PUBLIC TRANSIT PLANNING: TRAVEL TIME IMPROVEMENT BY ELIMINATING SUPERFLUOUS BUS STOPS IN THE CURRENT CUE BUS SYSTEM AND EVALUATION OF IMPROVEMENT BASED ON COVERAGE, EMISSIONS, AND TRANSIT OPERATIONAL COSTS

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Public Transit Planning: Travel Time Improvement By Eliminating Superfluous Bus Stops in the Current CUE Bus System and Evaluation of Improvement Based On Coverage, Emissions, and Transit Operational Costs

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DEDICATION

This is dedicated to my parents, Bhairab Man Shrestha and Jayanti Shrestha, who have always encouraged me in every step of my life.
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Without the support of my family, friends and colleagues this work would never been completed.

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LIST OF ABBREVIATIONS/SYMBOLS

INSTITUTIONAL ABBREVIATIONS

EPA, Environmental Protection Agency
GMU, George Mason University
NHTS, National Household Travel Survey
CUE, City University Energy-saver
GIS, Geographic Information System
ESRI, Environmental Systems Research Institute
MWCOC, Metropolitan Washington Council of Governments
NTD, National Transit Database

TERMINOLOGIES ABBREVIATIONS

CO, Carbon Monoxide
VOCs, Volatile Organic Compounds
NOx, Nitrogen Oxides
CO$_2$, Carbon dioxide
VMT, Vehicle Miles Travel (miles)
EF, Emission Factor (grams/miles)
HH, Household
VRH, Vehicle Revenue Hour (hr)
TOC, Total Operating Cost ($)
TOCH, Total Operating Cost per Hour ($/hr)
TOCS, Total Operating Cost Selected ($)
TOCSH, Total Operating Cost Selected per Hour ($/hr)
$T_o$, Travel time for old route (hr)
$T_n$, Travel time for new route (hr)
OC$_o$, Operational Cost for old route ($)
OC$_n$, Operational Cost for new route ($)
OC$_r$, Total Operational Cost reduction ($)
CRW, Cost Reduction per Week ($)
CALCULATION VARIABLES ABBREVIATIONS

$T_{a/d}$, Acc/Dec delay (sec),
$V$, Cruise speed of the bus (meters/sec),
$a$, Acceleration of the bus (meters/sec sq).
$b$, Deceleration of the bus (meters/sec sq).
$T_w$, Dwell delay (sec)
$Q$, Total number of passengers at the stop
$W$, Time to board/un-board each passenger (sec).
$N$, Total number of bus-stops
$T_v$, Time required to travel the route at cruise speed (sec)
$S$, Speed (miles/hr)
ABSTRACT

PUBLIC TRANSIT PLANNING: TRAVEL TIME IMPROVEMENT BY ELIMINATING SUPERFLUOUS BUS STOPS IN THE CURRENT CUE BUS SYSTEM AND EVALUATION OF IMPROVEMENT BASED ON COVERAGE, EMISSIONS, AND TRANSIT OPERATIONAL COSTS

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Current bus transit systems in the U.S. are considered unattractive to the travelers due to the lack of efficiency (especially in travel time), failure to proved adequate services, and infringement on the flexibility in their commute. It is believed that one of the reasons for the bus systems in the U.S. for not being able to provide faster services are due to densely spaced bus stops. Improvement in bus transit system by dropping some “extra” bus stops will yield in faster service, lower operating cost and reduction in transit based emission, but would also lower the ridership accessibility and coverage area. It is really important to understand the consequences of these costs and benefits associated with bus stop removal method to evaluate the tradeoffs.

This research examines the current CUE bus system in Fairfax City, VA to determine the superfluous bus stops in its current route and justifies the consequences after those stops were removed. The method in this research to identify the extra bus
stops is based on nearest facility algorithm with 800 m as the walking distance threshold between the bus stops and block-level based population center. Analyses of the social and economical impacts with the new route are based on the improvement on travel time after removing these bus stops. With the result achieved in this research, the current CUE bus route appears to have about 40% superfluous bus stops and eliminating them yield in transit time improvement and operational cost reduction by 23%. This transit time improvement triggered about 21% increment in overall ridership. Similarly transit based emissions such as: CO, VOC and NOx were also decreased by 34%, 18% and 10% respectively.

Demographic analysis was carried out on the dropped residential bus stops to capture the impact on ridership and coverage. The new route in this research failed to capture 8.2% of the population center resulting in about 10% of total Fairfax City population without the transit access. In spite of few untouched areas in the analysis, the research was able to identify some superfluous bus stops in the current CUE bus route. Additionally, after validating various social and economical tradeoffs, removing these stops were beneficial.
CHAPTER 1
INTRODUCTION

1.1. Public Transit
Public transportation has been viewed as the primary approach to improve the overall planning and management of the current transportation infrastructure. Unfortunately, the current public transit systems in the U.S. are considered slow and unattractive to travelers. Part of the reason for the public transit system’s unpopularity among potential patrons is the lack of efficiency in terms of travel time, failure to provide adequate services, and infringement on the flexibility in their commute (Balas, 2003).

Improvement in the public transit system by making it more attractive for the Single Occupancy Vehicle (SOV) drivers could possibly lead to an increment in ridership.

Improving public transportation, especially bus systems could be the potential solution for many of the modern day ills of urban regions in terms of transportation infrastructure (Murray, 2003). It is believed that travel time is one of the largest categories of transport costs, and time savings are often claimed to be the greatest benefit of transport projects such as public transit improvements (VTPI, 2009). One of the reasons for the bus system in the U.S. being unpopular among the riders is its inefficiency in terms of providing faster services due to densely spaced bus stops (Furth
et al., 2007). Even though additional bus stops will stimulate accessibility to riders and improve geographic coverage, the additional stops would likely increase the corresponding in-vehicle time and supply cost (Chien & Qin, 2004). On the other hand, sparsely spaced bus stops will yield faster services and lower operating cost, but would also lower the ridership accessibility and coverage areas (Murray & Wu, 2003). Hence it is really significant to be familiar with these tradeoffs and understand the potential benefits. Although this may appear to be a standard cost benefit analysis, some of the costs are not in direct monetary measurements. Costs like population coverage are usually considered a social impact and standard cost benefit analysis might not provide a clear picture on the tradeoffs. Transportation costing and benefit analysis with social impact has many specific applications to measure and evaluate its impacts. One of the applications to evaluate these sorts of social cost benefit analyses is equity analysis (Litman & Doherty, 2009). In simple terms, equity refers to the distribution of various social and/or economical impacts and whether those distributions are considered appropriate (Litman, 2002).

Transportation equity analysis generally is considered a complicated procedure as there is no single way to evaluate it. Its equity evaluation depends on the type of equity, the way people are categorized, which impacts are considered and how they are measured (Litman, 2002). That being said, there is a standard measurement procedure to evaluate the transportation equity. This standard method will analyze the transportation equity by measuring transportation quality such as speed, basic access such as coverage, and population categorization such as their demographics (Litman 2002). This research will
also follow the standard equity analysis protocol to evaluate the new bus route. The improvement in transportation quality due to the removable of bus stops will be measured by its overall fleet speed, reduction in operational cost and emission reduction. Furthermore, this research addresses basic transit access by examining the quality of the geographic coverage that is provided to passengers. Similarly, addressing the characteristics of bus stops such as residential, commercial or recreational would provide essential information toward the social impact on the population. Additionally, demographic knowledge on people who are not going to be covered by removing these bus stops would also be an important factor to be included in the equity analysis.

1.2. Motivation

Riding bus transit for daily commute to work and/or school and noticing its slowness was the key motivation for this research. The entire bus ride was extremely inefficient in terms of travel time due to the bus stops being too close to each other. Other riders also seem to have similar thoughts towards bus transit being slow due to this very reason, especially in case of bus transit within Fairfax City, VA. This could also be a key reason for people not opting to take bus transit for their daily commute. With these personal experiences, one can’t help thinking if there are some scientific methods to identify these superfluous bus stops and what would be the consequences if they were to be removed. Furthermore, it would be informative to understand why the numbers of transit riders are significantly low in the US. These were the main reasons which motivated to carry out this research to try to obtain efficiency by removing some extra bus stops. Moreover, examining the consequences on social and economical factors such as: emission
reduction, ridership improvements, cost reduction etc with bus transit improvement were also inspirational for this research.

![Fig 1: 2008 Greenhouse gas emissions by various sources. Source: EPA](image)

Expansion and development due to the growing population in a region brings adverse consequences for the environment as well as for the region’s overall physical infrastructure. Transportation within cities and urban regions brings about the majority of these impacts. In the past five decades, the suburbanization of America has rapidly progressed; suburbs are giving rise to newer suburbs and so the process continues (Sinha, 2003). As the suburbs grow, the distance from one’s home to their place of work has increased; resulting in a longer commute, though not by much. In the US, 93 % of total
work trips are private vehicle based (Murray, 2003). In many regions transportation has been one of the biggest causes for the environmental impact. The EPA (2010) reported that more than 23% of total greenhouse gas emissions, nationwide, are due to transportation (Fig 1). Therefore, all public transport planning and management bodies are continuously looking for ways to improve their services in order to support the demand for additional transportation and entice people to ride transit system more often. Although by only improving bus transit system might not cause overall reduction in transport based emissions, but will at least give option for better alternative mode of transportation to the riders as well as reduce transit base emissions.

Individuals decide their mode of transportation by construing their situation in two distinct ways: one, the pursuit of their personal convenience and two, the considerations of their travel efficiency such as travel time, price, ride continuity, and accessibility (Vaut and Meertens, 1995). These are the very reasons people tend to favor driving their own personal vehicle over riding public transit for their everyday commute. Most of the public transit modes, especially buses, in the U.S. have not been able to fulfill rider’s personal convenience and their travel efficiencies in a pleasing manner with the exception of New York City transit system (Bento et al., 2005). Even though some public services do exhibit capability in providing a desirable service to the riders, they are failing to gain ridership. Many drivers develop a habit or routine of regularly commuting by automobile, which is termed a social dilemma by Fujii et al. (2001). Today, people are highly dependent on their private vehicles and rarely will they think about alternative options for their commute. In fact, the recent facts suggest that the average American
household has more vehicles than members. In 2001, the National Household Travel Survey (NHTS) demonstrated that the average number of personal vehicles owned or available to U.S. households was 1.9, when the average size of the licensed drivers per household was 1.8. In recent years, there has been significant increment in the of dual-earner households resulting in more demand for private vehicles in a household. In fact, seventy percent of workers live in a household with at least one other worker and the number is increasing (Pisarski, 2006).

Hence, the improvement in the quality and services of the public transit system, to some extent, might be able to entice travelers to abstain from their cars. There has to be a feasible implementation to improve efficiency of the transit system to force, or at least entice drivers to choose public transit.

1.3. Research Question

There is no doubt that having a better bus transit in the region would play a central role towards improving overall transport infrastructure as well as helps in reducing transit based emissions, especially in a city with a big public school (George Mason University (GMU)) like Fairfax City, VA. In fact, college campuses have been considered as the privileged places to communicate sustainability and help reshape the society’s transportation pattern (Balas, 2003). With more than 30,000 students and about 2,000 faculty/staff, GMU is one of the central commuting targets for people in Northern Virginia and the District of Columbia (DC) area. Hence, this research focuses on the public bus service in Fairfax City, the City-University-Energysaver (CUE) bus system. The current CUE bus provides service to the local residents and GMU students in Fairfax
city to commute back and forth from their home to the work/study place and/or to the metro station. The primary goal of this research is to determine if it is possible to remove superfluous bus-stops in the current CUE bus routes without sacrificing significant service coverage. This research will also verify if the adjustments to the route are plausible by looking at the benefits in terms of reduction in transit related emissions and the dollar amount saved by the adjustments. Trade-off and equity analysis are performed by looking at the characteristics of stops and the people that are left without transit coverage.

The research begins by identifying the demand locations currently served along the bus route. Next it analyzes the travel routes as well as travel times and proposes an improved bus route to shorten the commuting time by eliminating some of the superfluous bus-stops which still facilitating bus access for the majority of the population. The research continues with equity analysis on the effect of the new route and evaluates its costs and benefits in two explicit phases. First it will estimate various improvements with the new route like, direct costs such as: total operating and maintenance costs as well as social cost such as: emissions. Secondly, it will examine the effect of these improvements towards riders and their transit accessibility. The research then try to answer, based on these tradeoffs, whether or not these improvements in the new route are viable.

The analysis of the public CUE bus system in this paper is carried out by using geographic information systems (GIS) based network analysis techniques. The next section reviews various literatures involving history and improvements of bus transit
system. Section 3 provides methods used in determining the superfluous stops and examines the resulting improvements transpire by the removable of these stops in new routes. Brief introduction of data used for the research is shown in Section 4 which is followed by the result of the analysis in Section 5. Section 6 gives an insight to the demography of the people who might be affected by the new route. Finally, conclusions and future directions are provided in Section 7 and Section 8, respectively.
CHAPTER 2
LITERATURE REVIEW

2.1. History of Public Transit

History of automobile and public transportation in the United States is about two century old. Before the major technical transformations brought forward by the industrial revolution at the end of the 18th century, forms of motorized transportation did not exist. It was during the industrial revolution when massive modification of the transport system took place in two major phases; canal systems and railways. The transportation system came a long way in the early 1890s with improvements in engine propulsion technology and the shift from coal to oil energy. Although in the 1920s the U.S. lead the world in public transit use (Sinha, 2003), it has since gone downhill. The Fordist Era (1920-1970) in transportation saw the development of internal combustion engines for private vehicles, which were a modified version of diesel engine. Vehicles made with these engines were faster and more comfortable in operations (Rodrigue et al., 2006). During this era, the US became the largest car manufacturing country, accounting for more than 80% of global car production. Due to the economies of scale, private vehicles became even more affordable and popular among the public; ultimately resulting in reduced public transit ridership (Rodrigue et al., 2006). Fig. 2 shows the motor vehicle manufacture graph for the United States, Japan and Germany since 1950.
The thirty year of public transit history between the years 1970 to 2000 has seen lots of fluctuations. There has been some increment in ridership due to the new built rail-transit infrastructure during the period of the late 1990s, along with increasing gas prices. On the other hand, there have also been a couple of major incidents in the early 1970s and 1980’s where public transit systems have lost their ridership due to relatively lower gas prices and higher transit fares (Pucher, 2002). It appears that the price of gasoline plays a key role in influencing public transit use. An article published on USA Today by Hagenbaugh, (2006) reported the growth of transit ridership due to soaring gas prices in the year 2006.

**Fig2.** Automobile Production, United States, Japan and Germany, 1950-2005 (in millions)

During that time, Washington, D.C. witnessed their sixth busiest day in history on their Metrorail operation and similar results were observed throughout the country where ridership has spiked as high as 50% (Hagenbaugh, 2006). That said, except in some rare occasions, prices of the gasoline in the U.S. are artificially low. The average gasoline price in the nation over the last 7 years ranged between $2.30 and $2.80 per gallon, except in the year 2008 when the price spiked worldwide. On the other hand, the gasoline price in the developed countries of Europe ranged from about $6 to $9 per gallon during the same time (EIA, 2011). This is also one of the key reasons for public transit not being as popular as in other developed countries. Fig 3 below shows the annual gasoline price for the U.S market as well as European countries between the years 2004 – 2010.

![Yearly Retail Gasoline Prices: 2004-2010](image)

**Fig2.** Automobile Production, United States, Japan and Germany, 1950-2005 (in millions)

*Source: EIA, 2011*
Similarly, factors such as: societal trends, land use, service-oriented markets and urbanization have also become more influential towards lessening public transit ridership (Rosenbloom, 1998). For example, as the job market becomes more and more service-oriented, it no longer has to locate itself within the core of the city. This phenomenon has led to new suburb expansion and wider spread of the population, making it difficult to provide public transit facilities for them. With no other alternative modes of transportation, drivers are very much dependent on their private vehicles. For them price of the gasoline would also play little significance as with no other commute option, they will pay almost any price for the gasoline to commute. Hence, the increasing decentralization of the population as well as the employment in metropolitan areas is to blame for declining public transit mode shares (Brown and Gregory, 2008).

2.2. Public Transportation Today

During the last hundred years, public transportation systems are experiencing a continuous decline in ridership. On the other hand, there has been consistent increment towards the automobile uses (Litman, 2010). That said there has been a continuous contradicting opinion among the critics regarding the development of public transit in the US. Some critics have their own point of view against public transit improvements and argue that beside few major cities in the US, the expansion and encouragement of transit uses are insignificant (Cox, 2010; Orski 2000; Balaker 2004). On the contrary, other groups of critics are showing their disagreement by highlighting the importance of improved transit system, especially in the city areas (Litman 2006; Puentes & Tomer,
People who are considered as “transportation disadvantaged” riders (people who cannot use automobile) which represent 5-10% are the primary transit riders in small cities, but as the density and size of the city grows, transit systems are equally important for the “discretionary riders” (people with option of driving) as well (Litman, 2010).

Today everyone is aware of the fact that increasing dependency of private vehicle based transportation brings about variety of social, environmental and economical problems such as: energy consumption, traffic accidents, emissions etc. A study done by Potter (2001) also showed that the rise in transport’s use of energy has primarily come about by the increased use of private car for personal transportation. Hossain and Kennedy (2008) further added that efficient bus rapid transit could lead to a reduction in transit based energy consumption and pollution caused by its emission by 29% in the short-run and 45% over the long run.

People these days are also realizing the importance of having smartly operated public transit in their community. A national random survey done by American Community in 2004 found out that new potential home buyers tend to place high value on public access with shorter commute times and walking access in the neighborhood. More than 72% of these people prefer to live in the place which has fine community-based amenities like sidewalks and public transit over automobile dependent ones (Belden & Stewart, 2004). This suggests that people do want to be less dependent on their private vehicles. However, they also realize that it is not always possible to get efficient transit access in their neighborhood. For this very reason, it is highly important to make public transit, especially in the US, not only easily accessible to the community, but also be able to
provide an excellent service quality. Service quality itself could be perceived differently by different users. Numerous transportation professionals have defined guidance on evaluating various transit service quality from the users perspectives such as: availability, frequency, travel speed, reliability, safety, etc. (Pratt, 1999; Rood, 1999; Phillips et al., 2001; Kittleson, 2003; Tumlin, et al., 2005; Kihl et. al, 2005; Marsden & Bonsall, 2006; Litman, 2007, 2008; Stradling, et al., 2007; Kenworthy, 2008). Although all of the suggestions mentioned above are equally important for transit service evaluation, due to the data availability and time constraint, this research, therefore, will only evaluate the improvement in the current city bus service in Fairfax City in terms of its travel time. Additionally, it will also examine the social and economical consequences such as: operating costs, transit based emissions and population coverage based on the improvements. Other evaluating factors mentioned above, which are not covered in this research, could be an area to explore for further research.

2.3. Stop Spacing

Numerous researches in the past recommended one way of improving the efficiency of the public bus system through appropriate spacing of their bus-stops. They suggested that the proper spacing of stops can significantly improve the quality of the transit system, and decrease travel times (Saka, 2001; Chien & Qin, 2004; Ziari et al., 2007; Alterkawi, 2006; Kocur & Hendrickson, 1982; Fitzpatrick, et al., 1997; Kuah & Perl, 2001; Wirasinghe & Ghoneim, 1981). One key aspect for determining the location for viable transit stops is to have an understanding of how far people are willing to walk to get to the facilities (Ziari et al., 2007). Determining walking distance to and from bus stops
presents two issues: knowledge of customers’ ultimate origins and destinations and feasible walking distance along network access (Furth et al., 2007).

One method which has been used in past research to estimate the origin/destination of the service areas is the centroid of the population (Furth et al., 2007; Murray, 2001; Murray, 2003; Saka, 2001). Since it will be difficult to do service location analysis on the block area of the population, the center point of each block needs to be considered as its service location (McElroy et al., 2003; Bielefeld et al., 1995). Generating parcel based centroid points using parcel-network method would provide a detail level of spatial accuracy regarding the population coverage (Biba et al., 2010). That said, due to the lack of parcel level data, this research is carried out at block level data to locate its service areas. Furthermore, unlike past methods of using Euclidean distance as the measure of walking-distance between origin and destination (Okabe et al., 2008; Gutierrez and Gracia-Palomares, 2008), it will use the actual road network distances.

Another key issue which has also been tackled by previous researchers with some educated estimation is the appropriate walking distance to the facility. Suitable access to public transit is typically characterized as a reasonable walk under normal conditions (Murray, 2003). Usually facilities are located based on simplified demand of the service areas (Fitzpatrick et al., 1997; Brouwer, 1983; Wirasinghe & Ghoneim, 1981). Others figured it depends on the density of the population and the number for the walking distances varies between 400 to 800 meters, where lower density corresponds to longer walking distance (Saka, 2001; Ziari et al., 2007). Thus this project, instead of just picking
a single distance value, will look at different scenarios and how it impacts on the actual coverage.

Calculating bus travel time seems also important to compare improvements in travel cost. Two basic delay factors in each bus stop: dwell time and acceleration/deceleration time, contribute time delay to the total bus travel time (Saka, 2001; Ziari et al., 2007; Chien & Qin, 2004). Although GPS and GIS have been frequently used in an attempt to determine these delays (El-Shair, 2003; Sankar et al., 2003; Srinivasan & Jovanis, 1996; Hellinga & Fu, 1999), this research will consider various delay variables to calculate them.

2.4. Costs and Benefits

Besides understanding the primary benefit of efficient travel time achieved by removing bus stops, it is also important to understand other costs and benefits associated with this action (ICF International, 2009). This is known as impact analysis, which refers to the impacts due to change in the transit services (Litman, 2004; Department of Transport, 2010). Researches on the improvement of public transit system are evaluated with various perspectives. The past researches on these sorts of studies were concerned with economic, spatial, and environmental factors that are affected by the improvements on public transits (Bento et. al, 2005; Brownstone & Small, 2005; Harford, 2006; Kennedy, 2002; Polzin, 1999). Hence the trade off factors with respect to the improvement of travel time in this research will also be based on: economic factors (operational cost reduction), spatial factors (residential impact) and environmental factors (emission reduction).
Furthermore by analyzing the effect on each impact factor based on the new bus route, this research, to some extent, will be able to portray on how effective the transit change will be.

### 2.4.1 Environmental Factor: Emissions Reduction

Transportation in the US these days is considered one of the leading causes of air pollution. Among the total air-related pollution, on road vehicle emissions in the US are responsible for about 45% of the total nationwide emission of EPA’s six criteria pollutants (National Research Council, 1995). Out of various greenhouse gases produced by on road vehicles, Carbon monoxide (CO), Volatile Organic Compounds (VOCs) and Nitrogen Oxides (NOx) contributes the most (Grant, 2007). CO and VOCs are produced with the incomplete combustion of motor fuels whereas NOx are the product of high-temperature chemical processes that occur during the combustion process in the engine itself (National Research Council, 1991). Even though the emissions caused by the heavy duty diesel fuel vehicle like bus is only 5% of the total on road emission, however, emission rates for these heavy duty vehicle are higher as they typically run at higher combustion pressures and temperatures than gasoline engines (Lilly, 1984). Hence even with the smaller number, these heavy duty vehicles due to their higher fuel burning rate are highly hazardous towards the environment. This research will look into the benefits of improvement in travel speed, in terms of emission reduction, especially CO, VOCs and NOx, in the new CUE bus route.
There are various ways to measure the amount of greenhouse gases for each type of vehicles. In fact, the amount emissions are considered to be function of several variables grouped in four main categories: travel-related factors, driver behavior, highway network characteristics and vehicle characteristics (National Research Council, 1995). Even though all of these factors are equally effective to measure or compare the emission reduction (or increment) via two different scenarios; however, for our research, only travel-related factors varies between the old and the proposed route, while the rest of the variables remain the same. The travel-related factor uses two distinct entities: Trip/Vehicle use and Speed/Acceleration, to calculate and compare the emission between two routes (National Research Council, 1995). Trip/Vehicle use emissions are simply a function of the total number of trips and total distance travelled by the vehicle whereas Speed/Acceleration emissions are the function of speed and acceleration of the vehicle over the distance of the trip. Improvements due to reduction of bus stops in the new route will only yield in improvement towards their travel speed. Other travel-related variables such as: vehicle miles traveled and numbers of trips will remains ineffective and will play a little role towards reducing overall transit based emissions. Hence this research will only utilize the Speed/Acceleration entities of the travel-related factor to estimate and compare the emissions between the old and new CUE bus route.

2.4.2 Economic Factors: Operational Cost Reduction

As mentioned above, economical analyses are considered to be important impact factors to consider while evaluating a transit system. There are various ways to put the context
into monetary perspective to perform an economical analysis such as: price of congestion, price of gasoline etc; however, to estimate the financial impact between two routes, operational cost of the transit would provide a direct monetary comparison (Karlaftis & McCarthy, 1999). Benjamin and Obeng (1990) discovered a significant relationship between vehicle efficiency in terms of travel time and financial cost, suggesting that reductions in operational cost in public transit could be achieved by increasing vehicle efficiency. In the US, all of the operating costs which are not covered by bus fares come from either taxation through directly dedicated revenues or local, state, and federal government tax-derived monies (Harford, 2006). Hence it will be important to understand the financial saving that might be achieved by improving the bus transit system.

2.4.3 Spatial Factor: Residential Impact

Residential impact will be another trade-off factor to consider while evaluating the costs and benefits in the transit system. It is highly significant to understand the characteristics of passengers who utilize public transit in order to plan any sort transit improvement strategies. Similarly, to evaluate the improvements in the transit, it is equally important to understand the characteristics of population which might be left out. One of the key characteristics of the population to comprehend not only in the transit enhancement, but also to plan the community’s future would be the demographic analysis (Neff & Pham, 2007; Lose & Associates, 2004). Understanding the demography of the passengers will help to describe the behavior of public transit trips and the people who take those trips
(Neff & Pham, 2007). Furthermore, this knowledge will also play a key role in deriving a relationship between the transit systems and the people influenced by it (Polzin, 1999). Even though this research does little to evaluating the behavior of a certain group of people who might be affected due to the removal of some of the bus stops, it will identify these people and represent their demographic profile to understand who they are. Knowing total number and demographic characteristics of these people will also be an important catalyst on evaluating costs and benefits carried out in this research. Any analysis of their behavior would be another topic to explore in the future. Having said that, the new more efficient bus stop system will most likely to attract drivers who perceive bus systems to be unattractive due to its slowness. Realizing the travel time improvement in the bus system, they would consider riding it more often.
CHAPTER 3
DATA

3.1. Survey Analysis

There was a survey analysis done in 2007 by the parking and transportation department at the GMU (Shrestha, 2007) to understand the behavior of the people who drove to the campus. They wanted to see the most influencing factors in their choice of mode even though they live within the Fairfax City. The result suggested that among 1000 sampled people, more than 75% of them who lived between 0-6 miles from the campus thinks that shorter commuting time was one the main reasons for them to drive to campus. They feel that the current CUE bus system is not efficient enough with respect to the travel time for their liking. Fig 4 shows the graphical representation of other factors influencing people to drive and the distance they live away from the campus.
Fig 4: Influencing factors and commuting distances.

3.2. Data Source

For the purpose of this research to demonstrate the demographic coverage, block level population and associate household data of Fairfax City was acquired from the US Census database (Census, 2009). To incorporate the population and household data, related block level boundaries and road network data of Fairfax city were also obtained via Environmental Systems Research Institute (ESRI) website (ESRI, 2009). Later these data were projected into WGS_1984_UTM_Zone_18N. Two CUE bus route (Gold and Green) along with its corresponding bus-stops (both directions) data were created. These data were also projected in similar fashion as the previous data for consistency. Finally, the current CUE bus travel time and schedule were obtained from the bus schedules at the City of Fairfax website (Fairfax, 2009).
Financial information on the CUE bus system for the year 2008 was obtained from the National Transit Database. These data included various operational and non-operational expenditures associated with the CUE bus services. Apart from that, information on the current CUE bus fuel type was obtained via a personal contact with Mr. Alexis L. Verzosa, Transportation Director, City of Fairfax.

For the emission estimation, emission factors based on the speed of the heavy duty buses for various greenhouse gases was obtained from Metropolitan Washington Council of Governments (MWCOG) report and from data model Mobile 5a developed by EPA.

3.3. Study Area

The study area for this research consists of census blocks served by the CUE bus route within the City of Fairfax. Additionally, there few additional census blocks included in this research which falls under Fairfax County jurisdiction as they were also served by the CUE bus route. Two of these blocks within the county were identified as George Mason University and Fairfax/Vienna Metro Station. Fig 5 below shows the study area and the CUE bus route in Fairfax City.
**Fig 5:** Study area: Fairfax City, VA and its CUE bus system
CHAPTER 4

METHODS

4.1. Method flow chart

Data Collection: CUE bus routes, stops, Fairfax city road network, population (block level)

Create road network with facilities and demand points

Find the Facilities utilized to serve the demand points at various walking distances.

Remove facilities from the route

Calculate total travel saved with the removal of stops

Calculate how much money and emission is saved with the new routed

Perform the trade off analysis.

Present the result and see if the trade off is beneficial.

Create demand points with population center

Create facilities with bus stops

Performing the nearest facility analysis for bus-stops and obtaining the number of bus stops utilized based on walking distance threshold.

Facilities which are not connected to any service areas were assumed to be unutilized bus-stops and considered to be removed from the route

Calculate the time delay on each bus stop: Acc/Dec delay and Dwell time

Based on the travel time improvement due to the removal of bus stops

Demographic analysis of people associated with the removed stops
4.2. Creating Service Areas

Each service area was created as the centroid of the block polygon. Each block polygon was assumed as an individual demand and the center point of the polygon would represent the total demand of the entire polygon. This may not sound the efficient way to deal with the issue, but given the availability of the data, this approach seems reasonable.

4.3. Creating Network

As the road network data does not have any connection to the block centroid points, new connection must be created to link between these points and the road network itself. These procedures are carried out by an automated process employed within the GIS which selects each centroid, finds its nearest point in the network and generates new connection between them (Biba, 2010). The final output would be a road network with set of block centroid points connect to it.

4.4. Estimating Walking Distances

With block centroid points as service areas and bus-stops as facilities, the network analysis for nearest facilities was performed with various walking distances. This network analysis is nothing but a shortest path algorithm which finds a closet facility for each service areas within a threshold distance. For the less densely populated areas like Fairfax city, the recommended walking distance was assumed to be 800 m (Saka, 2001; Ziari et. al, 2007; Demetsky & Lin, 1982) however, to get the grasp on change of distances with the total coverage, different scenarios of distances: 200, 400, 600 and 800
were selected. Apart from the constraints with the walking distances, one case without the walking distance constraint was also performed to cover all the service areas. This gave an idea on the maximum facilities required if it has to cover all the service area regardless of their distance. Fig 6 shows the result of nearest facilities for each service area which are within 800m walking distance.

4.5. **Removing superfluous bus stops**

After performing the nearest facility analysis for bus-stops with all four walking distance scenarios, the minimum number of bus-stops utilized at each walking distances was obtained. The nearest facility analysis is a simple algorithm which finds the nearest facility for a service area based on the allowed walking distance and creates a network connection between them. For each cases with different walking distances (200m, 400m, 600m and 800m), facilities which are not connected to any service areas were assumed to be unutilized bus-stops and considered to be removed from the route. The reason these bus stops does not have any network connection with block centriod are due to either the block centroid is beyond the walking distance threshold, or the closest block centroid is already served by other bus-stop. Hence in either case, these bus-stops were assumed to be superfluous for the purpose of this research.

Looking at the past methods used, 800 m for the walking distance to the bus-stop seemed appropriate bench mark (Saka, 2001; Murray, 2003; Ziari et al., 2007; Demetsky & Lin, 1982). Thus with 800 m walking consideration, excess bus stops, which did not
had any service areas associate with them, were removed from the existing bus route. Fig 7 shows the new route with only bus-stops which are serving at least one service area.
Fig 6: Coverage of the service area at 800m walking distance.
Fig 7: Reduce bus stop route at 800m walking distance.
4.6. Calculating bus stop delay

Two of the factors which significantly contribute to the time delay in each stop are: Acceleration/Deceleration delay and Dwell time delay. These delays could impact a major influence in the travel time as it might consume up to 26% to total bus travel time (Rajbhandari et al., 2003). Acceleration/Deceleration delay occurs when the bus is pulling in/pulling out of the bus stop. Similarly dwell delay refers to the time delay for a bus at each stop to load and unload the passengers and these factors could be derived from the following equations (Saka, 2001; Ziari et al., 2007; Chien & Qin, 2004):

\[
(1) \quad T_{ad} = \left( \frac{V}{a} \right) + \left( \frac{V}{b} \right)
\]

Where,

- \( T_{ad} \): Acc/Dec delay (sec),
- \( V \): cruise speed of the bus (meters/sec),
- \( a \): Acceleration of the bus (meters/sec sq).
- \( b \): Deceleration of the bus (meters/sec sq).

This equation will give the time delay at each stop for the bus when it has to decelerate to stop at a bus-stop and accelerate from a bus-stop to merge into the traffic.

\[
(2) \quad T_w = Q \times w
\]

Where,

- \( T_w \): Dwell delay (sec)
- \( Q \): number of passengers at the stop
- \( w \): time to board/un-board each passenger (sec).
By multiplying total number of passengers with the dwell delay for each passenger, this equation will give the total dwell delay for each bus-stop.

The cruise speed of the bus (V) was derived from the current CUE bus schedule which is about 12 meters/sec (~27 miles/hr) and acceleration and deceleration (a/b) to be around 2 meter/sec sq (Furth and SanClemente, 2006). Other variables associated with the time delay were collected from the personal observations while riding the bus every day. Table 1 shows the variables and their values.

<table>
<thead>
<tr>
<th>Variables</th>
<th>value</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>12</td>
<td>m/s</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>m/s sq</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>m/s sq</td>
</tr>
<tr>
<td>Q</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>5</td>
<td>sec</td>
</tr>
</tbody>
</table>

Thus using the equations and variables above, the time delay in each stop is calculated as follows:

\[
T_{a/d} = 12 \text{ sec}
\]
\[
T_w = 20 \text{ sec}
\]

4.7. Total Travel Time:

Total travel time for the new route was calculated from the equation (Saka, 2001):

\[
(3) \ T_{bus} = N \ast (T_{a/d} + T_w) + T_v
\]
Where,

\( N \): Total number of bus-stops

\( T_v \): Time required to travel the route at cruise speed

Other delays like: congestions, traffic signals etc were insignificant as probability of effect on the travel time in old and new route will be the same. This equation will provide the time required by the bus to make a single trip in one direction. The first part of the equation will give the total dwell time delay at each stop and multiplying it by the total number of stops (\( N \)) will result in the total delay for the entire trip. Hence the dwell delay will vary depending on the number of bus-stop used.

With the use of network analyst tool within the GIS software, the total route distance was obtained as

\[
\text{Vehicle Mile Travelled (VMT)} = 42890 \text{ m} = 26.65 \text{ miles.}
\]

Thus the bus travel time at cruise speed (12 m/s) is:

\[ T_v = 3574.16 \text{ sec} \]

Now using the equation 3, the total travel time for both old and new bus route was calculated, where old route had 121 bus stops and the new one had 68.

**4.8. Bus Operational Cost**

The overall annual bus operational cost for the CUE bus system in term of dollar per hour with respect to the bus-hours was estimated on the basis of data obtained from the National Transit Database (NTD). Although the database had the financial information on
the CUE bus system for the years ranging from 2001-2008, only the information of the year 2008 was used to reflect the most recent expenditure.

Table 2: CUE bus’s various annual operational costs (in thousands) along with total revenue hour, 2002-2008. Source (NTD).

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators Wages</td>
<td>1,072.73</td>
<td>985.93</td>
<td>1,029.32</td>
<td>986.82</td>
<td>1,018.15</td>
<td>1,107.20</td>
<td>1,158.50</td>
</tr>
<tr>
<td>Other Salaries &amp; Wages</td>
<td>245.47</td>
<td>349.81</td>
<td>382.45</td>
<td>332.79</td>
<td>300.04</td>
<td>297.58</td>
<td>279.80</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>266.15</td>
<td>277.04</td>
<td>312.44</td>
<td>700.23</td>
<td>781.04</td>
<td>828.03</td>
<td>859.70</td>
</tr>
<tr>
<td>Services</td>
<td>89.67</td>
<td>84.45</td>
<td>76.39</td>
<td>50.11</td>
<td>73.08</td>
<td>93.66</td>
<td>114.80</td>
</tr>
<tr>
<td>Fuel and Lube</td>
<td>87.42</td>
<td>111.69</td>
<td>115.09</td>
<td>140.53</td>
<td>282.56</td>
<td>281.96</td>
<td>358.10</td>
</tr>
<tr>
<td>Tires and Other</td>
<td>189.07</td>
<td>171.62</td>
<td>156.96</td>
<td>113.80</td>
<td>147.20</td>
<td>180.14</td>
<td>141.80</td>
</tr>
<tr>
<td>Casualty and Liabilities</td>
<td>50.00</td>
<td>50.00</td>
<td>50.00</td>
<td>50.00</td>
<td>50.00</td>
<td>50.00</td>
<td>50.00</td>
</tr>
<tr>
<td>Utilities</td>
<td>0.52</td>
<td>0.43</td>
<td>0.39</td>
<td>0.41</td>
<td>0.43</td>
<td>0.42</td>
<td>0.40</td>
</tr>
<tr>
<td>Others</td>
<td>27.70</td>
<td>31.19</td>
<td>107.87</td>
<td>29.33</td>
<td>33.96</td>
<td>30.53</td>
<td>17.50</td>
</tr>
<tr>
<td>Vehicle Revenue Hour (VRH)</td>
<td>41584</td>
<td>46601</td>
<td>29524</td>
<td>35191</td>
<td>33994</td>
<td>33994</td>
<td>34602</td>
</tr>
</tbody>
</table>

The annual operational costs are divided into four categories: Operational, Maintenance, Non-Vehicle and General Administrative cost. The operational cost includes costs like: Operators wages, Fringe Benefits and Services. Maintenance cost includes: Fuel and Lube, Tires and Other. Non-Vehicle cost consists of Casualty and Liabilities and utilities. Finally, the Administrative cost includes Other Wages and Salaries. The vehicle fleet size represents the total number of vehicles available to operate at for given year and the vehicle revenue hour represents the hours that vehicles are
scheduled to or actually travel while in revenue service including layover and recovery time (NTD). Table 2 above shows the complete breakdown of the expenses for years 2001-2008. Table 3 below shows these expenses for the year 2008 only.

**Table 3:** CUE bus’s various annual operational costs (in thousands) along with total revenue hour, 2008. Source (NTD).

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (in thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators Wages</td>
<td>$1158.5</td>
</tr>
<tr>
<td>Other Salaries &amp; Wages</td>
<td>$279.8</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>$859.7</td>
</tr>
<tr>
<td>Services</td>
<td>$114.8</td>
</tr>
<tr>
<td>Fuel and Lube</td>
<td>$358.1</td>
</tr>
<tr>
<td>Tires and Other</td>
<td>$141.8</td>
</tr>
<tr>
<td>Casualty and Liabilities</td>
<td>$50</td>
</tr>
<tr>
<td>Utilities</td>
<td>$0.4</td>
</tr>
<tr>
<td>Others</td>
<td>$17.5</td>
</tr>
<tr>
<td>Vehicle Revenue Hour (VRH)</td>
<td>34602</td>
</tr>
</tbody>
</table>

With a simple mathematical approach to estimate the total operational cost with respect to dollar per hour would be to add-up all the cost and divide it with VRH to get the total cost per hour (Bruun, 2005).

Hence,

\[(4) \text{Total Operating Cost (TOC)} = \text{Sum of all cost} = \$2,980,627\]

Similarly,

\[(5) \text{TOC per Hour (TOCH)} = \frac{\text{TOC}}{\text{VRH}} = \frac{2980627}{34602} = 86.14 \text{ ($/hour)}\]
Although, TOCH calculated above in EQ 5 would provide total operational cost for any given hour, however for the purpose of this research, this number might not reflect accurate information. One of the goals of this research is to estimate the cost-saving in a bus transit system by improving its travel time with the removal of some of the superfluous bus stops. With this regard, some of the costs, mentioned in table 3 above, such as Administrative salaries, Fringe Benefits and Casualty, and Liabilities might not be affected with this consolidation of bus-stops. Hence excluding these costs from the TOC would reflect the near accurate operating cost for the purpose of this research.

Hence,

\[
(6) \text{TOC Selected (TOCS)} = \text{TOC} - 279800 - 50000 - 859700 = \$1,791,127
\]

And,

\[
(7) \text{TOCS per Hour (TOCSH)} = \frac{1791127}{34602} = 51.76 \ ($/\text{hour}).
\]

This would be the approximate operational cost per hour for a single CUE bus.

4.9. **Emission Calculation**

For the calculation of CUE bus emission with respect to its cruise speed, the required emission factors for diesel buses were obtained from the Metropolitan Washington Council of Governments (MWCOG) report and from data model Mobile 5a developed by EPA. Their approach was based on EPA’s Mobile 6 tool which estimates emission factors based on the average speed of the diesel buses and use it to calculate the emissions: Carbon Monoxide (CO), Volatile Organic Compound (VOC) and Nitrogen
Oxide (NOx: which includes both NO and NO2), depending on its average vehicle speed. The emission analysis for the research could have been more efficient if the carbon dioxide emission (CO2) were included; however due to the insufficient information on these emission factors, in terms of speed of the vehicle, CO, VOC and NOx emission were considered. Besides, CO, VOC and NOx via road transportation contribute the highest amount of air pollutants in the environment (Grant, 2007). On average, in the United States, road transportation sources are responsible for 55% of CO, 27% of VOC and 35% of NOx towards the overall greenhouse gas emissions (Grant, 2007).

**Table 4:** MWCOS regional diesel bus emission factors, 2005. Source (MWCOSG & EPA).

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Diesel Bus Emission Factors (EF) (grams/mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>36.50</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>13</td>
<td>21</td>
</tr>
<tr>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>23</td>
<td>10.5</td>
</tr>
<tr>
<td>30</td>
<td>9</td>
</tr>
</tbody>
</table>
Although they also had emission factor lists for the date ranging from 1990 to 2005, only the information from the year 2005 were utilized in order to make it as recent as possible. Table 4 shows a snap shot of diesel buses average speed and its corresponding emission factors.

As mentioned earlier in the section, with the use of network analyst tool, the total route distance was obtained as 42890 meters (26.65 miles) one way. And also the actual travel time for the existing bus route which was obtained from the Fairfax City website (Fairfax, 2009) was 7440 sec (2.07 hr), hence the total initial cruise speed of the bus would be:

\[(8) \text{ Speed (S)} = \frac{\text{distance}}{\text{time}} = \frac{26.65}{2.07} \approx 13 \text{ miles/hr.}\]

With these information of bus route distance and speed of the bus along with emission factors obtained from the MWCOG, initial bus emission could be derived by multiplying the Emission Factor (EF) which corresponds to the appropriate speed in table 3, with the total distance traveled, i.e.,

\[(9) \text{ Emission (E)} = \text{EF (CO or VOC or NOx)} \times \text{VMT}\]

Similarly, after calculating the new reduced travel time for the bus route as a result of bus stop elimination, the result value can be used to derive new speed for the new route by using equation (8). Furthermore, the emission for the new route now can be drawn by using equation (9) with appropriate emission factors described in table 4. The result section will reflect the calculations.
CHAPTER 5
RESULT

5.1. Travel time improvement

On the basis of results obtained in this research, the current CUE bus appears to have numerous superfluous bus stops which are contributing on its travel efficiency. The result shown in table 5 for five different scenarios of walking distances versus the service coverage and the total facilities used indicates that even with the consideration of maximum coverage (99.20%), only about 58% of the total facilities were utilized. The two service areas missed out was due to the breakage on the route network. Interestingly enough, by just adding 3 facilities in the 800 m walking distance scenario, which was assumed to be ideal walking distance for not densely populated area like Fairfax city, the coverage will jump from 82% to almost 100%. Similarly with the same walking distance, it will cover about 88% of population and households, shown in table 5.

The improvement in terms of travel time between the existing bus route and the new proposed one also seems fairly significant as well. There was a travel time improvement of about 23% which is highlighted in table 7.
Table 5: Result on usage of facilities with different walking distances.

<table>
<thead>
<tr>
<th>Walking distance (m)</th>
<th>Total Facility Available</th>
<th>Facility Used</th>
<th>% Facility Used</th>
<th>Total Service Area</th>
<th>Service area served</th>
<th>% Service area served</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>121</td>
<td>29</td>
<td>23.97</td>
<td>251</td>
<td>51</td>
<td>20.32</td>
</tr>
<tr>
<td>400</td>
<td>121</td>
<td>52</td>
<td>42.98</td>
<td>251</td>
<td>112</td>
<td>44.62</td>
</tr>
<tr>
<td>600</td>
<td>121</td>
<td>66</td>
<td>54.55</td>
<td>251</td>
<td>177</td>
<td>70.52</td>
</tr>
<tr>
<td>800</td>
<td>121</td>
<td>68</td>
<td>56.20</td>
<td>251</td>
<td>207</td>
<td>82.47</td>
</tr>
<tr>
<td>No restriction</td>
<td>121</td>
<td>71</td>
<td>58.68</td>
<td>251</td>
<td>249</td>
<td>99.20</td>
</tr>
</tbody>
</table>

Table 6: Population and Household coverage with different walking distances.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Total Pop</th>
<th>Pop covered</th>
<th>% Pop Covered</th>
<th>Total HH</th>
<th>HH Covered</th>
<th>% HH Covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>34024</td>
<td>3815</td>
<td>11.21</td>
<td>12465</td>
<td>1248</td>
<td>10.01</td>
</tr>
<tr>
<td>400</td>
<td>34024</td>
<td>12340</td>
<td>36.27</td>
<td>12465</td>
<td>4075</td>
<td>32.69</td>
</tr>
<tr>
<td>600</td>
<td>34024</td>
<td>20896</td>
<td>61.42</td>
<td>12465</td>
<td>7426</td>
<td>59.57</td>
</tr>
<tr>
<td>800</td>
<td>34024</td>
<td>30102</td>
<td>88.47</td>
<td>12465</td>
<td>11004</td>
<td>88.28</td>
</tr>
</tbody>
</table>

Table 7: Travel time improvement comparison between existing and new route.

<table>
<thead>
<tr>
<th>Bus route</th>
<th># of Stops</th>
<th>Total Delay (sec)</th>
<th>Total Travel time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>121</td>
<td>3872</td>
<td>7446</td>
</tr>
<tr>
<td>New</td>
<td>68</td>
<td>2176</td>
<td>5750</td>
</tr>
<tr>
<td>% Improved</td>
<td></td>
<td></td>
<td><strong>23%</strong></td>
</tr>
</tbody>
</table>

This improvement on the travel time is derived with no other delay consideration except delays mentioned in previous chapter: dwell time delays and acceleration/deceleration delays. To portray the effect of the improvement in terms of actual travel time between the existing bus route and the new route with lesser bus stops.
proposed in this paper, the actual travel time for the existing bus route was obtained from the Fairfax City website (Fairfax, 2009). This travel time for the existing CUE bus route obtained from the actual schedule was very similar to the one calculated above with delays. Eq. 10 below shows the actual travel time for the CUE bus route:

\[ \text{(10) Travel time old route, } T_o = 7440 \text{ sec} = 2.07 \text{ hr} \]

Thus the actual travel time improvement (23%) from the existing bus route to the proposed one is 1711.20 sec (~29 min). This suggests that the new route with the 800 m walking distance to the bus stop will be 29 min faster than the existing bus route travelling in one direction.

Hence,

\[ \text{(11) Travel time new route, } T_n = T_o - \text{travel time improvement} \]
\[ = 7440 - 1711 = 5729 \text{ sec} = \sim 1.6 \text{ hr} \]

5.2. Cost Reduction

With the value of TOCSH derived from equation (7) and the values of \( T_o \) and \( T_n \) from equation (10 & 11) the calculation of the operational cost of the CUE bus in both the old route and the new proposed route will be straightforward.

The operational cost of a CUE bus operating in the old route would be:

\[ \text{(12) } OC_o (\text{Operational Cost Old}) = \text{TOCSH} * T_o \text{ (hr)} \]
\[ = 51.76 * 2.07 = 107.14 (\$) \]

Similarly, the operational cost of a CUE bus operating in new improved route would be:
(13) $OC_n (Operational Cost New) = TOSCH * T_n (hr)$ (EQ 11 for $T_n$ value)  

$= 51.76 * 1.6 = 82.37$ ($)

Hence, the total cost saving of a CUE bus operating in the new route for a single one way trip will be:

(14) $OC_r (Operational Cost Reduction) = OC_o - OC_n = 107.14 - 82.37$

$= 24.78$ Dollars (per one way trip per bus)

This would be the money (in dollars) saved by one CUE bus per trip which is about 23%. Table 8 below, which was derived from the Fairfax city’s CUE bus schedule, shows the total number of fleets per week. Normally the city has the service operations of two routes (Green and Gold), but the analysis and the results presented in the previous chapters of this research had combined two routes together due to the lack of accurate data, the table also show both Green and Gold route’s combine fleet size.

Hence the total operating cost that could be saved per with the new route selection will be:

Cost Reduction per Week (CRW) = Total Trips/Week * $OC_r = 312 * 24.78$ ($)

$= 7731.36$/week

So this would be the estimated operational cost per week that could be saved by the new routes which was obtained by eliminating some of the bus stops which were considered to be superfluous on the basis of nearest facility analysis with the benchmark of 800 m walking distance.
Table 8: Total weekly fleet size (Gold and Green route combined). Source (CUE, 2010).

<table>
<thead>
<tr>
<th></th>
<th>Total weekdays (Mon-Thur)</th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
<th>Total Trips (Per Week)</th>
</tr>
</thead>
<tbody>
<tr>
<td># of trips (one</td>
<td>116</td>
<td>30</td>
<td>11</td>
<td>7</td>
<td>164</td>
</tr>
<tr>
<td>direction)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of trips (opposite direction)</td>
<td>104</td>
<td>26</td>
<td>11</td>
<td>7</td>
<td>148</td>
</tr>
<tr>
<td>Total Trips (per week)</td>
<td>220</td>
<td>56</td>
<td>22</td>
<td>14</td>
<td>312</td>
</tr>
</tbody>
</table>

5.3. Emission Reduction

With the use of equation (9) and emission factors available for the diesel buses with respect to its speed in table 4, calculation of overall green house gas emission and the total amount of these gases that could be saved via new route will be straightforward as well.

For the old route with the initial cruise speed of 13 miles/hr (equation 8), the emission factors (CO, VOC and NOx) (Table 3) and the emission values are shown in table 9 below.

Table 9: Emission for a CUE bus per one way trip, Old Route.

<table>
<thead>
<tr>
<th></th>
<th>Speed (miles/hr)</th>
<th>Emission factor (grams/mile)</th>
<th>VMT (miles)</th>
<th>Total Emission (grams)</th>
<th>Total Emission (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>13</td>
<td>21</td>
<td>26.65</td>
<td>559.65</td>
<td>1.24</td>
</tr>
<tr>
<td>VOC</td>
<td>13</td>
<td>1.82</td>
<td>26.65</td>
<td>48.61</td>
<td>0.11</td>
</tr>
<tr>
<td>NOx</td>
<td>13</td>
<td>20.55</td>
<td>26.65</td>
<td>547.60</td>
<td>1.20</td>
</tr>
</tbody>
</table>
Now the new bus route travel time which consists of only 68 bus stops can be obtained from equation 11, which is 1.16 hr. Hence the cruise speed for the CUE bus at that travel time will be,

\[
\frac{\text{VMT}}{1.6 \text{ miles/hr}} = \frac{26.65}{1.16} \approx 17 \text{ miles/hr}
\]

Consequently, for the new CUE bus route with the cruise speed of 17 miles/hr, the emission factors (both VOC and NOx) (table 4) and the emission are shown in table 10.

As it was expected, the new bus route with less number of bus stops has reduced the emission. With the new CUE bus route, CO has decreased by 34%, the VOC by 18% and NOx by 10% per one-way trip.

**Table 10**: Emission for a CUE bus per one way trip, New Route.

<table>
<thead>
<tr>
<th></th>
<th>Speed (miles/hr)</th>
<th>Emission factor (gram/mile)</th>
<th>VMT (miles)</th>
<th>Total Emission (grams)</th>
<th>Total Emission (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>17</td>
<td>14</td>
<td>26.65</td>
<td>373.1</td>
<td>0.82</td>
</tr>
<tr>
<td>VOC</td>
<td>17</td>
<td>1.55</td>
<td>26.65</td>
<td>41.3075</td>
<td>0.09</td>
</tr>
<tr>
<td>NOx</td>
<td>17</td>
<td>18.51</td>
<td>26.65</td>
<td>493.2915</td>
<td>1.08</td>
</tr>
</tbody>
</table>

So with an average of 312 trips per week (Table 8), the bus would make about 14976 trips per year and the emission would be reduced by 6277.64 lb for CO, 240.58 lb for VOC and 1789.45 lb for NOx. Table 11 below shows the emission reduction per year with new route and figure 9 shows the graphical representation of the data.
Table 11: Emission Reduction Per Year with New Route

<table>
<thead>
<tr>
<th></th>
<th>Old Route</th>
<th>New Route</th>
<th>Emission Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (lb)</td>
<td>18570.24</td>
<td>12292.60</td>
<td>6277.64</td>
</tr>
<tr>
<td>VOC (lb)</td>
<td>1601.55</td>
<td>1360.97</td>
<td>240.58</td>
</tr>
<tr>
<td>NOx (lb)</td>
<td>18042.03</td>
<td>16252.57</td>
<td>1789.45</td>
</tr>
</tbody>
</table>

Fig 8: Emission Reduction between the old and new route per trip
5.4. Possible Alternatives

As results achieved in this research thus far are based on only one scenario of total number of removed bus stops, this section will examine some possible alternatives. It is probably not a realistic approach to remove almost half of the bus stops without examining other alternative. This section, hence, will present the costs and benefits in the new route depending on the selection on the number bus stops to be removed.

Fig 10 below shows the tradeoff between the number of removed bus stops and the percentage of total population coverage within the 800 m walking distance threshold. From the previous section, it was estimated that even by dropping 53 bus stops from the
current CUE bus route, 89% of population coverage was maintained. Additionally, by adding 3 extra bus stops, i.e. eliminating 50 stops, the coverage jumped to 99%. So eliminating less than 50 bus stops from the route will have at least 99% of the total population coverage.

Similarly, Fig 11 shows the tradeoffs between emissions (CO, VOC and NOx) and number of dropped bus stops. With the consideration of previous section, the range of number of eliminated bus stops was between 0-53. Interestingly enough, VOC appears to be showing a straight line trend with almost no slope. This suggests that changes in VOC with respect to dropped bus stops are not that significant. The two emission agents, CO and NOx, on the other hand do show gradual decrement as the number of dropped stops increased. These emission decrements for both CO and NOx appears to have similar trend up to 30 dropped bus stops; after which increment in the number of dropped bus stops seems to yield different decrement trends. As the number of dropped bus stops increases more than 30, NOx appears to show more steady decrement trend whereas CO demonstrate sharp drop off in its emission. This suggests that, compared to other two emission agents, CO emissions are more sensitive towards the number of dropped bus stops, especially if it is more than 30.
The graph between the annual operational cost reductions with respect to number of dropped bus stops (Fig 12) is illustrating a linear graphical trend. This suggests that if all the current bus stops were kept, it would not reduce any operational costs and from that point, any number of bus stop reductions would also reduce the total operational cost. This was an expected result as every dropped bus stop would improve the overall speed of the bus fleet and the transit operational costs are based on travel time.
Table 12 below summarizes the effects on population coverage, travel time reduction and emissions reductions with respect to the total number of dropped bus stops. This table would provide a better picture on the costs and benefits associated with the bus stops and be helpful to understand the effects if different number of bus stops were picked to remove.
**Fig 12:** Annual cost reduction with dropped bus stops

**Table 12:** Effects of dropped bus stops on population, travel time, annual cost reduction and emissions.

<table>
<thead>
<tr>
<th>No. of Stops dropped</th>
<th>Population Coverage (%)</th>
<th>Annual Cost Reduced ($)</th>
<th>Travel time reduction (mins)</th>
<th>Emission (lb/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CO</td>
</tr>
<tr>
<td>53</td>
<td>89</td>
<td>407517.59</td>
<td>29</td>
<td>12292.60</td>
</tr>
<tr>
<td>50</td>
<td>99</td>
<td>384450.56</td>
<td>27</td>
<td>13610.76</td>
</tr>
<tr>
<td>30</td>
<td>99</td>
<td>230670.34</td>
<td>16</td>
<td>16896.57</td>
</tr>
<tr>
<td>20</td>
<td>99</td>
<td>153780.22</td>
<td>11</td>
<td>17508.31</td>
</tr>
<tr>
<td>10</td>
<td>99</td>
<td>76890.11</td>
<td>5</td>
<td>18065.10</td>
</tr>
<tr>
<td>5</td>
<td>99</td>
<td>38445.06</td>
<td>3</td>
<td>18325.16</td>
</tr>
<tr>
<td>0</td>
<td>99</td>
<td>0.00</td>
<td>0</td>
<td>18472.43</td>
</tr>
</tbody>
</table>

|                      |                         |                         |                             | VOC              |
|                      |                         |                         |                             | 1360.97          |
|                      |                         |                         |                             | 1402.32          |
|                      |                         |                         |                             | 1506.39          |
|                      |                         |                         |                             | 1543.10          |
|                      |                         |                         |                             | 1576.50          |
|                      |                         |                         |                             | 1592.11          |
|                      |                         |                         |                             | 1600.94          |

|                      |                         |                         |                             | NOx              |
|                      |                         |                         |                             | 16252.57         |
|                      |                         |                         |                             | 16549.06         |
|                      |                         |                         |                             | 17280.78         |
|                      |                         |                         |                             | 17589.71         |
|                      |                         |                         |                             | 17870.89         |
|                      |                         |                         |                             | 18002.22         |

|                      |                         |                         |                             | 18076.59         |

As mentioned above, the purpose of this section was to illustrate other possible tradeoff alternatives, and show the benefit (in terms of emissions and cost reduction) and
cost (in terms of lost coverage) with respect to the dropped bus stops. The possible alternative tradeoffs in this section are based on the 800m walking distance to the bus stops threshold. Similarly any block data within the proximity of the route with no population were also not considered in the analysis. Inclusion of these blocks as well as other walking distance scenarios might yield in different outcome. That said due to the lack of detail information and time constrains, these would be something to explore in future research. This research however will continue to analyze further social tradeoffs based on 53 dropped bus stops.
CHAPTER 6
TRADEOFFS

This chapter will go in detail on the characteristics of the bus stops that were left out from the current CUE bus route and also would perform a demographic analysis on who would be the people that will be affected with the new route.

6.1. Dropped Stops
The bus stops that were left out from the current route are identified further in to four broad categories: Residential, Commercial, Shopping and Park/Recreational. Stops which are in the proximity of housing/apartments are considered residential stops. Similarly, stops close to major commercial landmarks such as restaurants, banks, metro stations, schools, etc are considered commercial. Bus stops closer to various shopping centers are grouped into shopping categories and finally, bus stops which are within an immediacy of park and recreational facilities are categorized into park/recreational category.

Among the 53 bus stops that were left out from the original route, 21 of them were shopping, 15 were residential, 3 were park/recreational and 14 were commercial. This identification of bus stops was based on recent CUE bus route map and personal observations while riding a bus. Table 12 shows the tally of these bus stops.
Table 13: Categorization of dropped bus stops.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Total Stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopping</td>
<td>21</td>
</tr>
<tr>
<td>Residential</td>
<td>15</td>
</tr>
<tr>
<td>Park/Recreation</td>
<td>3</td>
</tr>
<tr>
<td>Commercial</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
</tr>
</tbody>
</table>

Similarly, out of 68 bus stops that have been used for the new route, 35 were residential, 10 were shopping, 3 were park/recreational and 20 were commercial. Table 13 below shows these categories.

Table 14: Categorization of used bus stops.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Total Stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopping</td>
<td>10</td>
</tr>
<tr>
<td>Residential</td>
<td>35</td>
</tr>
<tr>
<td>Park/Recreation</td>
<td>3</td>
</tr>
<tr>
<td>Commercial</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>68</td>
</tr>
</tbody>
</table>

Looking further into the categories of bus stops that have been dropped, only 68% of stops which were categorized as shopping were eliminated. Furthermore, only 30%
and 41% of residential and commercial stops were dropped in the new route respectively. Finally 50% of park/recreation stops were also removed for the final route. This result suggests that the highest impact in the ridership with the new route would be to those people who go out for shopping. Less shopping stops means that now people will have to walk further than they used to before and might not consider taking a bus on a shopping trip, even though the nearest stop would be within 800 m radius. Having said that, it’s highly unlikely that average American families take a public transit to go on shopping; hence the removal of a high percentage shopping stops might not be too significant as it appears.

6.2. Coverage

The coverage on residents in terms of their demography is carried out on people who live within the proximity of the bus stops which are removed in the new route. Furthermore, this will also be the people who will be most affected by the new route as now they have to walk further than they used to. The analysis carried out in the previous chapter of this research assumed 800 m to be the maximum walking distance for the passengers willing to walk to access the bus stops (Saka, 2001). That said the passengers who now have to walk more than they used to might not feel comfortable with this longer walking distance. Hence it is important to capture these passengers, their total population and demography, who are most likely to be affected by the removal of their closest bus stops.

One of the difficult aspects of capturing the residential population who lives within the immediacy of the removed bus stops would be to determine the distance of
proximity between the bus stop and the population center. Similar researches in the past have used various estimated values for these distances of proximity. Murray (2003) stipulated that 400 meters would be an ideal buffer distance for a city area to convey the effect of bus stop removal. Other approaches have taken into account the population density on determination of effective distances between bus stops and population center and furthermore suggested that for a city area, like Fairfax City, the suitable distance would be between 200 to 300 meters (Ziari et al., 2007). Hence for this research 300 meters of the buffer region, which would be the middle ground between 200 and 400 meters, was chosen to capture the population which would be most likely to be affected with the removal of the bus stop. It is important to bear in mind that this would be the worst case scenario assuming that all the passengers living within the 300 m around the removed bus stops will consider themselves not taking the bus services.
Fig 13: 300 m buffered around removed 15 residential bus stops.
Removal of bus stops which were categorized as shopping, park/recreational and commercial equally affects the population around them if they were removed, however it doesn’t reflect the direct effect of population coverage as all the other category of bus stops doesn’t have population center associated with them. Hence consequence of the removal of the bus stops on the demography of the population coverage from the original route is only carried out on the 15 removed residential bus stops (see table 12). Fig 10 shows the 300 m buffered around 15 residential bus stops which were removed.

6.3. Demography

The coverage analysis done in the previous section with the 300 m accessibility buffered around the removed 15 residential bus stops (see figure 10) showed direct impact on the 21 population center which is approximately 8.3% of the total existing population center. Furthermore, this will impact 1315 household with 3588 resident living there which is around 10.5% of the total household as well as population within the Fairfax City.

The demographic analysis on the residential population was further broken down into various racial groups living within the proximity of the removed bus stops. This would highlight which group of people would end up enduring maximum impact if this new route were to be placed. The group of people that would be most affected by the removal of the residential bus stops would be Caucasians which comprise about 57% of the total residential population. Similarly, Hispanic and Asian population represents around 20% and 15% respectively towards the total resident population. African American represents one of the least affected groups of people with about 5% of the total
population. Other groups including Native Americans and Hawaiians cover the remaining 3% of the population. Table 13 shows the actual size of these various racial groups along with the total household and population. Similarly figure 10 shows the graphical breakdown of the percentage of all the ethnic groups.

To validate the removal of these residential bus stops, it is also important to understand how the demography of residents living within the proximity of dropped bus stops is represented compare to the demography of the total population. It would be impractical if majority of removed bus stops represent only a certain group of people who never take a public transit. Hence it has to show similar demographic representation to that of overall potential riders. To examine this comparison, demography of overall residents living within the proximity of the bus stops were obtained (shown in table 16). Additionally, the demographic percentage representing each racial group of the total population is also shown in figure 15 below. The comparison of demography between residents living around the dropped bus stops and the total resident are showing similar percentage representation on their respective racial group’s breakdown. The Caucasians represent the majority of the population (57% and 60%). Similarly, comparison among other racial groups such as Hispanic (20% and 14%), African American (5% and 7%), Asian (15% and 16%) etc are also showing extreme similarities in their demographic representation. This indicates the viability on removing mentioned 15 residential bus stops based on the representation of racial group living within its proximity being similar to that of total population.
Ideally, these numbers reflect the impacts on the overall population living around the removed bus stops; in reality however, it could be misleading. According to the National Household Survey (2001), only 5% of the total population takes any sort of public transit and even though Fairfax City has a good public transit infrastructure compare to the rest of the country, it would be highly unlikely to have significantly higher transit ridership compare to other part of the country. Thus the total population impacted by the new route would be much less than what it is showed right now and would be something to explore in further researches.

Table 15: Demography: Remove bus stops.

<table>
<thead>
<tr>
<th># of population center</th>
<th>Total Population</th>
<th>Total Household</th>
<th>Hispanic</th>
<th>Caucasian</th>
<th>African American</th>
<th>American Indian and Alaska Native</th>
<th>Asian</th>
<th>Native Hawaiian</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>3588</td>
<td>1315</td>
<td>737</td>
<td>2057</td>
<td>16</td>
<td>16</td>
<td>533</td>
<td>9</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 16: Demography: Total Resident Population.

<table>
<thead>
<tr>
<th># of population center</th>
<th>Total Population</th>
<th>Total Household</th>
<th>Hispanic</th>
<th>Caucasian</th>
<th>African American</th>
<th>American Indian and Alaska Native</th>
<th>Asian</th>
<th>Native Hawaiian</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>251</td>
<td>34024</td>
<td>12465</td>
<td>4833</td>
<td>20539</td>
<td>2247</td>
<td>79</td>
<td>5355</td>
<td>35</td>
<td>936</td>
</tr>
</tbody>
</table>
Fig 14: Demography of resident living within the proximity of removed 15 residential bus stops.

Fig 15: Demography of the total resident population living within the proximity of the bus stops.
CHAPTER 7

CONCLUSION

With the performed analysis of excess bus stops, their travel time improvements and results, the current CUE bus route, Green and Gold combined, appear to have 40% redundant stops with the standard walking distance of 800 m to the bus stops. The proposed new route, without these superfluous bus stops, was still able to maintain the service area coverage of 84% along with 88% of total population and household coverage. Elimination of these extra facilities also improved the travel time by 23%, which resulted in 29 minutes faster travel time in the entire one-way trip. Faster trip also consequently triggered higher frequency of bus flow and result in less waiting time for the passengers at the bus-stops. As the lack of flexibility and slowness being the key reasons for passenger declination in the U.S.’s public transit system, improvement of 23% in travel time would definitely uplift the ridership.

Transit passengers are indeed sensitive towards comfort and convenience enhancements (Phillips, Karachepone and Landis 2001, Litman 2004; Litman 2008; Department of Transport, 2010). It is fairly obvious that improvement in the bus transit travel time would appear more attractive to passengers. That said it will also be informative to express these improvements into some numeric representation. Knowing
the elasticity between improve travel time verses the gain of ridership would provide better picture on understanding the effect of these improvements. There are many examples presented by researches to deal with this very scenario (Evans 2004; Wall and McDonald 2007; Litman 2008). Balcombe et. al. (2004) calculated the elasticity between bus transit travel time improvement and the ridership in the urban areas of London, UK, to be between – 0.4 to -1.7. Similarly, case study done by Dowling et. al. (2005) in Portland, Oregon estimated the very elasticity to be – 0.129. These numbers implies that every unit decrement in travel time would result in ridership increment by the elasticity unit. These elasticity values will vary based on the various journey attributes such as: user type, journey purpose, type of region (urban, sub-urban) etc (Balcombe et. al., 2004). Hence there is no single way to accurately predict or estimate a single elasticity value between the travel time and ridership in Fairfax City. So this research, therefore, will examine range of elasticity values suggested in the literature to obtain the range of ridership increment based on the 23% improvement in the travel time achieved by the new route. Additionally this range will put forward the best and the worse case scenario in terms of gain in ridership with the new route in the CUE bus system.

With the range of elasticity values, -0.129 to -1.7, the possible gain of ridership for the new route would range between 3% and 40%. This means with 23% travel time improvement, the new route would at least be able to gain the ridership by 3%. Similarly, in the best case scenario, the new route would up lift the ridership by 40%. As mentioned earlier, it difficult to predict a single elasticity value for the CUE bus system without in depth knowledge of the transit system and the behavior of people who uses it. Hence by
taking more conservative approach and selecting the middle value for the ridership
elasticity (-0.91), the new route with 23% of travel time improvement would yield in
possible 21% increment in ridership.

Similarly with the new proposed route with 23% of travel time efficiency, the
operating cost for each one-way trip will also be reduced by 23%. With the older route,
the operating cost was around $1604529 per year whereas for the new route, the cost for
the similar scenario would be $1233573 per year. Hence on an average, a new route
would save about close to $370956. This is the money that the CUE bus service
authorities would save on their bus operating cost, not to mention other monetary
benefits they would have by not having to maintain the bus stops which will be removed
as well as revenue they might get by attracting possible 21% more passenger with the
new efficient, in terms of travel time, route. Furthermore, with the healthy savings, they
could use that money to improve the other aspect of transit services such as: fare
reduction or better bus stop facilities to attract more passengers.

Beside the financial benefits that the CUE bus authorities would get by the new
route, they would also be able to lend their hands on saving the environment. With the
new route, they will be able to reduce the greenhouse gases emission, CO, VOC and
NOx, by 34%, 18% and 10% respectively. On an average, with the new route, the bus
transit would be able to reduce 6277.64 lb of CO, 240.58 lb of VOC and 1789 lb of NOx
per year. For year 2008, the total amount of on road vehicle emission nationwide for CO
was about 38 million tons, for VOC about 2.5 million tons and for NOx about 4.2 million
tons (EPA, 2009). With these mammoth numbers, the reduction of emission with the new
route for CO, VOC and NOx might not seem too significant compared to the average emission nationwide, however for its scale and population size, 34%, 18% and 10% emission reduction in CO, VOC and NOx respectively within the Fairfax City would be quite significant. Besides that, although the CO$_2$ emissions were not included as part of this research, looking at the ratio of reduction in CO, VOCs and NOx, CO$_2$ emission, most likely, would also exhibits the similar reduction trend. Furthermore with benefits such as faster fleet services with reasonable service coverage and reduction in fleet operational costs, any amount of emission reduction would be a bonus towards the overall transit improvement.

In spite of all the advantages such as: faster services, financial benefits and environmental improvements, the new route could possibly bring discomfort to some residential passengers. Among the bus stops which were left out from the original route, 15 of them were identified as residential stops which might have direct impact on people living within the proximity. With the 300 m radius coverage of assumption, the 15 removed bus stops covered around 10% of the total population and removal of these stops might directly affect those people. Looking at these numbers, it does shows that handful of people will be directly affected by the new route, however looking at the other benefits the new route brings about, this tradeoff might be beneficial.

In summary, this research, with the use of tools such as: Network Analyst and Closet Facilities, was able to discriminate, to some extent, some of the superfluous bus stops in the current CUE bus system while maintaining reasonable service coverage. With the utilization of only 57% from the existing bus stops, around 83% of the service
area and 89% of the total population was covered by the new route. Furthermore, this improvement enhanced the travel time by 23%, cut down the transit expenses also by 23% as well as reduced the total emissions, CO, VOC and NOx, by 34%, 18% and 10% respectively. Hence, with these results, one could conclude that there are some superfluous bus stops in the current CUE bus route and eliminating them not only will improve the transit system but will also save some money to the transit operational bodies as well as reduces the transit based emissions. Looking at the flip side of it however, elimination of these stops, especially the ones in the residential area might affect the people living in the proximity of the stop. Beside residential stops, other facilities such as commercials, park/recreational, shopping, which were not included in this research, will also yield in indirect effect on the population if they were to be removed. So more accurate information on these stops in the future research might suggest the outcome of this research otherwise. That said based on the analysis and results achieved by this research, it could certainly conclude that there are some superfluous bus stops present in the current CUE bus system in Fairfax City, VA. Furthermore, removing these bus stops would certainly improve the travel time efficiency while maintaining good service coverage. And finally these changes would also be beneficial in terms of reducing the overall transit based emissions and operational costs.
CHAPTER 8

FUTURE DIRECTIONS

Due to the limitations of the available data and scarcity of time to complete within the scope of the research duration, this paper does have few untouched areas in which some of them might be highly significant towards the outcome. The data used for this research were 2000 census data, hence might not reflect the current population matter; hence use of more recent data in future, whenever its available, will give better picture of population coverage. Similarly, some of the block data which had no population associated with them were removed from the study area to simplify the analysis process; however, since these blocks could be a major service areas like: shopping malls, hospitals, grocery store etc, inclusion of these parcel in the future analysis might present more realistic results.

The current CUE bus system has two routes: Gold and Green; however, to be consistent with other data such as: operating cost and emission data which were for the entire route, both routes were combined as a single route. Thus, when more detailed data is available, performing separate analysis on each route in future work would be beneficial in achieving more accurate results. And also representing a measure of efficiency in terms of accessibility to the significant places like: job opportunity, metro
stations, schools, hospitals, post-offices, grocery stores etc would also be something to look at in future researches.

Similarly, eliminating almost half of the existing bus stops might not be a realistic approach to undertake. The chief reason for this high number might be due to the lack of population information on some of the block level data. With the data utilized in this research, city blocks such as parks, schools, shopping centers, metro stations etc, don’t have any population associated with them. Hence bus stops which are in the proximity of these blocks were considered unutilized based on the lack of association with the population center. In future research, with more accurate data, identifying and including these stops might not only provide realistic approach to categorize the bus stops to be eliminated, but might also generate more accurate tradeoffs estimations.

This research on identifying the bus stops to eliminate from its current route was based on “no-restriction” toward the maximum number of stops allowed to be removed. In some cases however, there might a restriction on the number of bus stops that can be dropped. In this case, the most important subject is to recognize which bus stops to drop in order to achieve near optimum result. In this case, conducting a research only based on the threshold of walking distances and utilizing only the blocks with population might not provide accurate analysis. One approach would be to rank all the bus stops based on its weighted service area coverage. Service areas would include not only block centroid points with population, but also the ones with on population such as school, park, shopping etc. Furthermore bus stops which are associated with large population service areas would get larger weight, hence will rank higher. Finally, with the walking distance
to the bus stop threshold, lower ranked bus stops which are further away from the service areas would be the ones, based on the maximum allowed number, to be dropped. This is only one plausible approach when there is a limit on how many bus stops are allowed to eliminate. That said there are limitations to this approach which might yield in eliminating bus stops which are significant to the route. By only looking at the ranked value on the bus stops, this method would fail to recognize the case if most of the bus stops with high rank value are clustered only on a segment of the route. Additionally, in this situation, the ranked method would keep all the clustered bus stops hence would fail to improve the efficiency of the travel. This drawback of the rank method could be minimized by adding a step in the method to keep track of neighboring stops while ranking the bus stop. This is just a suggestive approach, in future, with additional information on bus stops and service areas, better approach might be possible.

During the emission calculation, due to the insufficient information on other greenhouse gases such as CO2 where not included. Only emission factors (with respect to the speed of the vehicle) which was available to calculate the emission were for CO, VOC and NOx, hence this research only utilized these emission entities to evaluate the effect of emission in the new route. Hence, in near future, when the data is available to estimate other greenhouse gases with respect to the improvement of bus speed, much more accurate result could be achieved in terms of emission reduction.
REFERENCES


http://www.eia.doe.gov/emeu/international/prices.html#Motor.

El-Geneidy, Ahmed, James Strathman, James Kimpel, and David Crout. “Effects of Bus 
Stop Consolidation on Passenger Activity and Transit Operations.” *Transportation 

El-Shair, Issa M. “GIS and remote sensing in urban transportation planning: A case study 
of Birkenhead, Auckland.” Paper presented at the 6th annual international conference on 
map India, 2003. 


EPA. “MOBILE6 Inventories and Documentation: Appendix B.” Accessed November 

ESRI. “Download Census 2000 TIGER/Line Data.” Accessed July 11, 2009, 
http://arcdata.esri.com/data/tiger2000/tiger_download.cfm

Evans, John E. “TCRP Report 95: Transit Scheduling And Frequency - Traveler 
Response to Transportation System Changes.” *Transportation Research Board* 2004. 
http://www.trb.org/Main/Blurbs/Transit_Scheduling_and_Frequency_Traveler_Response _154748.aspx

Fairfax. “CUE Bus Map and Schedule.” Accessed December 15, 2009, 
http://www.fairfaxva.gov/cueBus/Routes_Schedules.asp

Fitzpatrick, Kay, Dennis Perkinson, and Kevin Hall. “Findings from a survey on bus stop 

Fujii, Satoshi, Tommy Garling, and Ryuichi Kitamura. “Change in Drivers’ Perceptions 
and Use of Public Transport during a Freeway Closure: Effects of Temporary Structural 
Change on Cooperation in a Real-Life Social Dilemma.” *Environment and Behavior* 33, 
no.6 (2001): 796–808.


CURRICULUM VITAE

Ranjay Man Shrestha was born in Kathmandu Nepal. He graduated from Campion Academy in 1999 and also completed his Bachelor of Science in Computer Applications from Campion Kathmandu College in 2003, Kathmandu, Nepal. To continue his studies, he came to the U.S. in 2004 to pursue his further education. Ranjay completed his undergraduate degree with double major in Bachelor of Engineering in Computer Science and Bachelor of Science in Geography Information Science (GIS) along with minor in Mathematics from the University of Idaho, Moscow, Idaho in 2008. During his undergraduate study, he enhanced his educational knowledge by working in numerous teaching and scientific research jobs. He worked as a math tutor (University of Idaho Math Center, 2004-2006), computer science assistant (University of Idaho Computer Science Department, 2005-2006) and GIS teaching assistant (University of Idaho Geography Department, 2007-2008) helping student in their math, computer science and GIS classes respectively. These experiences not only helped him to understand the subject matter better, but also gave him a good practice on teaching and interacting with students. He was also involved in a scientific research with Dr. Gary Daughdrill (University of Idaho MMBB Department, 2006-2007) as a research assistant where he was responsible for computerized simulation of protein analysis. This yielded in Ranjay’s first publication, a modeling and analysis of protein 53 in the journal PROTIENS. During the summer of 2007, he did an internship as a GIS Technician at the Coeur d’Alene Tribe, Plummer, Idaho. There he was involved in collecting and analyzing remote sensing data to access the accuracy of the LiDAR remote sensing system. In fall 2008, Ranjay enrolled in the graduate program in George Mason University for Master of Science Geography and Cartographic Science. During his master’s degree pursued, he worked as a research assistant for George Mason Parking and Transportation Department (2008-2010) under Dr. Edmund Zolink. His involvement in the research was to facilitate on brining sustainability in campus transportation by conducting surveys on behavior of people towards choosing their mode of transportation. Ranjay has recently (2010-2011) completed a project for Fairfax County to perform their greenhouse gas inventory under Dr. Dann Sklarew. For this project, he was primarily responsible for obtaining data and calculating emissions for mobile sources within the county. He is presently working at the Center for Spatial Information Science and Systems (CSISS), George Mason University, on web applications for The Global Earth Observation System.