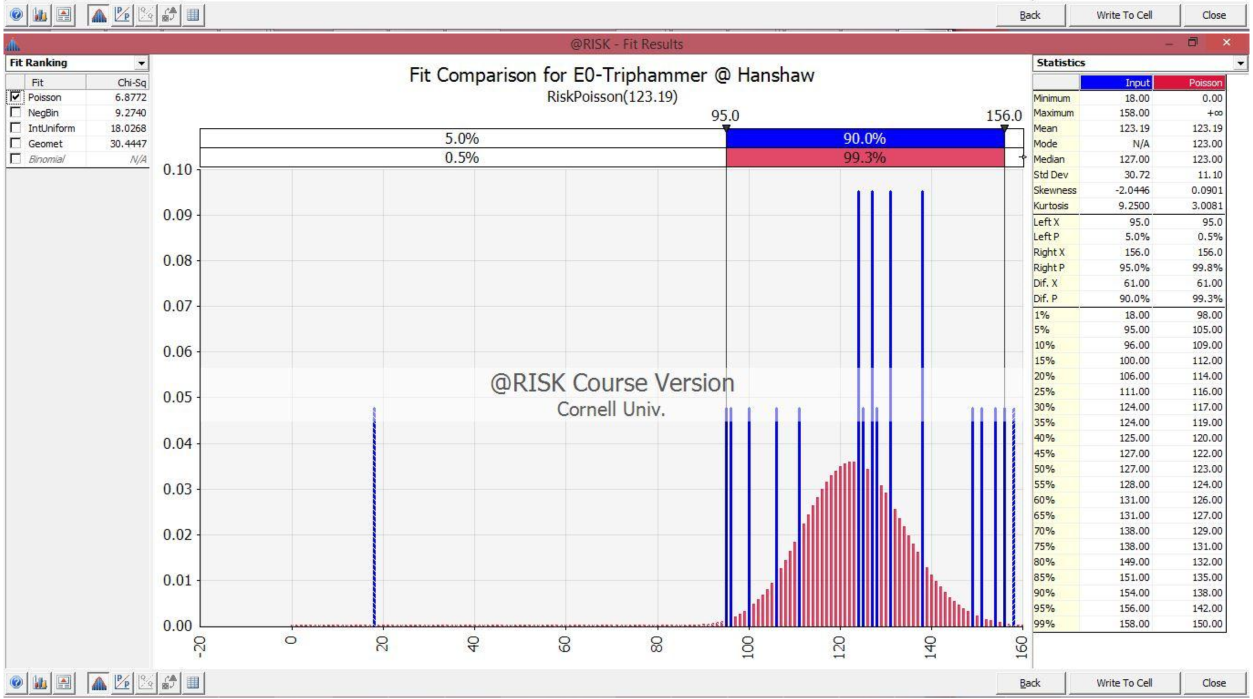
20	11	22	8	8	7	0	10	3	8	3	2	29	22	58.37

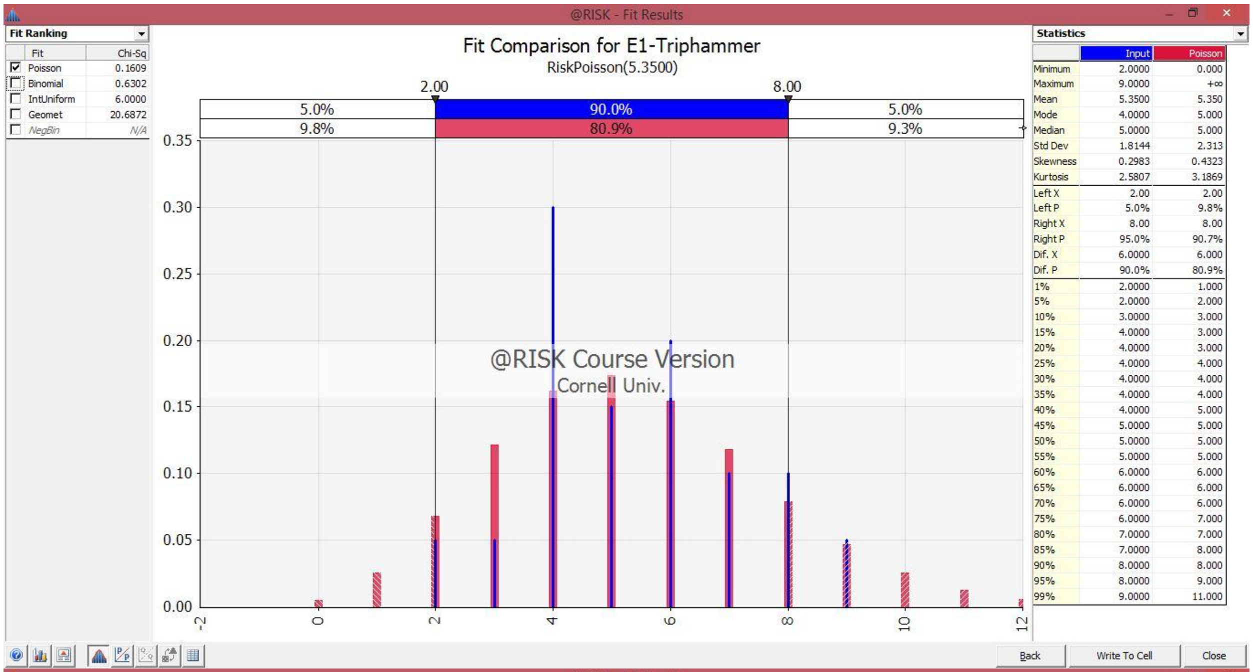
Simulation – Distribution Fitting of Arrival Frequencies

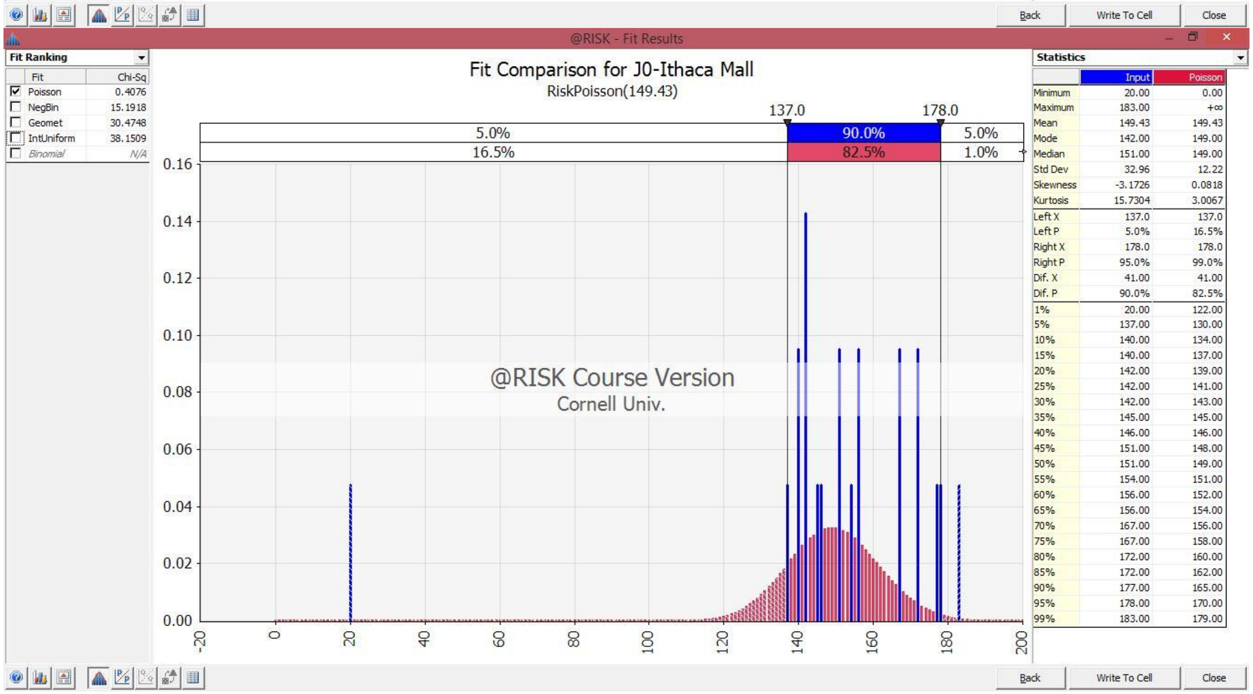





@RISK - Fit Results
Fit Ranking
Fit Chi-Sq
Geomet 0.00050534
NegBin 1.4264
Poisson 3.1904
IntUniform 21.1250
Binomial N/A
Fit Comparison for D1-Highland Dist
RiskPoisson(2.4375)
1.00
12.00
5.0% 90.0% 5.0%
30.0% 70.0% 0.0%
@RISK Course Version
Cornell Univ.
Statistics
Input Poisson
Minimum 1.000 0.0000
Maximum 12.000 +∞
Mean 2.438 2.4375
Mode 1.000 2.0000
Median 1.000 2.0000
Std Dev 2.851 1.5612
Skewness 2.9441 0.6405
Kurtosis 12.1926 3.4103
Left X 1.00 1.00
Left P 5.0% 30.0%
Right X 12.00 12.00
Right P 95.0% 100.0%
Dif. X 11.000 11.0000
Dif. P 90.0% 70.0%
1% 1.000 0.0000
5% 1.000 0.0000
10% 1.000 1.0000
15% 1.000 1.0000
20% 1.000 1.0000
25% 1.000 1.0000
30% 1.000 1.0000
35% 1.000 2.0000
40% 1.000 2.0000
45% 1.000 2.0000
50% 1.000 2.0000
55% 2.000 2.0000
60% 2.000 3.0000
65% 2.000 3.0000
70% 2.000 3.0000
75% 2.000 3.0000
80% 2.000 4.0000
85% 3.000 4.0000
90% 6.000 5.0000
95% 12.000 5.0000
99% 12.000 7.0000
Back Write To Cell Close


@RISK - Fit Results
Fit Ranking
Fit Chi-Sq
Poisson 6.8772
NegBin 9.2740
IntUniform 18.0268
Geomet 30.4447
Binomial N/A
Fit Comparison for E0-Triphammer @ Hanshaw
RiskPoisson(123.19)
95.0
156.0
5.0% 90.0%
0.5% 99.3%
@RISK Course Version
Cornell Univ.
Statistics
Input Poisson
Minimum 18.00 0.00
Maximum 158.00 +∞
Mean 123.19 123.19
Mode N/A 123.00
Median 127.00 123.00
Std Dev 30.72 11.10
Skewness -2.0446 0.0901
Kurtosis 9.2500 3.0081
Left X 95.0 95.0
Left P 5.0% 0.5%
Right X 156.0 156.0
Right P 95.0% 99.8%
Dif. X 61.00 61.00
Dif. P 90.0% 99.3%
1% 18.00 98.00
5% 95.00 105.00
10% 96.00 109.00
15% 100.00 112.00
20% 106.00 114.00
25% 111.00 116.00
30% 124.00 117.00
35% 124.00 119.00
40% 125.00 120.00
45% 127.00 122.00
50% 127.00 123.00
55% 128.00 124.00
60% 131.00 126.00
65% 131.00 127.00
70% 138.00 129.00
75% 138.00 131.00
80% 149.00 132.00
85% 151.00 135.00
90% 154.00 138.00
95% 156.00 142.00
99% 158.00 150.00
Back Write To Cell Close


@RISK - Fit Results
Fit Ranking
Fit Chi-Sq
Poisson 0.1609
Binomial 0.6302
IntUniform 6.0000
Geomet 20.6872
NegBin N/A
Fit Comparison for E1-Triphammer
RiskPoisson(5.3500)
2.00 8.00
5.0% 90.0% 5.0%
9.8% 80.9% 9.3%
@RISK Course Version
Cornell Univ.
Statistics
Input Poisson
Minimum 2.0000 0.000
Maximum 9.0000 +∞
Mean 5.3500 5.350
Mode 4.0000 5.000
Median 5.0000 5.000
Std Dev 1.8144 2.313
Skewness 0.2983 0.4323
Kurtosis 2.5807 3.1869
Left X 2.00 2.00
Left P 5.0% 9.8%
Right X 8.00 8.00
Right P 95.0% 90.7%
Dif. X 6.0000 6.000
Dif. P 90.0% 80.9%
1% 2.0000 1.000
5% 2.0000 2.000
10% 3.0000 3.000
15% 4.0000 3.000
20% 4.0000 3.000
25% 4.0000 4.000
30% 4.0000 4.000
35% 4.0000 4.000
40% 4.0000 5.000
45% 5.0000 5.000
50% 5.0000 5.000
55% 5.0000 5.000
60% 6.0000 6.000
65% 6.0000 6.000
70% 6.0000 6.000
75% 6.0000 7.000
80% 7.0000 7.000
85% 7.0000 8.000
90% 8.0000 8.000
95% 8.0000 9.000
99% 9.0000 11.000
Back Write To Cell Close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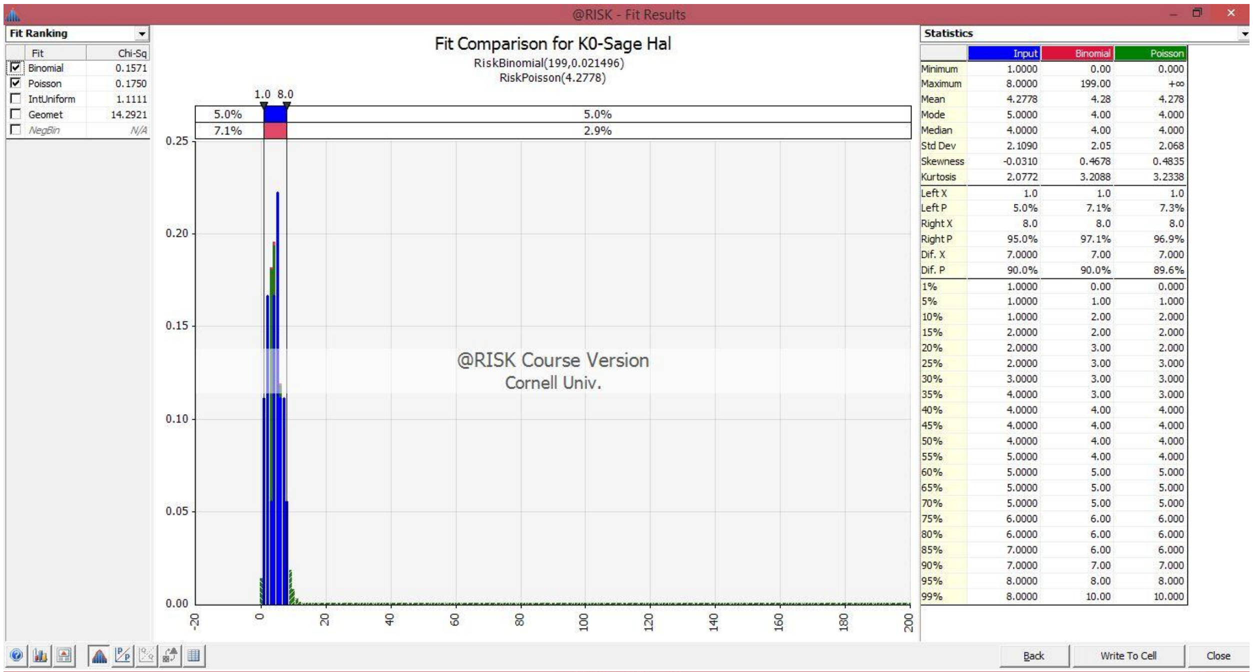
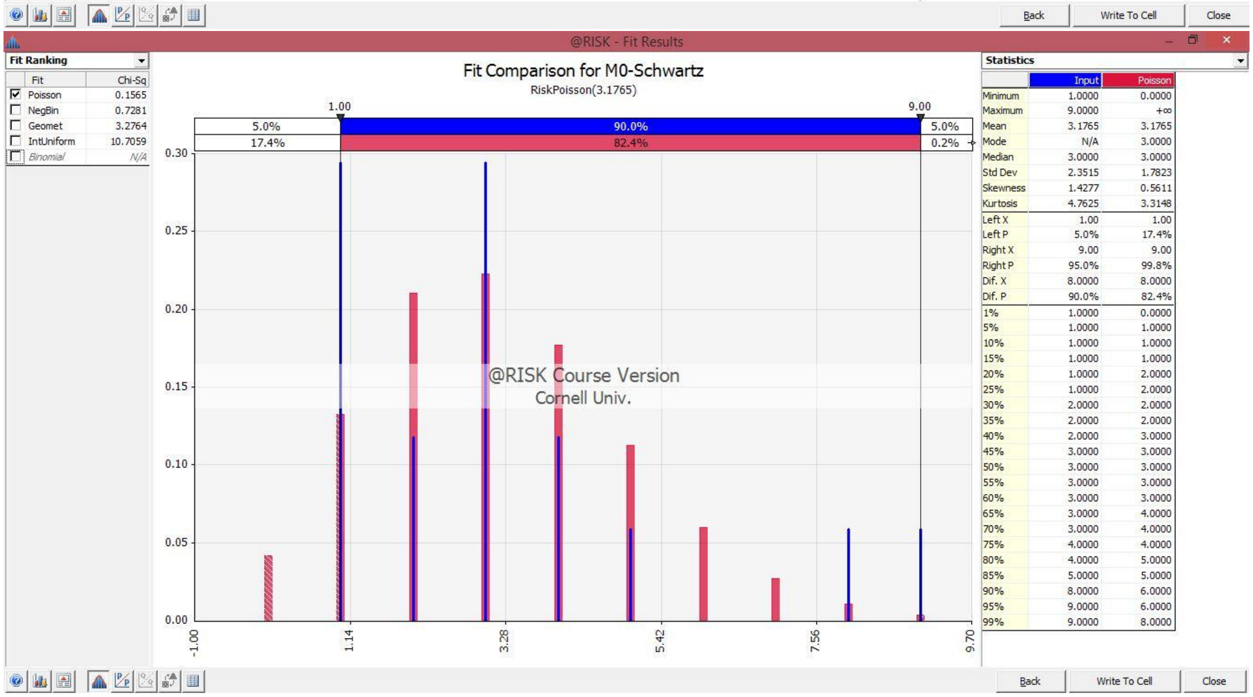
Fit Ranking
Fit Chi-Sq
Poisson 0.4076
NegBin 15.1918
Geomet 30.4748
IntUniform 38.1509
Binomial N/A
Fit Comparison for J0-Ithaca Mall
RiskPoisson(149.43)
137.0 178.0
5.0% 90.0% 5.0%
16.5% 82.5% 1.0%
@RISK Course Version
Cornell Univ.
Statistics
Input Poisson
Minimum 20.00 0.00
Maximum 183.00 +∞
Mean 149.43 149.43
Mode 142.00 149.00
Median 151.00 149.00
Std Dev 32.96 12.22
Skewness -3.1726 0.0818
Kurtosis 15.7304 3.0067
Left X 137.0 137.0
Left P 5.0% 16.5%
Right X 178.0 178.0
Right P 95.0% 99.0%
Dif. X 41.00 41.00
Dif. P 90.0% 82.5%
1% 20.00 122.00
5% 137.00 130.00
10% 140.00 134.00
15% 140.00 137.00
20% 142.00 139.00
25% 142.00 141.00
30% 142.00 143.00
35% 145.00 145.00
40% 146.00 146.00
45% 151.00 148.00
50% 151.00 149.00
55% 154.00 151.00
60% 156.00 152.00
65% 156.00 154.00
70% 167.00 156.00
75% 167.00 158.00
80% 172.00 160.00
85% 172.00 162.00
90% 177.00 165.00
95% 178.00 170.00
99% 183.00 179.00
Back Write To Cell Close



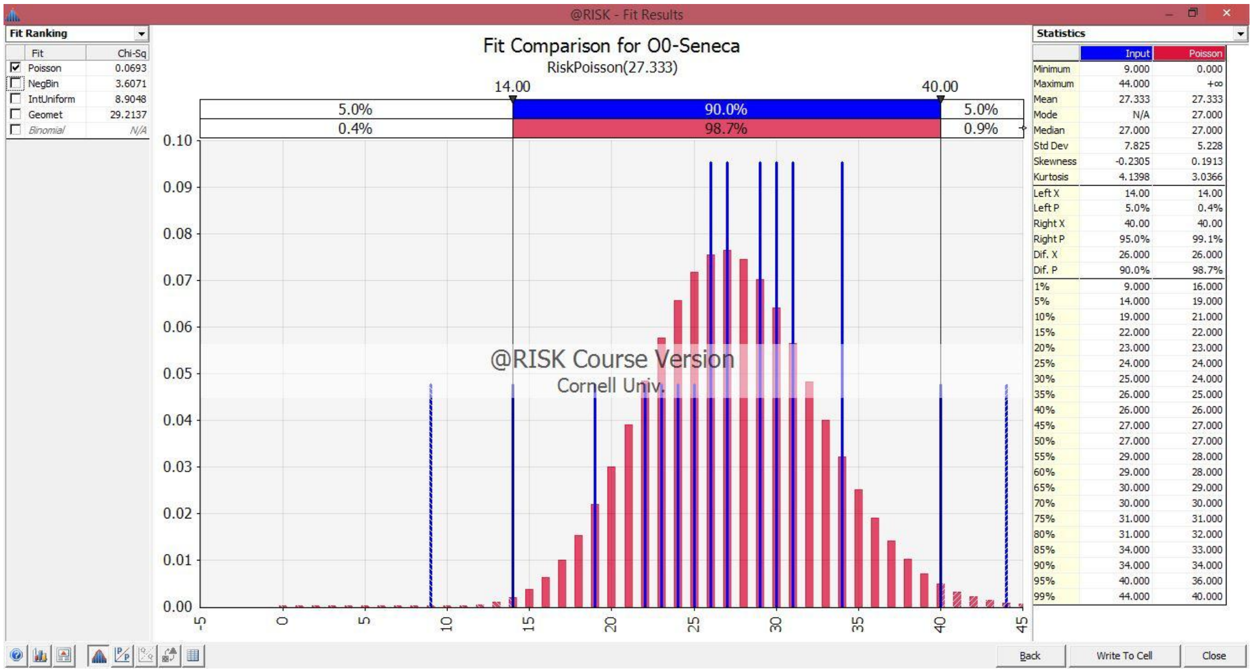
Statistics

	Input	Binomial	Poisson
Minimum	1.0000	0.00	0.000
Maximum	8.0000	199.00	+∞
Mean	4.2778	4.28	4.278
Mode	5.0000	4.00	4.000
Median	4.0000	4.00	4.000
Std Dev	2.1090	2.05	2.068
Skewness	-0.0310	0.4678	0.4835
Kurtosis	2.0772	3.2088	3.2338
Left X	1.0	1.0	1.0
Left P	5.0%	7.1%	7.3%
Right X	8.0	8.0	8.0
Right P	95.0%	97.1%	96.9%
Dif. X	7.0000	7.00	7.000
Dif. P	90.0%	90.0%	89.6%
1%	1.0000	0.00	0.000
5%	1.0000	1.00	1.000
10%	1.0000	2.00	2.000
15%	2.0000	2.00	2.000
20%	2.0000	3.00	2.000
25%	2.0000	3.00	3.000
30%	3.0000	3.00	3.000
35%	4.0000	3.00	3.000
40%	4.0000	4.00	4.000
45%	4.0000	4.00	4.000
50%	4.0000	4.00	4.000
55%	5.0000	4.00	4.000
60%	5.0000	5.00	5.000
65%	5.0000	5.00	5.000
70%	5.0000	5.00	5.000
75%	6.0000	6.00	6.000
80%	6.0000	6.00	6.000
85%	7.0000	6.00	6.000
90%	7.0000	7.00	7.000
95%	8.0000	8.00	8.000
99%	8.0000	10.00	10.000



Statistics

	Input	Poisson
Minimum	1.0000	0.0000
Maximum	9.0000	+∞
Mean	3.1765	3.1765
Mode	N/A	3.0000
Median	3.0000	3.0000
Std Dev	2.3515	1.7823
Skewness	1.4277	0.5611
Kurtosis	4.7625	3.3148
Left X	1.00	1.00
Left P	5.0%	17.4%
Right X	9.00	9.00
Right P	95.0%	99.8%
Dif. X	8.0000	8.0000
Dif. P	90.0%	82.4%
1%	1.0000	0.0000
5%	1.0000	1.0000
10%	1.0000	1.0000
15%	1.0000	1.0000
20%	1.0000	2.0000
25%	1.0000	2.0000
30%	2.0000	2.0000
35%	2.0000	2.0000
40%	2.0000	3.0000
45%	3.0000	3.0000
50%	3.0000	3.0000
55%	3.0000	3.0000
60%	3.0000	3.0000
65%	3.0000	4.0000
70%	3.0000	4.0000
75%	4.0000	4.0000
80%	4.0000	5.0000
85%	5.0000	5.0000
90%	8.0000	6.0000
95%	9.0000	6.0000
99%	9.0000	8.0000


@RISK - Fit Results
Fit Ranking
Fit Chi-Sq
Poisson 0.0693
NegBin 3.6071
IntUniform 8.9048
Geomet 29.2137
Binomial N/A
Fit Comparison for O0-Seneca
RiskPoisson(27.333)
14.00
40.00
5.0%
90.0%
5.0%
0.4%
98.7%
0.9%
@RISK Course Version
Cornell Univ.
Statistics
Input
Poisson
Back
Write To Cell
Close

Appendix B. Discussion of the findings of the report between Doug Swarts, TCAT representative, and Francis Vanek, project advisor

Note: The following comments on the final report were offered by Doug Swarts from TCAT, who represented the agency in the project, based on questions that arose at the presentation on May 9, 2014. The comments were then discussed with Francis Vanek, project advisor, in a meeting on May 30, after the end of the project, so that they appear in an appendix rather than in the body of the report. Hereafter, "the report" refers to information contained in the main body of this report above, written by members of the Master of Engineering team that carried out the research.

<u>TCAT Route System Improvements:</u>

Plans to cancel the route 13 and create a new route 84 on the Cornell campus raise a concern for people who depend on route 13, including transit dependent populations on the northside of Ithaca. These concerns are partially addressed by the explanation in the body of the report but are further explored here.

In a real-world context, proposed changes to schedules come up against planning and politics. One mandate of public transportation is to provide all parts of the service district with service, which would not be met by entirely eliminating the 13.

The profit calculations comparing the 13 and 84 in the report are unrealistic in the sense that they consider only fuel cost. The revenue figures are based on $1.49 per boarding, but this figure is high, the average value of a boarding to TCAT is currently $1.01 given the number of reduced cost fares collected. Also, "profit" is not the appropriate word for comparing routes, a term that compares total revenue and cost would be more appropriate, because as a public agency the mission of TCAT is not to be "profitable." Instead, the public must be served in a way where resources are used wisely. Cost is only one metric. Others include passengers boarding per hour, passengers per mile driven, and passengers per trip. If a route fails on all metrics, then it is easy for TCAT to discontinue it, but often decisions are more nuanced.

Another improvement that, although not considered in the report, could be applied to the northside is some sort of flexible routing or realignment of route. A straighter route might win more passengers if it gets them to final destinations (The commons, the Shops at Ithaca mall) more quickly. Flexible routing and route deviation could be used judiciously to making riding more convenient without sacrificing travel time.

Although it was not in the scope of the report, the flex routing concept could be extended to other nearby areas on West Hill in Ithaca. Small buses capable of route deviation might serve a hub at the West end of Ithaca and access both multi-family housing and residential neighborhoods. A proposed road to be built by the Town of Ithaca connecting Rt.79 to the hospital might help both fixed route busing such as the 14 and 20 and flex-route busing.

The body of the report treats the launch of the proposed route 84 and the use of articulated buses separately, but actually the two topics can be linked. The 84 is proposed as a way to address denied boardings in the mornings on north campus. Articulated buses, however, might address that need without needing to move resources from northside to campus.

Although the idea of a North-Central-Collegetown service in the morning peak is useful, the addition of another bus route number 84 to the very large list works against the goal of simplifying the overall roster of TCAT routes. Instead, an existing route might be short-turned in campus in the mornings so as to avoid adding another route number.

Use of Google Transit is generally desirable, but the report does not consider the implementation and ongoing maintenance cost of participating in the Google system. Although Google transit is free, it is not free of charge to TCAT to participate in this service. TCAT is, however, planning to join Google Transit as part of its larger ramping up of real-time passenger information, with a likely launch date sometime in 2015.

The Ride14850 bus schedule app mentioned in the report does not belong to TCAT. It was developed by a private app developer, with the prior knowledge of TCAT but without official endorsement. The developer takes publicly available data from the TCAT website to create the app and make schedule information available to the public, however TCAT is not responsible for its veracity.

The proposal to replace “Inbound/Outbound” with compass directions has merit but also may create ambiguity. A stop may be served by routes that are N/S and those that are E/W. A northbound route may at times travel east or west. A related problem is that some stops in the network have the same name in both directions, e.g., College & Mitchell northbound or southbound, while others have different names but are effectively the same paired stop, e.g., Statler and Sage. There may not be an ideal solution.

Emissions Reductions:

Findings in this part of the report are generally consistent with TCAT’s own views on the subject. The report finds that Hydrogen Fuel Cell are not economically feasible, although the most environmentally friendly. One factor not considered in the report is the role of Department of Energy financial support for capital cost of hydrogen buses, which in fact will help to deliver a hydrogen bus to TCAT sometime in 2015, according to plans. Based on currently available data, and depending on assumptions, conversion to B20 biodiesel would be moderately better for the environment and be cheaper in terms of fuel cost than, for example, hydrogen. However, the gains are limited, since the fuel is still 80% petro-diesel. Furthermore, new information currently arriving suggests that when biofuels are considered in the broadest possible context, they may not decrease CO_2 emissions overall. So TCAT might proceed cautiously: adopt B20 based on likely but not certain CO_2 benefits, as well as benefits for the agricultural sector, or decide to wait until the CO_2 debate is better resolved. Biodiesel made from waste bio-matter streams, for example from the Ithaca Area Waste Water Treatment Facility, although not considered in the report, would be a more certain ecological benefit since they are not derived directly from crops.

Buses with a High Level of Service (BHLS):

BHLS is defined as an option mid-way between regular bus service and BRT. The report proposes a BHLS service that combines the current Rt. 30 and Rt. 15, but with limited stops. This might be sensible, as long as the southside neighborhood and Titus Towers continues to be served somehow. Although the report does not mention it, TCAT in fact operated the Route 28 service, which provided direct service from the Cornell campus to southwest office park businesses such as Wegmans. The Rt.28 was discontinued in 2010 in order to provide more resources elsewhere.

According to the report, mandatory rear-door exiting should reduce dwell time by 1.3 seconds, but it is difficult to enforce under current conditions, for example when the aisle is crowded with standees, or in the case of wheelchairs that must enter and exit by the back. Although it was not included in the report, it would interesting to estimate the time savings possible from a voluntary system where passengers alight from the rear door whenever conditions allow.

The BHLS analysis chose to focus on dwell time, reducing the number of stops, and realigning the route. It would have been interesting to also study the time benefits of signal prioritization and off-board fare collection, as well as the potential new ridership that might be realized with increased service, in addition to riders shifting from other routes. Regarding signal priority, both the city engineering department and emergency services (fire, rescue, police) are supportive of this change if it can be funded.

The proposed BHLS would result in duplication of service along the current Rt.30 alignment since the 30 provides service at each stop while the BHLS provides a duplicative express service. Therefore, it might be advantageous to lengthen the Rt.30 headway to reflect the fact that the new route will take some of the ridership.

Bus Rapid Transit (BRT):

Regarding off-board Fare payment, more work can be done to explain how proof of payment (POP) would work. Some questions include the verification of fare payments, the person responsible for checking compliance, and the enforcement of monetary fines that result from unpaid fares. The costs of off-board fare payment devices may be unrealistically low. TCAT's own ITS strategic plan identifies $172k in capital costs for "several" vending kiosks for the system, so this amount would likely not be enough for each station along the BRT route, as well as $14k operating and maintenance per year.

In some cases, the cost in time and burden to collect a fare is such a large fraction of the fare's value that it is questionable to spend the resources. In these situations, a fare-free system could be studied, such as the one seen in Buffalo or Portland downtown business districts. On the other hand, at present a large fraction of TCAT's ridership pays using passes or swipe cards, so these approaches may be fairly efficient in terms of the total value of the fare allocated to the direct cost of collecting the fare.

Off-board fare collection can be done using an enclosure where the rider is confirmed to enter at a turnstile, waits for the bus, and then boards without further examination when the bus arrives, as is done in Curitiba or Bogota. However, this practice is capital intensive and is therefore reserved for larger cities, unless possibly for some of the busiest stops in the TCAT system. Otherwise, it is less expensive and complex to allow passengers to buy fares from an off-board device, board the bus without examination, and then wait for onboard inspection to verify that the fares have been paid. Note that this system is in widespread use in other countries but may encounter cultural obstacles or those of expectations in the U.S.

The evaluation of Level Platform Boarding may have had some cost figures that are unrealistically low. For instance, the platform needs to be a depth greater than 3 feet to be ADA-compliant (5 ft minimum).

For branding, while it is reasonable to assume some level of increase in ridership will result, the 15-20% ridership increase projection in the report is not backed up with a specific location and is somewhat speculative. Also, Table 28 leaves out some important stops but presumably important, high ridership stops such as Risley/Balch would also be considered.

Regarding express BRT service (and BHLS also), a neighborhood will be reluctant to accept the impact of a service passing through without also having access in the form of stops. In the case of Cayuga Heights, the only road on which a non-stop service makes sense is Triphammer Rd, and then only if the BRT (or BHLS) service makes a stops at the community corners (junction Triphammer and Hanshaw).
Stops: 7 proposed stops.

Articulated Buses:

The case for articulated buses could be further made by considering that back-up buses are currently used to accommodate peak-hour loads, meaning that one 40’ standard bus will follow close behind another. This practice is double the labor cost and nearly double the fuel cost of a standard bus, but was not factored into the analysis.

One question that arises with the use of the number of riders left waiting a stop when the bus is full is whether the riders wanted that particular bus. For instance, a 30 bus may have left one or more riders at a stop when full, yet the driver has no way to tell whether the riders wanted the 30 or e.g., and 81 bus instead.

(No comments offered about the simulation modeling chapter.)