Transit planning and social equity: A comparative analysis in West Seattle

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Abstract

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In today's financially constrained environment, public transit agencies face difficult decisions about how to allocate transit infrastructure and service in order to balance competing priorities including geographic coverage, social equity, and maximizing ridership and/or efficiency. Increasingly, some agencies are choosing to reallocate resources towards high quality, frequent service networks with high ridership potential, and away from routes with low productivity. While this type of network restructure has the potential to significantly improve mobility and the quality of transit experience for many citizens, some riders and geographic areas may be negatively affected.

This study set out to compare the social equity implications of a hypothetical network restructure oriented around reallocating transit service on low-productivity routes to higher productivity routes in Seattle's West Seattle neighborhood. I developed a hypothetical scenario (Scenario 2) using the productivity measures that King County Metro applies to all routes in the transit system, and compared the results to current service (Scenario 1). Social equity impacts were evaluated by examining the change in transit service, measure by total weekly trips, for several population groups that are likely to experience a disadvantage in transportation. These groups included households below poverty, population over 65 years of age, population under 18 years of age, and people of color. Zero car households were also examined, though this variable was considered separately.

The comparative analysis found that for four out of the five population groups studied, Census tracts in the study area with higher than average densities of those groups of

experienced even greater benefit from the high-productivity network structure (Scenario 2) than the tracts with lower concentrations. The exception was tracts with a high percentage of people over 65 years of age; these tracts still gained service but to a lesser degree than tracts with a low percentage of population over 65. In general, these findings suggest that there may be positive social equity impacts from a transit network structure that emphasizes productivity over geographic coverage. However, several census tracts with above average concentrations of the transport-disadvantaged populations studied did experience negative outcomes. Negative impacts to these "high-impact, high-disadvantage" areas could be avoided using a more complex restructure design, and/or mitigated through innovative programs to provide alternatives to fixed-route transit service.

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1 Introduction

1.1 Study Context

In today's financially constrained environment, public transit agencies face difficult decisions about how to allocate transit infrastructure and service. In the Puget Sound region, declining revenue in recent years has forced significant cuts to service combined with fare increases. In King County, WA, the primary transit service provider, King County Metro Transit (Metro) has deferred planned service expansions, cut capital programs, and raised fares 4 times in as many years, and eliminated over 100 staff positions. Thanks to a temporary funding measure passed by voters in the fall of 2011, the agency was able to stave off an additional 30% cut to service. (King County Metro 2012a)

For many agencies, including Metro, this recent financial hardship has forced reevaluation of policies governing service allocation and investment. In 2011, the agency adopted the *Strategic Plan for Public Transportation 2011-2021*, (King County Metro 2011a) and along with it, revised service guidelines. The new service guidelines replaced a geographic equity approach known as 40/40/20 (whereby service hours were distributed between subareas within the County according to this pre-determined formula) with a new strategy designed to emphasize productivity and social equity. The revised service guidelines employ a set of indicators measuring productivity, social equity, and geographic value, with productivity indicators weighed 50% and the other two 25% each. These indicators are explained in the 2011 Revised Service Guidelines Report as follows (SG-1):

- **Productivity indicators** "demonstrate market potential of corridors using land use factors of housing and employment density."
- **Social Equity indicators** "provide an evaluation of how well corridors serve concentrations of minority and low-income populations by comparing boardings in these areas along each corridor against the systemwide average of all corridor boardings within minority and low-income census tracts. "

- **Geographic Value indicators** “establish how well corridors preserve connections and service throughout King County.”

The selection of these three indicator categories highlights the challenge transit agencies face in balancing policy goals that each carry unique (and at times conflicting) implications for service allocation.

Increasingly, some agencies are choosing to reallocate resources towards high quality, frequent service networks with high ridership potential, and away from routes with low productivity. TransLink, the transit service provider in Vancouver, Canada, refers to this process as “service optimization”. Since implementing a service optimization regime in the Fall of 2010, the agency has reallocated over 170,000 service hours from low-productivity routes to high-productivity routes. The result has been a 3.1% increase in productivity and a 5% increase in ridership (TransLink 2012). A similar service optimization initiative was launched by New Jersey’s transit agency, where savings from discontinuation and reduction of service along underutilized routes are planned for reinvestment in higher productivity routes and restructures (NJ TRANSIT 2012).

Building the frequent service network may include significant infrastructure investment, including upgrading the level of service and transit technology to forms of high-capacity transit such as light rail or rapid bus. Such upgrades in service quality to portions of the transit network often require restructuring of local service provision and, given constrained resources, may result in the loss of low-ridership routes that provide geographic coverage, convenient one-seat rides, or one-way peak service. While this type of network restructure has the potential to significantly improve mobility and the quality of transit experience for many citizens, there will undoubtedly be people for whom transit service quantity or access is reduced. Transit agencies have both a legal and an ethical obligation to consider the distribution of these costs and benefits.

1.1.1 Transport Disadvantage and Social Exclusion

This study explores the potential effects that shifting transit service away from low-productivity service and towards the “frequent service” network might have on communities that have a historical, demographic, or economic disadvantage in transportation and are therefore more reliant on the public transit network. Transport disadvantage has been studied in a number of contexts, particularly in relation to the broader topic of social exclusion and disadvantage (Kamruzzaman and Hine 2012; Delbosc and Currie 2011b; Diana 2004; Hine 2003; Currie et al. 2009; Cervero and Tsai 2003). Social exclusion generally refers to a factors - beyond poverty alone - that prevent individuals from participating in what Burchardt (2000) has called “normal activities” that they would like to participate in (Church, Frost, and Sullivan 2000; Hine 2003; Delbosc and Currie 2011a). Transportation systems have the potential to either “facilitate social inclusion or exacerbate social exclusion” (Delbosc and Currie 2011a, 556). Research on how transportation systems influence social exclusion has therefore evaluated social exclusion and transportation, particularly the spatial and demographic groups that experience additional social exclusion because of limited transportation options, as well as the transportation strategies that could reduce exclusion.

There are a number of mobility barriers that certain groups are more likely to encounter, giving them a disadvantage in the transportation arena. This paper identifies only a handful of factors that may contribute to transport disadvantage – including poverty, age, race, and car ownership. Further discussion on the process for selecting these characteristics and literature on transport disadvantage is found in Chapters 2 and 3. For now, it is important to understand that a change in the public transportation system has the potential to have both positive and negative impacts on the relative transport disadvantage of different population groups. Therefore the proposed comparative analysis between two transit service scenarios – “current service” and a reallocation of service towards a hypothetical “frequent network” allows for an investigation of the potential overall effects and mapping of their distribution among transport disadvantaged populations. The discussion briefly introduces potential mitigation alternatives for the transport disadvantaged communities that are found to lose transit service.

1.1.2 Transit Policy in Seattle

The city's current diesel and trolley bus network developed over the course of many years, with some routing dating back to the original streetcar system from the early 1900s. Seattle's original streetcar network was dismantled and replaced with a rubber-tired transit system between 1939-1942, after which point the bus system was known as the Seattle Transit System (Blanchard 1968). Between 1972 and 1994 a new, countywide system operated by the Municipality of Metropolitan Seattle (Metro) replaced the Seattle system and suburban service operating in other parts of the county. Some of the existing route structure within the City of Seattle was preserved during this changeover. When the governance structure of the Municipality of Metropolitan Seattle was found to be unconstitutional in 1992, responsibility for the transit system was transferred to King County. Around this time, King, Pierce, and Snohomish Counties formed the Regional Transit Authority, (today Sound Transit) which is responsible for transit service that provides important regional connections.

Transit service provision in the Puget Sound region now involves multiple jurisdictions including cities, counties, and regional planning organizations. King County Metro (Metro) is the primary transit service provider in Seattle, although Sound Transit (ST) also plans, builds, and operates vital regional service including express buses, commuter rail and light rail. The City of Seattle owns and operates the South Lake Union Streetcar and the planned First Hill Streetcar. The Puget Sound Regional Council (PSRC), while not a transit service agency, undertakes transportation planning and distributes funding as the Puget Sound region's official Metropolitan Planning Organization (MPO). To the extent possible, these agencies coordinate strategic transportation planning. PSRC's *Transportation 2040* (Puget Sound Regional Council 2010) and the Seattle Comprehensive Plan, *Toward a Sustainable Seattle* (City of Seattle 1994) both outline a regional growth strategy, which in turn shapes the development of transit planning documents such as Seattle's recently updated *Transit Master Plan* (City of Seattle Department of Transportation 2011) and King County Metro's *Strategic Plan for Public Transportation 2011-2021* (King County Metro 2011a). The latest versions of the TMP and Metro's strategic plan both emphasize a shift in focus towards a high-productivity frequent service network. These plans are discussed in greater detail in section 2.3: Equity in Practice: Seattle.

1.2 Proposed Research Design

This work attempts to find out what the potential equity effects might be from a shift away from transit service that emphasizes geographic coverage and local routes, towards service that emphasizes productivity and frequent service along core routes. This research operationalizes the research question by developing two transit service provision scenarios. The first, Scenario 1, represents current service patterns. Current service is the product of many historical and political factors that do not relate to achieving specific transit planning goals. However, past service guidelines did encourage a network that emphasized geographic distribution of service above productivity (King County Metro 2011a).

The 2011 King County Metro Service Guidelines represent a major shift towards emphasizing productivity over geographic coverage, in part due to the need to maximize the usefulness of declining tax revenue. The introduction of significant infrastructure upgrades in some cities, including Bus Rapid Transit or Light Rail technology, compounds the need to restructure local service and accommodate increased frequency along core routes. Scenario 2 is designed to simulate a network designed under these new principles, with reductions in service on low productivity lines reallocated towards a few core routes. In order to assess the potential impacts of moving from Scenario 1 to Scenario 2, the research question is broken into several sub-questions:

1. How should the population against which “equity” is measured be defined and identified?
2. What form might this type of shift in service provision take within the study area?
3. What and where are the impacts of moving from Scenario 1 to Scenario 2?
4. Finally, how might any negative impacts identified in subquestion 3 be mitigated through alternatives to fixed route service or would an alternative transit planning approach be better?

The first two questions are largely identified in the literature review, while the third question is the subject of the analysis, which in turn feeds into question four, addressed in the discussion portion of the thesis.

1.3 Study Purpose

The findings of this study will provide several contributions to the field of transit planning and social justice. First, the research will identify potential consequences that could result from a simple application of the overall strategies advanced in these planning documents. Although the scenario developed in this thesis is not likely to mirror the future transit network for West Seattle in terms of specific service levels on specific routes, the study design should identify a similar distribution of impacts from a service restructure according to Metro's new service guidelines. The findings may justify the "service optimization" approach that is now being used by some North American transit agencies. While there is a great body of engineering literature on system optimization to meet parameters such as operating cost and ridership, and similarly, a great deal of literature on social equity and public transit, there are currently few studies that evaluate equity in regard to a specific transit network structure and service optimization. The strength of this paper is in its comparative analysis of two contrasting approaches to transit network design, each of which includes an underlying emphasis on different visions for what the fundamental purpose of a public transit system should be.

This work also seeks to identify the areas and populations, if any, that are not beneficiaries of the increased frequencies provided in Scenario 2, and instead may become worse off. Although detailed development of mitigation alternatives is beyond the scope of this paper, several promising avenues for future study are explored. This work, while similar to the recently published study by Metro, *King County Metro Transit Five-year implementation plan for alternatives to traditional transit service delivery* (June 2012) is designed to apply specifically to urban areas, where the mitigation needs are somewhat different than those identified in the report. As cities in the United States begin replacing local, radial transit service with a frequent network that sometimes involves significant upgrades to dedicated or grade-separated Right-of-Way, the network needs to be restructured. When the quality of service increase on the frequent service network is high enough, it can provide coverage to a larger geographic area, thereby replacing a large amount of local service. If this occurs, transit agencies must find ways to ensure that the frequent service access can be quickly and easily accessed from areas that previously had their own direct service. Research in this area is just beginning.

2 Literature Review

This literature review consists of three primary components: 1) an overview of the theoretical literature on notions of equity with respect to transportation infrastructure; 2) a summary of the empirical literature on transit service structure and equity; and 3) a brief discussion of current practice for including equity in transit planning decisions in Seattle. Equity here is discussed primarily from a distributional perspective. Although there are critiques of this approach, (See Young 1990) distributional issues with regard to transit service continue to contribute to injustice and thus merit further investigation. Martens et al (2007, 684) find that: "(1) there is no clear definition, in practice or theory, of what constitutes a fair distribution of benefits from transportation investments; and (2) no standards, goals or performance measures exist, against which agencies can measure progress or success in the distribution of transportation benefits." Despite the lack of consensus, Section 2.1 of this chapter summarizes available theoretical approaches to transportation equity, while sections 2.2 and 2.3 emphasize empirical and practical approaches, including applied tools for measuring transit equity.

2.1 Theory

There is a large body of theoretical literature on the topic of equity and transportation, much of which builds on the seminal work of John Rawls, *A Theory of Justice* (Rawls 1999). Since the publication of Rawls' theories in 1971, equity planning has come to encompass an entire field of literature considering the ultimate *fairness* of planning processes (Garrett and Taylor 1999; Lucy 1988; Beatley 1988; Hay 1995). The literature on equity is immense, spanning a number of movements and theories within the field of urban planning, such as advocacy planning, equity planning, and communicative planning, as well as the broader fields of environmental and social justice, welfare economics, philosophy and others. Although the overall body of literature is quite expansive, this portion of the literature review is primarily designed to inform the methodology regarding how to identify and define equity with respect to the distribution of public transportation service. Therefore the focus of this section is a limited subset of theoretical literature that pertains directly to notions of equity in the field of public transportation, including the topics of access and accessibility and different definitions of equity in public transit.

2.1.1 Access, Accessibility and Mobility

The challenge of defining access and accessibility in transportation studies is well stated by O'Sullivan and Morrison (2010, 86): "Accessibility is generally agreed to be hard to define but critical to any serious understanding of transport issues." Kwan (1998) also finds that accessibility has been defined and operationalized in many ways, depending on context (Kwan 1998). In the broadest sense, accessibility means the ease of reaching desired activities and destinations (Litman 2011a; O'Sullivan, Morrison, and Shearer 2010; Hanson and Giuliano 2004). Accessibility therefore comprises several factors – 1) land use patterns and the spatial location of origins and destinations, 2) the transportation system allowing travel between them, and to some extent other factors such as mobility substitutes (Litman 2011a) and timing (Hanson and Giuliano 2004). The second component of accessibility is essentially *mobility*, or "the ability of people to travel over distances" (O'Sullivan & Morrison 2010, 86). Although the goal of transportation systems isn't mobility itself (trip-making) but overall accessibility, this paper focuses on service provided by transit service agencies, who are not generally involved in other components of accessibility such as land use or mobility substitutes, at least in the United States context (O'Sullivan, Morrison, and Shearer 2010).

Mobility is closely tied to *access* to public transportation. Murray (2003) identifies access as physical proximity to service and its cost, which can include both the distance to a transit stop as well as the distance to a destination. Cost can include monetary cost as well as the cost of time spent reaching transit service, waiting time, and travel time (Murray 2003). A great deal of research suggests that transit users value these different types of costs differently (Thompson 1977; Taylor and Fink 2003; Sakano and Benjamin 2011; Newell 1979). However, for the purposes of this study the term "access" is used to mean physical access to a transit stop, as this is the most easily measured variable that changes between the two scenarios. Other costs are assumed to be constant between the scenarios. Some are likely to actually be constant in practice (for example fares) while others would require complex modeling to evaluate (for example travel time costs for specific origin/destination pairs). Greater discussion of how these terms are operationalized is found in Chapter 3.

2.1.2 Equity and Equality

The previous discussion on accessibility and mobility helps to inform how well a given population or area is served by public transport. Another important question with regard to transportation equity is the fairness of the distribution of this service *between* different groups or areas. One component of this distribution comes into play during the decision-making process used to allocate service and investment - this is known as *procedural equity*. The second component emphasizes the consequences of implementing the planned service, which is known as *distributional equity*. Each of these concepts is important to understanding transit equity.

Procedural equity deals with the institutional and structural elements of a society that influence decision-making and what Beatley terms the *political equality*. Within this category are considerations such as equality of participation and meaningful access to the political process (Beatley 1988). Young (1990) identifies these procedural issues, or questions of the distribution of power, as largely missing from traditional theories of social justice. Procedural equity is no doubt critical to societal efforts to combat systematic perpetuation of inequities and should be included in social justice work. Still, many of the problematic aspects of distributional equity that Young cites as evidence of its theoretical insufficiency continue to pose real challenges to planning agencies tasked primarily with the allocation of resources, such as transit agencies. In this study *equity* is used to refer to distributional equity unless otherwise specified.

A number of authors have addressed distributional equity with respect to public transportation service provision (Litman 2011a; Martens, Golub, and Robinson 2012;

Khisty 1996; Hay 1995; Steven E. Polzin et al. 1997; Duthie and Waller 2007; Garrett and Taylor 1999). Many of these authors rely heavily on the work of John Rawls in *A Theory of Justice*. The Rawlsian notion of justice is in contrast to utilitarianism, which though derived from the field of economics, has been widespread in traditional planning decision-making (Beatley 1988; Khisty 1996). Utility theory argues that the primary goal of policy should be to maximize the *net* benefit to society, regardless of the distribution of these benefits and their associated costs (Beatley 1988). In contrast, Rawls formulated a new notion of social justice, comprised of two principles:

> First Principle: Each person is to have an equal right to the most extensive total system of equal basic liberties compatible with a similar system of liberty for all.
>
> Second Principle: Social and economic inequalities are to be arranged so that they are both (a) to the greatest benefit of the least advantaged, consistent with the just savings principle, and (b) attached to offices and positions open to all under conditions of fair equality of opportunity. (Rawls 1999)

In terms of infrastructure planning, this approach (particularly the second principle, known as the “Difference Principle”) means that plans and investment should have the greatest benefit for the least advantaged societal groups. Adherence to this principle is a radical departure from utilitarianism, as it requires not only consideration of the distribution of costs and benefits, but that this distribution meets a particular criteria – that the largest net benefit to individual groups accrue to those that are least advantaged.

Distributional equity can also be evaluated in different ways. Notions of *horizontal* equity and *vertical* equity derive from the field of welfare economics, where horizontal equity refers to “the impartial treatment of individuals in similar circumstances” and vertical equity refers to the distribution of benefits *between* different groups or types of individuals (Khisty, 1996). Vertical equity considerations are necessary in order to assess whether the Rawlsian Difference principle is being met. However as Beatley (1988) highlights, practical difficulties associated with evaluations of vertical equity include delineating the relevant social groups and determining which actions will best serve their interest(s). These questions remain challenging in the literature - there is not a clear consensus about how to categorize the possible approaches or even what different models should be called (Martens, Golub, and Robinson 2012; Khisty 1996; Beatley 1988; Murray 2003; Hay 1993; Duthie and Waller 2007; Levinson 2002). Several models that could be applied to transit service are described below:

Substantive Equality (of Access): A substantive equality uniform access model requires that "like net outcomes are experienced by like persons" (Hay 1993). Under a substantive equality model, transit would be proportional to the area served for all populated areas (Hay 1993). Importantly, the outcome considered here is not the *final* outcome of total access per person, but the outcome of a specific investment (*i.e.* a given investment should result in one unit of additional access for each individual).

Equality/Egalitarian: The most prominent type of vertical equity is the equality or egalitarian model, which has the goal of equal outcomes for each population, accounting for existing conditions and need. The principle of egalitarianism posits that groups should *not* be treated in like ways in like situations, but should be treated differently in order to achieve equal *final* outcomes for different groups (i.e. the net total of pre-existing access plus increased access resulting from a given investment is the same across groups). An option "that would distribute higher benefits to the lower end of the socioeconomic hierarchy would be considered an egalitarian option" (Khisty 1996).

Rawlsian: Rawls' Difference Principle goes beyond the equality/egalitarian model to suggest that not only is an unequal distribution of service acceptable so long as it has overall equalizing effects, but indeed such distributions must benefit the least advantaged the *most*. Whereas an egalitarian approach could be used to defend a transit investment that brought a medium-low income group closer to the average level of transit access, a Rawlsian approach would allow this distribution only if accompanied by an even greater investment for the lowest income group (Beatley 1988; Khisty 1996). This is a rather extreme interpretation that is not often found in practice, addressed in the next section.

The present study uses a methodology that primarily evaluates whether the equality/egalitarian model is being met – first by ensuring that any negative impacts are not disproportionately distributed towards transport disadvantaged communities, and second by evaluating whether or not these communities might in fact benefit equally or more than non-transport disadvantaged areas. In order to conduct a calculation of the impacts, it is helpful to review the empirical literature on quantifying both transit service and transport disadvantage.

2.2 Empirical Literature

The following sections provide an overview of relevant empirical studies, which generally fall into two categories: engineering studies of hypothetical network optimization given specific parameters and structure, and planning and transit equity studies that evaluate the link between a specific geographic area or socio-demographic population and the existing transportation system. Much of this literature evaluates overall transportation access and mobility (including all modes) between groups. Research that specifically addresses disadvantage and public transportation has analyzed the spatial location, characteristics, and trip-making behavior of people with low mobility (Church, Frost, and Sullivan 2000; Pucher 1988; Pucher and Renne 2005; Delbosc and Currie 2011a; Kamruzzaman and Hine 2012) and the relationship between public policy and communities with low mobility or transport disadvantage (Cervero and Tsai 2003; Pucher 1988; Diana 2004). Very few studies combine research on the specific structure of a transit network in terms of the prioritization process for allocating and distributing service with research on social equity and transportation disadvantage, though there has been some work in this area (Dodson et al. 2011). Additionally, the final section of this chapter, *2.3 Equity in Transit* does address current practice in this area within local planning documents and through documentation associated with Title VI reporting requirements.

2.2.1 Network Structure

The bulk of empirical research on transit network design has centered on network optimization, beginning with early studies such as Newell (1979), which evaluated both route structure and scheduling or frequency. However because these studies generally employ computational models, early studies were limited by technological capabilities. Since then, studies such as Daganzo (2010) and Estrada et al (2011) have developed models capable of optimizing network design to meet certain parameters, such as a network structure that provides accessibility levels comparable to automobile travel and at reasonable cost. While these studies do not provide direct comparison with the two alterative network structures analyzed in this paper, they do support the conclusion that in an optimized scenario, a frequent service, transfer-based network could offer significant ridership benefits over more traditional radial systems that offer broader geographic coverage and more one-seat rides.

A report by Dodson, Mees, Stone, and Burke at Griffith University in Brisbane, Australia provides an overview of the literature on public transport network planning principles, including network structure and service allocation. The report (2001, 2) cites the findings of several other studies (Thompson 1977; Mees 2000; Nielsen et al. 2005; Vuchic 2005; Mees 2010) for evidence that transit networks designed to emphasize connectivity and transfers offer better service provision then those that are heavily catered to specific origin/destination pairs. High connectivity can support a ‘network effect’ that induces increased ridership. One of the main arguments in this text, building off that of Mees (2010) is that higher transit ridership is largely dependent on network design and institutional factors, as opposed to urban form, which has been a greater focus in previous literature. With respect to network design, the authors argue that a highly integrated transfer-based network is much better than a radial or cohort-specific network. For planners, this finding means that transit service should be thought of as a unified commodity that travelers pay to access, instead of a choice or routes or corridors. For such a system to work, network legibility to the user is essential, the network and schedule must be simple to understand. Another critical factor for success of such a network design, which creates forced transfers, is the use of schedule coordination and other tools to make sure transfers can be completed as quickly and comfortably as possible. Increased frequency inherently reduces the penalty for transfers by reducing average waiting time, which is usually assumed to be half of the headway (Dodson et al. 2011).

The findings from several network optimization studies support the conclusions of Dodson et al. Building off of Daganzo (2010) Estrada, Roca-Riu, Robusté, & Daganzo (2011) find that a "semialternate" structure combining a radial system and a grid system (adjusted for variations in the street grid due and incorporating known demand generators) performed better that either a pure grid or pure radial system. It is important to note that as in Daganzo 2010, this work assumes that origins and destinations are "uniformly and independently distributed in the service region". While this is clearly not universally true in real-world circumstances due to the higher and lower areas of demand density, this assumption does tend to create a network well suited to all trip types, as opposed to a traditional commute-oriented network. Estrada et al (2011, 123) find that "the new system improves the door-to-door travel speed, captures most of the demand from the old bus system and (combined with the old) reduces the agency cost by 24%".

While the findings of these studies support the premise used to develop scenarios in Chapter 3, the empirical research on network design does not provide insight as to the potential impacts a frequent service, grid or hybrid network structure might have on the transport disadvantaged. Conversely, work in the field of environmental justice field has focused on issues such as "specific analysis techniques, or the equity impacts of specific projects, modes, and funding structures", and not network structure (Duthie and Waller 2007, 1). The following sections therefore consider identification and definition of the transport disadvantage of interest for public transit planning separately from network design.

2.2.2 Defining Transport disadvantage

As mentioned in the Introduction, there is a substantial body of literature on the topic of transport disadvantage. One of the critical questions in transport disadvantage studies is identification of the factors that contribute to either social exclusion or transport disadvantage and its effects. With respect to causal factors, Church (2000) identifies seven transportation-related factors that contribute to disadvantage for socially excluded groups: Physical exclusion, geographic exclusion, exclusion from facilities, economic exclusion, time-based exclusion, fear-based exclusion, and space exclusion. Some groups are more likely than others to encounter these barriers are due to their social exclusion. Discrimination or disadvantage in society may be caused by a wide range of factors: age, race, gender, physical or mental disability, sexual orientation, income, family status, employment status, language, country of origin, and others (Duthie and Waller 2007; Levinson 2002; Martens, Golub, and Robinson 2012; Currie et al. 2009; Church, Frost, and Sullivan 2000).

In order to examine the extent to which different groups are disadvantaged in transportation and mobility, researchers must decide which population groups to study and how to measure their relative advantage or disadvantage. Because socio-demographic data is usually available only at an aggregated geographic level due to privacy concerns, most studies use a geographic unit as the level of analysis, quantifying the population within a given area. As Duthie et al (2007) point out, this approach makes it hard to identify populations that do not congregate spatially. Some studies combat this by using travel surveys that ask individuals about their travel behavior, potentially including specific information about trip frequency and type, origins and destinations, and barriers to trip-making (or accessing needed destinations) – for example Hine 2003; Delbosc and Currie 2011a; Currie 2004. Studies that do not have extensive resources for conducing travel surveys, however, generally rely on aggregate demographic data, such as Currie 2004; Cervero, Murakami, and Miller 2009.

The most commonly used categories for transport disadvantage in transit planning, of those mentioned above, are poverty/income, age, disability, race/ethnicity, and car ownership. These groupings are found in the empirical literature on ridership modeling and mode choice, transit equity studies, and in local practice and planning documents (discussed in section 2.3). Litman (2011) argues that transit disadvantage is multi-dimensional and cumulative, that is to say that the factors that influence transit disadvantage can influence individuals to varying degrees, and that more factors taken together contribute to greater disadvantage (Litman 2011a).

In the empirical literature, the types of measures used to identify these population groups range from simple to very complex. Cervero (2009) uses median household incomes and vehicle ownership levels as proxies for levels of transit dependence. Currie (2004) combines several weighted indicators into one composite “needs” score (listed in order of weight given): Adults without cars, Accessibility, Persons aged over 60 years, Persons on a disability pension, Adults on a low income, Adults not in the labor force, and Students. In a later study (2009) Currie uses this index as well as an Index of Relative Socio-economic Advantage/Disadvantage from the Australian Bureau of Statistics to identify transit-dependent populations. Another Australian study, building on Currie’s methodology, employed an Index of Relative Socio-Economic Disadvantage (IRSD) which includes a large number of variables such as private dwellings with no internet connection, unemployment, employment in low-skill industries, education, familial status, rent, and English proficiency. (Cervero, Murakami, and Miller 2009; Currie et al. 2009; Currie 2004; ACT Government 2011)

Perhaps the most obvious measure of transport disadvantage in the United States context, where the past 70 years of transportation planning has been focused largely on facilitating private automobile travel, is lack of access to an automobile. At least one study uses car ownership as the only measure of transport disadvantage, employing the following definition: “A person 5 years old or older is transit dependent if that person either is not a licensed driver or lives in a household without a private vehicle” (Steve E. Polzin, Chu, and Rey 1995). However, this grouping is complicated by the fact that car ownership is not necessarily correlated with an individual’s transport advantage or disadvantage. For a variety of reasons, very low income households may be forced to own a car (forced ownership), while conversely medium and high income households may chose not to own a car (Currie et al. 2009; Delbosc and Currie 2011b; Litman 2011a; Litman 2011b). Car ownership therefore should be considered somewhat separately from other demographic characteristics, as it is in the Seattle Transit Master Plan.

2.3 Equity in Practice: Seattle

Transit planning documents in the Seattle region also contain information regarding the definition and identification of transport disadvantages in practice and methodology for quantifying transit service provision. The two primary documents are the recently completed Seattle Transit Master Plan, produced by SDOT, and the King County Metro Service Guidelines. In addition to planning documents, transit agencies must comply with Title VI of the Civil Rights Act and other Federal directives that forbid discrimination on certain grounds, and mandate that recipients of federal aid address disproportionate impacts to social or environmental justice communities.

2.3.1 Federal Legislation

Title VI of the Civil Rights Act, passed in 1964, states that: "No person in the United States shall, on the ground of race, color, or national origin, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving Federal financial assistance" (DOL 1964). Implementation of Title VI has been clarified in Executive Order 12898 (1994), ''Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" signed into law by President Clinton in 1994. EO 12898 expanded the list of protected classes to include low-income populations and emphasized the public participation as part of the National Environmental Policy Act review process. The Department of Transportation (DOT) and Federal Highway Administration (FHWA) each adopted Environmental Justice directives regarding EO 12898, clarifying the importance of addressing disproportionate impacts at the federal agency level (Department of Transportation, 1997; FHWA, 1998 in Martens et al., 2012).

2.3.2 King County Metro

Like other transit agencies that receive federal funding, Metro applies an equity evaluation to all major service changes in order to ensure that Title VI is not violated. Metro uses its own process to evaluate the service change according to the service guidelines and an equity process that complies with Title VI (King County Metro 2012b).

The first step in Metro's Title VI process is identification of the service change area, including the routes that will be affected, the census tracts that these routes pass through, and their average daily ridership. Then a series of thresholds are applied in order to evaluate the impacts to these census tracts.

The first threshold, required by the FTA, is determining whether the proposed service change qualifies as "major service change", which Metro defines as any change that requires King County Council approval, according to King County Code 28.94.020. The second threshold is where equity comes into the process. This threshold asks whether minority or low-income tracts are affected. Tracts with above average minority or low-income populations compared to the King County average are classified as minority. The fourth threshold asks whether there is a disproportionate impact on minority or low-income tracts. This compares the number and percentage of tracts that are minority, non-minority, low-income, and non-low-income that have either a 25% or greater reduction in service or a 25% or greater service increase. Service increases and decreases are calculated based on the percentage change in weekly bus trips for each census tract. Metro then conducts a qualitative evaluation of the impacts for each tract and identifies mitigation alternatives, primarily consisting of route restructures and alternative service options on other routes.

2.3.3 Seattle Transit Master Plan

The *Seattle Transit Master Plan* (TMP) includes equity as a core component of the policy framework and plan vision. One of the plan goals is to "Respond to the needs of vulnerable populations" (City of Seattle 2011, 1-10) and the plan later describes the Complete Transit System as a network of high-quality, frequent transit routes that connect urban centers and provide a system that "uses transit to create a transportation system responsive to the needs of people for whom transit is a necessity (e.g., youth, seniors, people with disabilities, low income populations, people without autos)" (City of Seattle 2011, 2-2). In order to incorporate various policy goals into the creation of the plan itself, the TMP used a multiple account evaluation process (MAE). The five accounts were community, efficiency, economy, environment, and equity. For each account, a series of criteria and sub-criteria were used to measure the strength of possible corridors. The weighting of each account was reviewed by the TMP's oversight groups including a technical team of City and other agency staff and a citizen advisory board (City of Seattle Department of Transportation 2012).

The precise weighting and description of the evaluation process described here is drawn from documents internal to the Seattle Department of Transportation (City of Seattle 2012, unpublished), obtained by the author. The first phase of corridor evaluation, Stage I, was primarily focused on identifying corridors with enough potential demand to warrant significant investment. Only two criteria related to equity were included in this step:

- Service to areas with higher than average concentrations of people with low incomes, people with disabilities, and people who depend on transit (whether by need or by choice)
- Service to low car ownership areas

In Stage II, which involved the most significant application of the MAE approach, several similar measures to Stage I were augmented with new measures to address housing and transportation costs as well as job access. These measures were as follows:

- Provides service to vulnerable communities (areas with higher than average concentrations of low income, people with disabilities, and transit dependent people)
- Combined housing and transportation costs in corridor
- Provides access to areas with high concentrations of service sector and living wage jobs

Stage III did not directly incorporate further equity measures, but instead identified the corridors that rose to the top of the Stage II evaluation as "High Capacity Transit Candidate Corridors" and the remaining corridors as "Priority Bus Corridors".

Throughout these processes, the TMP used the terms "vulnerable populations" to express general equity goals, with "transit-reliant" to refer specifically to "residents more likely to be reliant on transit as their primary means of transportation" (City of Seattle Department of Transportation 2012, 1-6). The TMP Transit Reliance Index was based on the combined density of low-income persons, youth aged 10-15, seniors over 65, persons with disabilities, and minorities. This index was used in Stage II. Car ownership was included only in Stage I.

2.4 Literature Review Summary

This chapter frames the proposed research in the broader context of the literature, and also provides guidance to portions of the methodology and subsequent analysis. Although there is limited research that specifically addresses the potential equity impacts of current transit service planning trends towards investment in high frequency, core routes at the expense of local service and broader geographic coverage, there is evidence of work in this area in current practice. King County Metro's *Strategic Plan for Public Transportation 2011-2021* (King County Metro 2011a) and accompanying service guidelines (King County Metro 2011b) both document attention to this topic, indicating that transit agencies are considering equity in the design and planning process for such service changes.

The literature does offer greater insight into the theoretical underpinnings for defining equity in public transportation provision, building on the Rawlsian notions of equity and justice. Meanwhile, the empirical literature suggests a methodology for quantifying transit service provision itself that is slightly more complex than the approach used by Metro, in that it includes a simple measure of the walkshed for stops within a given census tract (instead of simply calculating the weekly trips as accruing to the entire tract that a stop falls within). All three types of literature used here feed directly into the methodology, described in the following chapter.

3 Methods

3.1 Research Questions

This chapter describes the methodology I propose to address the set of research questions introduced previously in section 1.2 *Proposed Research*. The main research question is: What are the potential equity effects of a shift away from transit service emphasizing geographic coverage and local routes, towards service that emphasizes productivity and service along core frequent routes? This question is broken into several sub-questions:

1. How should the population against which “equity” is measured be defined and identified? Methods for analysis of this question include:
    a. A literature review of transportation and transit equity, including an overview of the processes used at SDOT and Metro to define the populations of interest (Chapter 2)
    b. GIS mapping of data from the US Census to identify the spatial location and density of these populations (Chapter 4)
2. What form might this type of shift in service provision take within the study area? Methods include:
    a. Review of Metro service guidelines and route analysis process (Chapter 2)
    b. Development of a Scenario 1: “Current Service” and Scenario 2: “Productivity-based Service” scenarios using data from Metro and GIS mapping (Chapter 4)
3. What and where are the impacts of moving from Scenario 1 to Scenario 2? Methods include:
    a. Qualitative comparison of the change in transit service, using a transit supply index (SI), between scenarios for those census tracts with high densities of the populations identified in subquestion1 (Chapter 4)
4. Finally, how might any negative impacts identified in subquestion 3 be mitigated through alternatives to fixed route service or would an alternative transit planning approach be better?

a. This question will be addressed by identifying the spatial location of census tracks that lose transit service and have above average portions of the transit-reliant populations identified previously in the results chapter, with suggestions for mitigation in Chapter 5, Discussion.

Before detailing the methodology for each of these questions, it is worthwhile to briefly explain the process that I used to identify an appropriate study area and introduce the area in more detail.

3.2 Study Area: West Seattle Peninsula

3.2.1 Selection

The process for selecting a study area included several criteria. Guiding criteria from the outset included a study area within the City of Seattle limits, so as to align with the Seattle Transit Master Plan boundaries. Furthermore, the study area size was important in order to select an area large enough to contain a meaningful number of Census Tracts yet small enough that compiling the necessary data would be within reasonable scope of the project. Therefore the study area could not be the entire City of Seattle, nor could it be a very small neighborhood area. I also hoped to identify an area with discrete geography, such that transit service within the study area could be considered without a great deal of consideration for the destinations and linkages provided to other areas. This criteria is important because the proxy measure for the amount transit service supplied in each scenario is not complex enough to incorporate destinations served. Many of the neighborhoods in North Seattle were eliminated in this step, as neighborhoods such as Ballard/Crown Hill or the University District/Ravenna/Roosevelt have complex route patterns including a high demand for both North/South and East/West routes, as well as unique routes providing service to and from major destinations within North Seattle such as the Northgate Urban Village and the University of Washington.

Having thus decided that a large neighborhood area would be the appropriate scale, I further refined the criteria to exclude portions of the city that have already undergone a change in transit service somewhat similar to the changes studied here – primarily a reorganization or reduction of local service in response to a significant investment in a high ridership, frequent service route. This criterion eliminated neighborhoods currently served by Sound Transit's Link Light Rail – primarily Southeast Seattle and the Rainier Valley. West Seattle appeared to be both an appropriate size, and its geographic isolation concentrates transit service to other areas almost entirely on routes exiting the study area to the Northeast in the direction of Downtown Seattle and Southward.

3.2.2 Study Area Boundaries

The next step in identifying the study area was therefore definition of the boundaries for West Seattle, which was relatively easy given the geographic boundaries of the area. The West Seattle Peninsula is bounded to the North by Elliott Bay, to the East by the Duwamish River, to the West by the Puget Sound, and to the South by the limit of the City of Seattle. There are several neighborhoods and sub-neighborhoods within the study area, whose boundaries vary somewhat according to different sources. The neighborhood typically referred to as "West Seattle" or "West Seattle Junction" is one of the city's oldest neighborhoods and was the first place that Seattle's early settlers arrived (Tate 2001). However this neighborhood alone does not include enough census tracts to provide an interesting study, therefore the entire West Seattle Peninsula is a more suitable scale.

Within the study area outlined above there are many sub-areas and neighborhoods defined according to different sources as listed below:

- Community Reporting Districts, which share most boundaries with the US Census 2000 tract divisions
- Neighborhood Districts, representing the boundaries used for representation on the Community Neighborhood Council and neighborhood service center service areas

- Neighborhood Planning Areas, which align with those areas identified in the City of Seattle Comprehensive Plan as an Urban Center/Urban Center Village, Hub/Residential Urban Village, or Manufacturing & Industrial Center
    - West Seattle contains portions of the Duwamish Manufacturing & Industrial Center and several Hub/Residential Urban Villages (Admiral, West Seattle Junction, Morgan Junction, and Westwood Highland Park, and South Park)
- Census geographies
    - The 2010 US Census includes 19 census tracts within the study area boundaries

Because this study uses data from the US Census and these boundaries do not completely align with other neighborhood geographies, it was not possible to exclude the industrial portions of the study area, which likely have very low population densities.

3.2.3 Transit planning in West Seattle

West Seattle has a lengthy transit history, stretching back to before the area was incorporated as a part of Seattle, when a short streetcar ran to the ferry terminal at Alki beach. Since then, transit has evolved a great deal to include twenty-eight route variations, shown below in Figure 1.

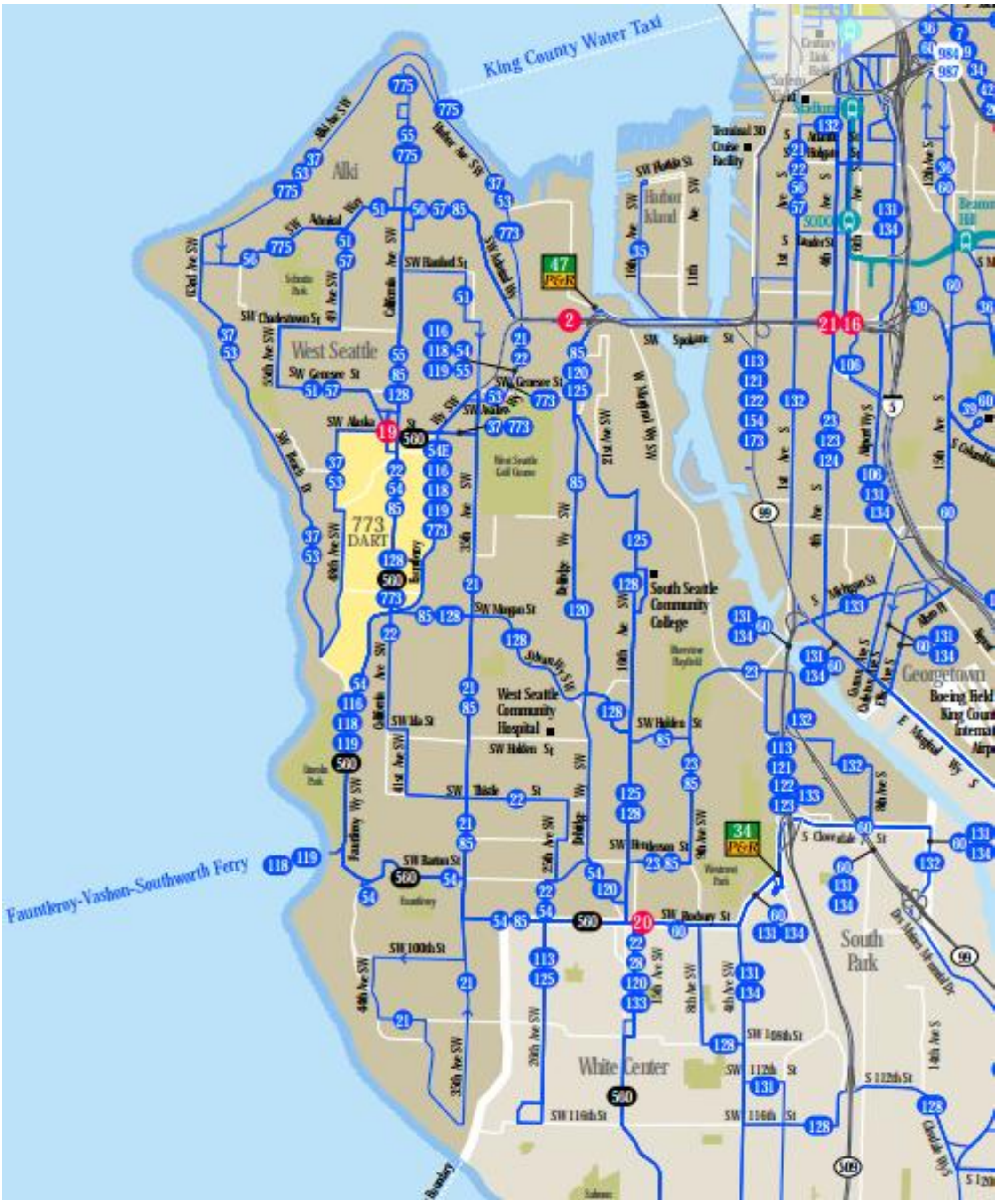


Figure 1: Metro Transit System Map *Source:* King County Metro, 2012c.

West Seattle is a particularly interesting study area because of current transit planning efforts in the area. Metro proposed a significant restructure for Fall 2012, the first major restructure to be designed according to new productivity-based service guidelines that replaced the former 40/40/20 policy. Although some compromises were made to the original proposal following citizen objections (Lindblom 2012) the fall restructure will represent a step towards upgrading the frequent service network. The fall restructure proposal (Figure 2) also supports one of the underlying assumptions in this this study, which is that some transit agencies are planning and implementing service changes with increased emphasis on high frequency service on the highest productivity routes. The public response to this restructure is also indicative of the political challenges inherent in reallocating service.

All-day and peak network changes for fall 2012

Route Number	Routing Change	Minutes between trips (frequency) or number of trips (am/pm)				
		Peak	Off-Peak	Night	Saturday	Sunday
RapidRide C Line	New route to serve Westwood Village, Fauntleroy, Alaska Junction and downtown Seattle. Replaces a portion of Route 54 local and express and Route 55.	10-15	15	15-30	15	15
21	Revise routing to provide service between Westwood Village and downtown Seattle.	15	15	30	15	30
21EX	No routing changes are recommended at this time.	10/10	--	--	--	--
22	Revise routing to serve Arbor Heights, Alaska Junction, Westwood Village and Gatewood.	60	60	--	60	60
37	No changes to the current routing are recommended.	4/4	--	--	--	--
50	New route to serve Alki, Admiral District, North Delridge, SODO station, VA Medical Center, Beacon Hill, Columbia City, Seward Park, and Othello Station.	20	30	60	30	60
55	No changes to the current routing are recommended; operate peak period only	5/5	--	--	--	--
56EX	No changes are recommended at this time.	9/9	--	--	--	--
57	Revise routing to operate on the Alaskan Way Viaduct. Operate peak period only; routes 21 and 50 provide alternate service.	4/4	--	--	--	--
60	Revise routing to extend to Westwood Village.	20	20	30-60	30	30
116EX	No changes are recommended at this time.	10/8	--	--	--	--
120	Revise routing to serve Westwood Village. Route 60 provides alternate service.	8-15	15	30-60	15	30
125	Revise routing to operate between Westwood Village and downtown Seattle via South Seattle Community College and the Alaskan Way Viaduct. The C Line and routes 21, 22, 113, 120 and 128 provide alternate service.	20	30	45	45	--
128	Revise routing to extend to Atlantic Street in the Admiral District.	30	30	30	30	30
131	Revise routing to operate between the Burien Transit Center and downtown Seattle via Highland Park and 4th Avenue S. Provide alternate service on routes 60, 106, 124, 132, and 166.	20-30	30	30-60	30	30
132	Revise routing to operate between the Burien Transit Center and downtown Seattle via South Park and 4th Avenue S. Provide alternate service on routes 156 and 166.	20-30	30	30-60	30	30
773	No changes are recommended at this time.	6/7	20-40 **	--	20-40 **	20-40 **
775	No changes are recommended at this time.	7/8	20-40 **	--	20-40 **	20-40 **

** -- Operates only during Water Taxi "Summer"

Deleted routes/concepts						
20	This concept introduced during the planning process is no longer recommended.	--	--	--	--	--
23	Discontinue; provide alternate service on with Route 131.	--	--	--	--	--
51	Discontinue; provide alternate service on routes 50 and 128.	--	--	--	--	--
53	Discontinue; provide alternate service on routes 37, 773, and 775.	--	--	--	--	--
54	Discontinue; provide alternate service on RapidRide C Line, and routes 116 and 120.	--	--	--	--	--
54EX	Discontinue; provide alternate service on RapidRide C Line, and routes 116 and 120.	--	--	--	--	--
56	Discontinue; provide alternate service on routes 50 and 56 Express.	--	--	--	--	--
85	Discontinue; provide alternate service on RapidRide C Line and Route 120.	--	--	--	--	--

Increased frequency or increased number of trips | Decreased frequency or decreased number of trips

X/X notes the number of morning and afternoon peak period trips

X or X-X notes the minutes between trips

Figure 2. Proposed Fall 2012 Metro Restructure for West Seattle *Source:* King County Metro, 2012d.

Fall will also see the introduction of Rapid Ride C, shown in Figure 3. Rapid Ride C Proposed Route Source: King County Metro, 2012e.

Figure 3. Rapid Ride C Proposed Route *Source*: King County Metro, 2012e.

The Rapid Ride C route is essential the same as one of the high priority corridors identified for West Seattle in the Seattle Transit Master Plan (Figure 4).

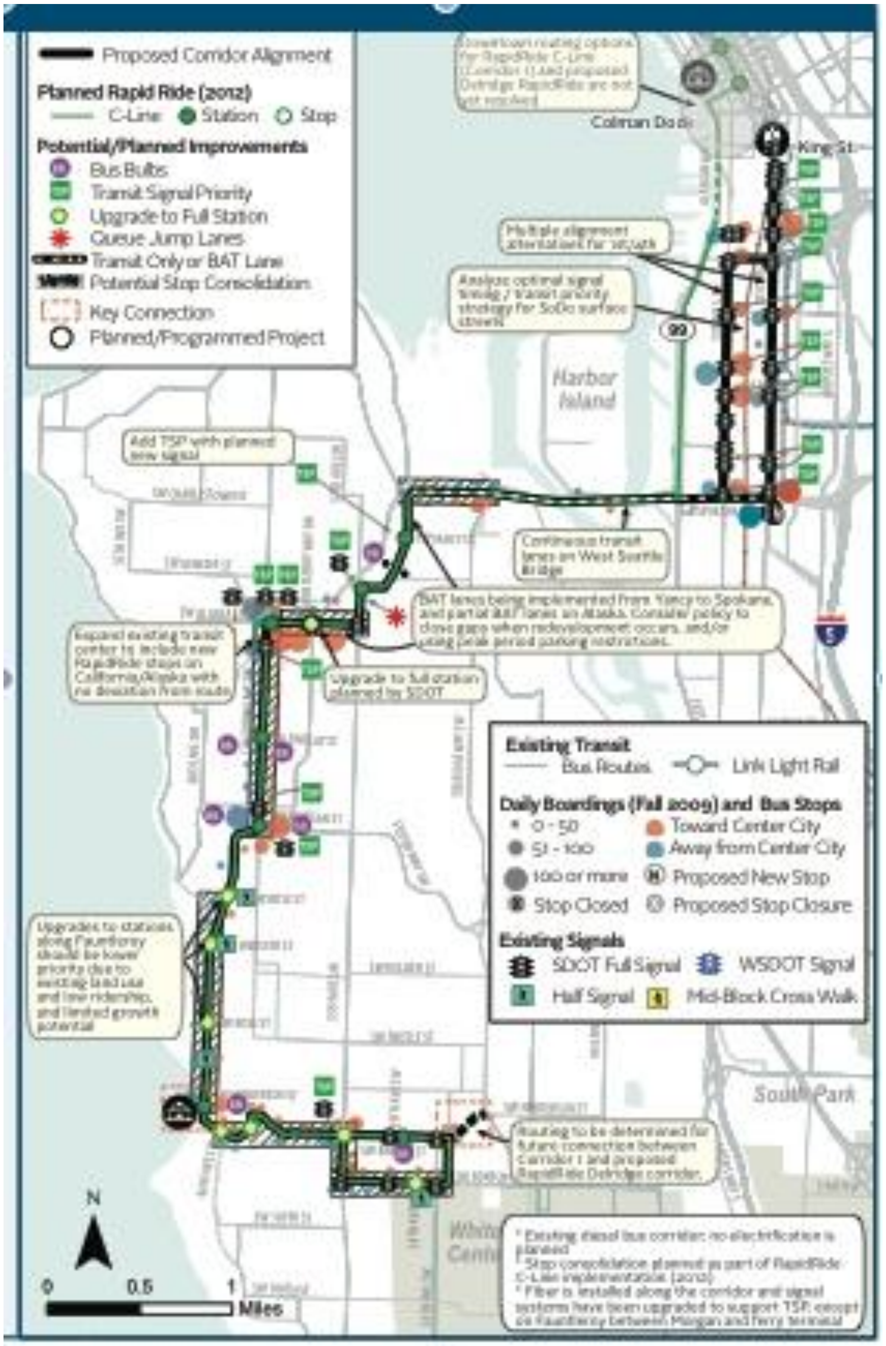


Figure 4. TMP Bus Priority Corridor 1: Downtown to West Seattle *Source*: City of Seattle Department of Transportation, 2012.

This proposed restructure and the introduction of Rapid Ride C offer the opportunity to compare the results of the current study with the process employed to make real service allocation decisions in King County. If my methodology for creating Scenario 2 produces similarities with respect to where service is reduced and where it is added, the validity of my findings will be improved. If anything, my findings are likely to be more inequitable than the routing changes currently planned by King County Metro or proposed in the Transit Master Plan, since both processes include significant consideration of social equity in the identification and prioritization of routes for increased or reduced service. This topic will be discussed further in Chapter 4.

3.3 Defining the transport disadvantage

This study uses Geographic Information System (GIS) mapping software to identify transport disadvantages in the study area. Demographic data for King County is available through the King County GIS Portal. The most recent data provided is the 2010 US Census data for basic demographic data such as population and race, and the 2005-2009 American Community Survey (ACS), which includes more detailed information such as income and car ownership. Although basic census data is available at smaller geographies, the methodology for collecting ACS changed after the 2010 census so that the survey is given to smaller segments of the population, but with greater frequency – the survey is now administered annually. While this change provides some benefits to researchers in that previously updated data was only available every 10 years, it also significantly increases the margin of error. For some measures, the margin of error in ACS data may now be as large as the estimate itself (ESRI 2011). Neither King County nor the City of Seattle publishes ACS data beyond 2010 below the census tract group. Although census tracts are much larger and therefore limit the level of detail for analysis, the tradeoffs in improved reliability and data availability outweigh this disadvantage.

As discussed previously in Chapter 2, a wide number of variables have been considered in studies of transit equity. The most common variables, and those used by the TMP, are income, age, race/ethnicity, disability, and car ownership. Unfortunately, census data more recent than the year 2000 is not yet available for disability, and because the boundaries for the 2000 census are slightly different, it was not possible to include this variable.

Table 1. Transport disadvantage groups

Variable	Census	Definition
Income	Low-income households	Percentage of households below the Federal poverty line
Race/Ethnicity	People of color	Percentage of population that identifies as non-white and non-Hispanic
Age	Youth	Percentage of population under 18
Age	Elderly	Percentage of population above 65
Additional Consideration:		
Car-ownership	Car-less households	Percentage of households that do not own a car

Source: Census categories and definitions from US Census 2010 data, accessed through King County GIS Data Portal, 2012.

Table 1 shows the variable and US Census data that the present study will use to evaluate different transport disadvantaged populations.

3.4 Scenario development

This study uses two scenarios designed to compare a "traditional" transit network planning approach (Scenario 1), emphasizing geographic coverage, with a frequent service network (Scenario 2), emphasizing frequent service on high productivity routes. The primary goal is to quantify the amount of transit service in each scenario and compare the amount that is distributed to areas with high concentrations of transport-disadvantaged populations. There are several key steps to creating each scenario:

1. Scenario 1: Quantify and map current service
2. Scenario 2:
    a. Identify low productivity service
    b. Identify high productivity routes
    c. Shift service from low productivity to high productivity routes
    d. Quantify and map Scenario 2 service

In order to complete these steps, I need to establish a methodology for each component of the analysis. The first issue is how to quantify transit service. The second issue is how to identify high or low productivity service, and the third issue is how to move “service” between high productivity routes to low productivity routes. The final question for analysis is addressed in Section 3.5, how to compare the two scenarios from a social equity perspective and identify impacts to transport-disadvantaged areas. The methodology for the remaining issues, quantifying transit and measuring productivity, was ultimately driven by the availability and practicality of using data from Metro.

3.4.1 Data Inputs

In order to begin developing Scenario 1, the first decision I made was how to quantify the “amount” of transit provided to each geographic unit, in this case, each Census tract. Based on the methodology in Currie (2009) I decided to use **the total number of weekly trips accessible to each Census tract**. Accessible is defined as those trips to stops within a quarter-mile walking distance to the Census tract. I also needed to quantify transit service in a way that would allow for service to be reallocated between Census tracts according to productivity. Ultimately, because the productivity measures from Metro that I used are at the route level, I chose to use **weekly trips per route** to move service from Scenario 1 to Scenario 2. In essence, weekly trips per route served as a “common currency” for reallocating service. When I reallocated service, I kept routes intact, and reallocated trips from some routes to others.

Before going further, it is worth noting that the use of weekly trips carries several limitations. For one, holding weekly trips constant does not necessarily hold financial resources constant. This is because the actual operating cost of one trip can vary widely between routes. One of the most significant sources of operating costs for bus transit is the amount of time it takes to complete one trip from beginning to end (including any time without fare-paying passengers), as this is the amount of time that the bus driver must be paid. Anything that contributes to making a route take longer – route length, number of stops, average travel speed, or other factors, increases the cost of each trip on that route. King County Metro uses a measure that addresses this limitation by including the length of time required for each trip in addition to weekly trips as a simple measure of operating cost. Weekly trips therefore represent a simplification of the actual resources required to operate the two scenarios.

Using weekly trips as a transfer currency is also imperfect because it applies equally to the entire route. In other words, it is not possible to move service on any unit smaller than a route (such as a route section or even individual stop). Doing so would allow for greater precision in creating Scenario 2 based on productivity. For example, it might be possible to eliminate trips to individual stops that have low boardings in the study area, and then use the revenue savings (from saved time at each stop) towards additional trips on the same route or another route. However, to do this level of analysis would require two things:

- Productivity measured by stop (or route segment)
- A “common currency” for moving service between stops

Both of these data needs are problematic. Although *ridership* can be measured by stop, in terms of boardings and alightings (people getting on and off the bus), *productivity* relates the ridership over a period of time or distance. The 2011 Service Guidelines report describes two primary measures of transit productivity:

> 1. “**Rides per platform hour** is the total rides per hour that a bus provides from the time it leaves its base until it returns. Routes with many riders boarding the bus during each trip tend to perform well on this measure.
> 2. **Passenger miles per platform mile** is the sum of miles traveled by all passengers per mile the bus operates from its base until it returns. Routes that have full, even loading tend to perform well on this measure – including routes that pick up many riders at transit centers or park-and-rides, then travel long distances with few people getting on or off on the way to their destination” (King County Metro 2011b, 24)

These measures can only be applied to entire routes (or perhaps segments of routes). Furthermore, even if there was a measure of productivity at the stop level, dividing service by stop would have dramatic impacts on the real cost of operating transit service. For example, it would be possible to cut all trips to all the stops except for two “high productivity” stops on a route, but this would not necessarily reduce the cost of providing service in any proportional manner to the loss in transit access. Therefore this would not provide a suitable “common currency” for transferring service.

Ultimately, using **weekly trips per route** as the common currency for transferring service, but measuring the outcome – transit supply - based on **the number of weekly trips per stop** means that resources are not held constant in both scenarios. It is conceivable that unproductive service on routes with many stops could be reallocated to productive routes with few stops, (or vice versa) which would result in an overall increase or decrease in transit supply. Even if this occurs, the goal of my research is to identify whether there are *disproportional* impacts to transport disadvantaged communities, and determine whether the definitions of equity introduced in Chapter Two are being met.

The use of productivity measures by route also carries another limitation, which is that it is not possible for me to understand the relationship between productivity and the area contained within the study area boundaries – I do not know whether high-performing routes draw most of their high ridership from origins and destinations within the study area or outside. Table 2 shows the total length for each route variant and the length within the study area according to the GIS route layer.

Table 2. Portion of route length within Study Area

Route Name	Length in Study Area (Miles)	Total Length (Miles)	Portion in Study Area
21	10.3	18.1	57%
21 EP	3.5	18.1	20%
22	7.6	15.9	48%
23	4.5	11.9	37%
37	9.1	13.8	66%
37 EE	9.4	18.1	52%
51	5.2	5.2	100%
53	10.2	10.2	100%
54	9.2	17.4	53%
54 AT	9.8	13.8	71%
54 EX	8.8	17.4	51%
55 AS	6.7	17.4	38%
56	5.4	13.2	41%
56 EE	2.6	2.6	100%
57	6.0	12.3	48%
60	7.1	19.0	38%
85 AO	5.1	13.2	39%
113	14.3	24.6	58%
113 AS	6.8	22.4	30%

116 EE	0.2	1.9	11%
118 EQ	5.5	12.5	44%
119 EE	5.5	13.5	41%
120	1.9	4.2	45%
121 AT	5.5	30.9	18%
125	4.8	17.3	28%
125 AN	3.0	30.1	10%
125 AT	4.9	15.8	31%
128	6.1	15.8	39%
128 AT	6.0	15.8	38%
131	8.1	19.2	42%
131 AT	6.8	22.9	30%
132	6.8	22.9	30%
132 AT	5.2	19.2	27%
133	3.5	18.1	20%
134	4.0	28.2	14%

Source: Route data from King County GIS Data Portal, 2012.

However, the purpose of this study is to evaluate the impacts of a hypothetical, but realistic transit service restructure. If Metro were to apply my methodology and reallocate transit service purely on the basis of productivity as measured by route (and not by a portion of the route), a route that is productive within the study area but unproductive outside of it would be cut or retained based on the total performance over the course of the route. If this method were used the outcome in terms of impacts would likely be similar to my research. Of course, in practice, transit agencies do employ a more complex toolkit that allows for consideration of both ridership and social equity. My research question attempts to find out what would happen in the absence of this nuanced toolbox, so the distribution of ridership along the route is unimportant given the assumption that *productivity* is measured by route. The following sections describe the creation of each scenario in greater detail.

3.4.2 Scenario 1: Current service network

Since Scenario 1 is current service, creating this data is fairly straightforward using the following steps:

1. Obtain tables from Metro staff showing: a) The number of weekly trips per route and b) The ID number of each stop used by each route, as of Summer 2012.
2. Join these two tables in MS Access using the route number fields as the common field to obtain the number of weekly trips per route per stop.

3. Dissolve the table with weekly trips per route per stop to obtain the total weekly trips for all routes per stop.
4. Obtain, from the King County Metro data portal, a spatial layer with geocoded bus stop locations, including their ID number.
5. Join the spatial layer obtained in step four with the table generated in step three using ArcGIS, based on the common attribute, Stop ID. This assigns the total weekly trip value to each stop on the map.
6. Using the ArcGIS spatial join tool, create a new layer that joins the census tract number that each stop is located within to the stop information layer. ArcGIS can produce statistics using this layer to summarize the total weekly stops per Tract.

This process does not alter the King County Metro data – it simply assigns the trip frequency information to a spatial location on the map. Later, in section 3.5, the weekly trip frequency per stop is combined with information about what portion of the census tract area is within walking distance of the stop to obtain a transit Supply Index score.

3.4.3 Scenario 2: Productivity-based frequent network

Scenario 2, requires several steps additional steps, including identifying the lowest performing routes, reducing weekly trips on these routes, identifying the highest productivity routes and distributing new weekly trips in equal number to those cut among them, and finally calculating the old and new weekly trips per stop for analysis.

As mentioned in section 3.4.1, I rely on productivity data from King County Metro. For all routes, Metro calculates the two different productivity measures (rides per platform hour and passenger miles per platform mile) for three time periods – peak, off-peak, and night. Metro then identifies the top 25% and bottom 25% performing routes for two types of routes – routes that serve the Seattle Central Business District (CBD) and routes that do not - in for each measure for each period. The result of Metro's productivity analysis for routes within the study area is shown in **Error! Reference source not found.**. Each measure that is in the top 25% is highlighted in green, while measures in the bottom 25% are in black.

Table 3. West Seattle route productivity (Metro measures)

Route	Part	Corri-dor	Between	Peak		Off-Peak		Night	
				Rides/ Plat Hr	Pass Mi/ Plat Mi	Rides/ Plat Hr	Pass Mi/ Plat Mi	Rides/ Plat Hr	Pass Mi/ Plat Mi
21		13L	Arbor Heights and Seattle CBD via 35th Ave SE and 4th Ave S	24.9	7.4	24.2	9.9	14.0	5.1
22		None	White Center and Seattle CBD via Alaska Junction and SODO	25.2	8.3	20.3	8.8		
23		17L	White Center and Seattle CBD	37.5	14.4	28.2	11.0	15.0	5.8
51		None	Alaska Junction and Admiral District	25.1	3.2	19.5	3.6		
53		None	Alaska Junction and Alki			12.5	3.6		
54		50C	White Center and Seattle CBD via Fauntleroy	29.5	11.5	36.2	14.6	24.7	10.2
55		None	Admiral District and Seattle CBD	38.9	15.1	31.9	12.6	17.4	7.2
56		12L	Alki and Seattle CBD	30.4	10.1	23.2	8.8	11.4	4.2
57		Peak	Alaska Junction and Seattle CBD via Admiral	21.6	8.1				
60		14C	Broadway and White Center via Georgetown and Beacon Hill	31.3	9.3	29.8	9.5	16.1	4.7
85		None	Owl: Seattle CBD and White Center via West Seattle					17.5	8.8
113		Peak	Shorewood and Seattle CBD via White Center and SR-509	25.6	10.8				
118		68L	Vashon Island	23.3	4.6	9.6	2.4	4.6	1.0
119		None	Vashon Island	16.3	4.8	13.9	3.1	2.5	0.3
120		13C	Burien and Seattle CBD via White Center and Delridge	44.3	17.4	47.2	21.9	36.2	16.6
125		14L	Shorewood and Seattle CBD via SSCC	36.2	12.3	33.6	13.4	17.6	7.1
128		1C	South Center and Admiral District via White Center	38.7	13.4	36.5	17.1	20.4	6.4
131		18L	Midway/Des Moines and Seattle CBD (Burien and Seattle CBD)	20.3	8.0	20.0	9.8	14.6	6.8
131		26C	Midway/Des Moines and Seattle CBD (Kent and Burien)	20.3	8.0	20.0	9.8	14.6	6.8
132		19L	Burien and Seattle CBD	26.2	10.9	27.6	12.9	12.4	6.0
133		Peak	University District and Burien	17.3	10.5				
134		Peak	Burien and Seattle CBD via Georgetown	10.6	4.1				
116	EX	Peak	Fauntleroy and Seattle CBD	12.4	5.3				
118	EX	Peak	Seattle CBD and Vashon Heights and Tahlequah via Ferry	13.7	5.7				
119	EX	Peak	Seattle CBD and Vashon Heights and Dockton via Ferry	13.0	7.2				
21	EX	Peak	Arbor Heights and Seattle CBD	32.8	12.9				
37	EX	Peak	Alaska Junction and Seattle CBD via Alki	16.6	6.4				
54	EX	Peak	Fauntleroy and Seattle CBD	34.3	12.6				

Source: King County Metro, 2012, unpublished.

West Seattle has two routes that are noted in the 2011 Service Guidelines report as among the best performing in the system – route 120 and route 128. However outside of these very high ridership routes, many West Seattle routes fall in the bottom 25% on one or more of Metro productivity measures. It should also be noted that the two high-performing routes include substantial portions outside of the study area, providing connection to Burien, White Center, and South Center.

In order to reduce and add service in proportion to how unproductive or productive a route was, I developed a productivity scoring system. To score routes, I use the Metro evaluation process from **Error! Reference source not found.** in combination with a measure of productivity relative to the study area. This scoring system, when applied to low-productivity routes, assigned one point for each of the possible six measures that fell into Metro's bottom 25% (or one point for each black box in **Error! Reference source not found.**). Then I ranked each route within the study area in order of lowest productivity to highest productivity for each of Metro's six categories and assigned one point for each measure that fell in the bottom three for routes in the study area. For example, I ranked all routes from low to high for "Rides per platform hour: peak period" and assigned one point to each of the three routes with the lowest performance on this measure.

For each route, the maximum possible score would therefore be 12 - 6 measures that could fall in Metro's over all bottom 25%, and 6 that could rank in the bottom 3 for the study area. I then reduced frequency according to this new "productivity score" – 20% reduction for a score of 2, 30% reduction for a score of 3, and so on. However I decided to hold the maximum score to 9, because it is not possible to reduce service by more than one hundred percent, and this avoids the possibility that any route will be cut entirely. Additionally, since my goal was to reduce service by 15%, I only cut service on routes with a score higher than 2. The service reduction program is shown in Table 4.

Table 4. Service reduction program

Route	E/L	Ex	Product-ivity Score	% Reduced	Current Weekly Trips (Scenario 1)	Number Reduced Trips	New Weekly Trips after Reduction
21	E	EP		0	110	0.0	110
21	L			0	529	0.0	529
22	L		2	20%	333	-66.6	266
23	L		2	20%	490	-98.0	392
37	E	EE		0	40	0.0	40
37	L			0	35	0.0	35
51	L		1	0	306	0.0	306
53	L		3	30%	80	-24.0	56
54	E	EX	3	30%	70	-21.0	49
54	L			0	649	0.0	649
54	L	AT		0	303	0.0	303
55	L		1	0	436	0.0	436
55	L	AS	1	0	163	0.0	163
56	E	EE	6	60%	95	-57.0	38
56	L		6	60%	385	-231.0	154
57	L				60	0.0	60
60	L		3	30%	568	-170.4	398
60	L	AT	3	30%	5	-1.5	4
85	L	A O	1		28	0.0	28
113	L				45	0.0	45
113	L	AS			10	0.0	10
116	E	EE	2	20%	75	-15.0	60
118	E	E Q	2	20%	20	-4.0	16
118	L	AD	9	90%	47	-42.3	5
118	L	AS	9	90%	5	-4.5	1
118	L	AT	9	90%	40	-36.0	4
118	L	AV	9	90%	20	-18.0	2
118	L	A W	9	90%	98	-88.2	10
118	L	AZ	9	90%	5	-4.5	1
119	E	EE	3	30%	10	-3.0	7
119	L	AS	7	70%	85	-59.5	26
120	L				904	0.0	904
125	L		1		293	0.0	293
125	L	AN	1		45	0.0	45
125	L	AT	1		240	0.0	240
128	L				390	0.0	390
128	L	AT			28	0.0	28
131	L		2	20%	207	-41.4	166

131	L	AT	2	20%	50	-10.0	40
132	L		2	20%	235	-47.0	188
132	L	AT	2	20%	105	-21.0	84
133	L		1		40	0.0	40
134	L		4	40%	45	-18.0	27
Total					**7727**	**-1081.9**	**6645.1**

Source: Route data and weekly trips from King County Metro, 2012, unpublished. Other data was computed by author.

I used the same productivity scoring system to add service in proportion to the productivity score. That is to say, routes received one point per productivity measure that is in the top 25% of routes for all of Metro (Recall Table 3) and one point per productivity measure that is in the top 3 for the study area. Again, the scoring had a theoretical maximum of 12 but I imposed a scoring cap of 9. Therefore the maximum addition would be 90%. Trips were added proportionally to the productivity score until all trips reduced in the previous step were used up. In the end, the 1,081 weekly trips cut from low-productivity routes were used up after adding service to the top two high-productivity routes, the 120 and the 128, as shown in Table 5.

Table 5. Service addition program

Route	E/L	Ex	Product-ivity Score	% Added	Weekly Trips (after reduction)	Number Added Trips	New Net Weekly Trips (Scenario 2)
21	E	EP			110	0.0	110
21	L				529	0.0	529
22	L				266	0.0	266
23	L		2		392	0.0	392
37	E	EE			40	0.0	40
37	L				35	0.0	35
51	L				306	0.0	306
53	L				56	0.0	56
54	E	EX	5		49	0.0	49
54	L		5		649	0.0	649
54	L	AT	5		303	0.0	303
55	L		3		436	0.0	436
55	L	AS	3		163	0.0	163

56	E	E E			38	0.0	38
56	L				154	0.0	154
57	L				60	0.0	60
60	L				398	0.0	398
60	L	A T			4	0.0	4
85	L	A O	2		28	0.0	28
113	L				45	0.0	45
113	L	A S			10	0.0	10
116	E	E E			60	0.0	60
118	E	E Q			16	0.0	16
118	L	A D			5	0.0	5
118	L	A S			1	0.0	1
118	L	A T			4	0.0	4
118	L	A V			2	0.0	2
118	L	A W			10	0.0	10
118	L	A Z			1	0.0	1
119	E	E E			7	0.0	7
119	L	A S			26	0.0	26
120	L		9	90%	904	813.6	1718
125	L				293	0.0	293
125	L	A N			45	0.0	45
125	L	A T			240	0.0	240
128	L		9	90%	390	351.0	741
128	L	A T	9	90%	28	25.2	53
131	L				166	0.0	166
131	L	A T			40	0.0	40
132	L				188	0.0	188
132	L	A T			84	0.0	84
133	L				40	0.0	40
134	L				27	0.0	27
Total					**6645.1**	1189.8	7834.9

Source: Route data and weekly trips from King County Metro, 2012, unpublished. Other data was computed by author.

The reason that trips were reduced on many routes, but only added to two is because the low productivity routes already had relatively few weekly trips and the highest productivity routes were already very frequent. There is an interrelationship between frequency and productivity – Metro would logically make more productive routes more frequent in order to meet the apparent demand, while increased frequencies makes the service more appealing, increasing demand, and in turn, productivity (Nielsen et al. 2005; Transportation Research Board 2004). The top performing routes, route 128 and route 120, already had very high weekly frequencies, so a 90% increase in weekly trips on those two routes alone resulted in 1190 additional trips, or just over 15% of total weekly trips in the study area. The routes that would have received increased service, but did not, are shown in **Error! Reference source not found.**.

The final step in creating Scenario 2 was rejoining the new number of weekly trips to the GIS data. This process followed the same data manipulation steps as Scenario 1, only using the adjusted number of weekly trips per route. By joining the new number of weekly trips per route with the Stop ID for each stop served by each route, I generated a new number for total weekly trips per route per stop. This data was then joined to the same spatial layer with stop location to allow for calculation of the new number of total weekly trips per stop and per census tract.

3.5 Measuring and comparing transit supply

The final, but important, step in the methodology for this study requires developing a measure of transit service that will be used to compare the "amount" of transit supplied to each census tract in the first scenario with the amount supplied in the second scenario. Ideally, this measure would capture and quantify many of the most important components of transit service from a user perspective – such as frequency (time between trips), span (hours of the day that service operates), travel time (on-board travel time, time spent going to and from the stop, and waiting time), comfort, cost, and so on and so forth. However, to do so would be incredibly complex and is far beyond my capacity for this project. Instead, frequency will serve as a proxy measure for the quantity and quality of overall transit supply.

Using the methodology developed by Currie (2009), I used a transit Supply Index (SI) to calculate transit supply in each census tract. The transit SI is calculated as the portion of the each census tracts within walking distance to a stop multiplied by the total number of weekly trips arriving at that stop. Walking distance is defined as the area within a quarter mile of a bus stop. The formula for calculating the total SI is:

> SI = SUM ((Census tract area within a quarter mile of stop/total census tract area)*weekly trips) for each stop/station. (Currie et al. 2009)

One of the major limitations of this methodology is that it assumes that population is evenly distributed within each tract. In reality, population density varies within tracts. Areas that are not within walking distance to any bus stops presumably have low population, which is why they are not served by Metro. The quarter mile buffers and stops are shown in Figure 5.

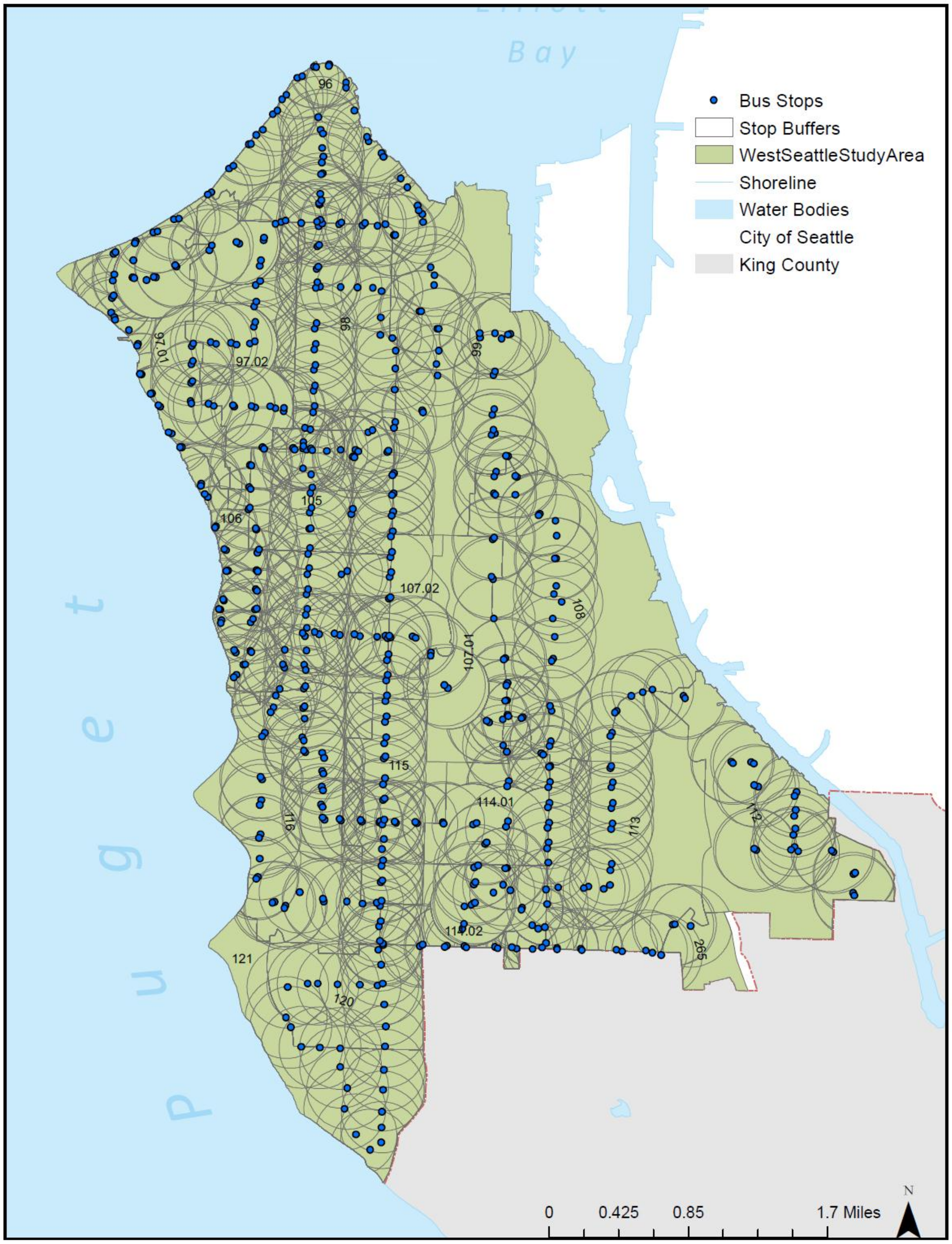


Figure 5. Bus stops with quarter mile buffers

The total SI for each census tract is the sum of the SI calculated for each portion of a quarter-mile buffer within the tract, first using the weekly trips for Scenario 1 and then the weekly trips for Scenario 2. The percentage change between these scenarios will provide the primary basis for assessing potential impacts to the transport disadvantaged populations identified in section 3.3.

Finally, the analysis identifies the spatial location of census tracts with both above average percentages of populations in the social justice categories used for this study, and negative change in transit SI from Scenario 1 to Scenario 2. This information should be used to inform potential mitigation efforts for specific areas, based on the needs of the population groups in tracts that have both high densities of a transport-disadvantaged population, and high negative impacts from moving to the productivity-based network in Scenario 2. For example a tract with a high proportion of very young people (who are not old enough to drive) would not be well served by an alternative that provided car sharing. The discussion in Chapter 5 will draw on some of the recent literature that has begun to emerge in light of the shift away from providing fixed route transit to very low density or low demand areas.

4 Results

4.1 Change in Supply Index

Once the service reallocation process was complete and the new number of weekly trips per stop was calculated, I found the new SI for each tract and calculated the percent change. Change in transit Supply Index ranged from negative 35% to positive 87%.

Table 6. Change in Transit Supply Index by Tract

Census Tract	Scenario 1 Supply Index	Scenario 2 Supply Index	Percent Change	Total Population
97.01	1394	901	-35%	5622
265	1724	1291	-25%	2905
112	2592	1968	-24%	4102
96	3616	3351	-7%	5714
97.02	2037	1913	-6%	2620
116	4937	4689	-5%	6304
115	5508	5293	-4%	4152
120	3666	3665	0%	3632
121	2260	2259	0%	2565
113	3723	3996	7%	5527
105	10420	11304	8%	6424
99	3876	4211	9%	5091
98	6388	7306	14%	6127
106	5950	6785	14%	7087
114.02	6093	6955	14%	4193
107.02	2663	3513	32%	2620
108	3291	4650	41%	4683
114.01	4356	6604	52%	3919
107.01	2553	4770	87%	2622
TOTAL	**77047**	**85424**	**(Average) 9%**	**85909**

Source: Census Tract and Population from US Census 2010, accessed through King County GIS Portal, 2012

On average, the supply index for tracts within the study area rose by 440 in Scenario 2, with a standard deviation of 853. This indicates that overall, tracts were generally made better off by the change in service. This could be because low productivity routes, which lost service, made fewer stops within the study area, while high-productivity routes made more stops. Indeed, the total number of weekly trips for all stops was 758,588 in Scenario

1, compared to 846316 in Scenario 2, a difference of approximately 11%. The net percentage change in SI was also 11%. The transit Supply Index for Scenario 1 and Scenario 2 are shown in the following maps.

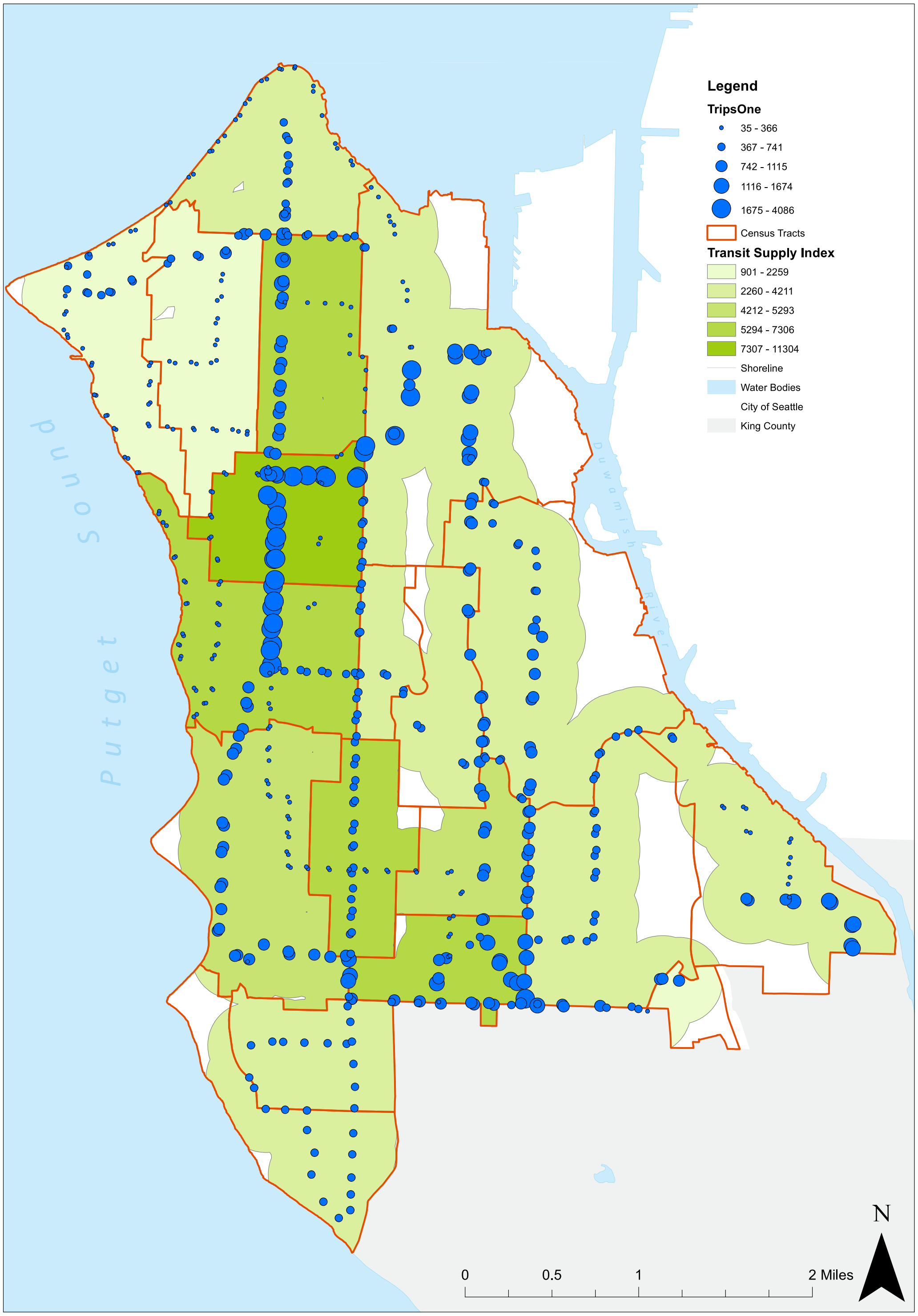


Figure 6. Map of Weekly Trips and Transit Supply Index: Scenario 1

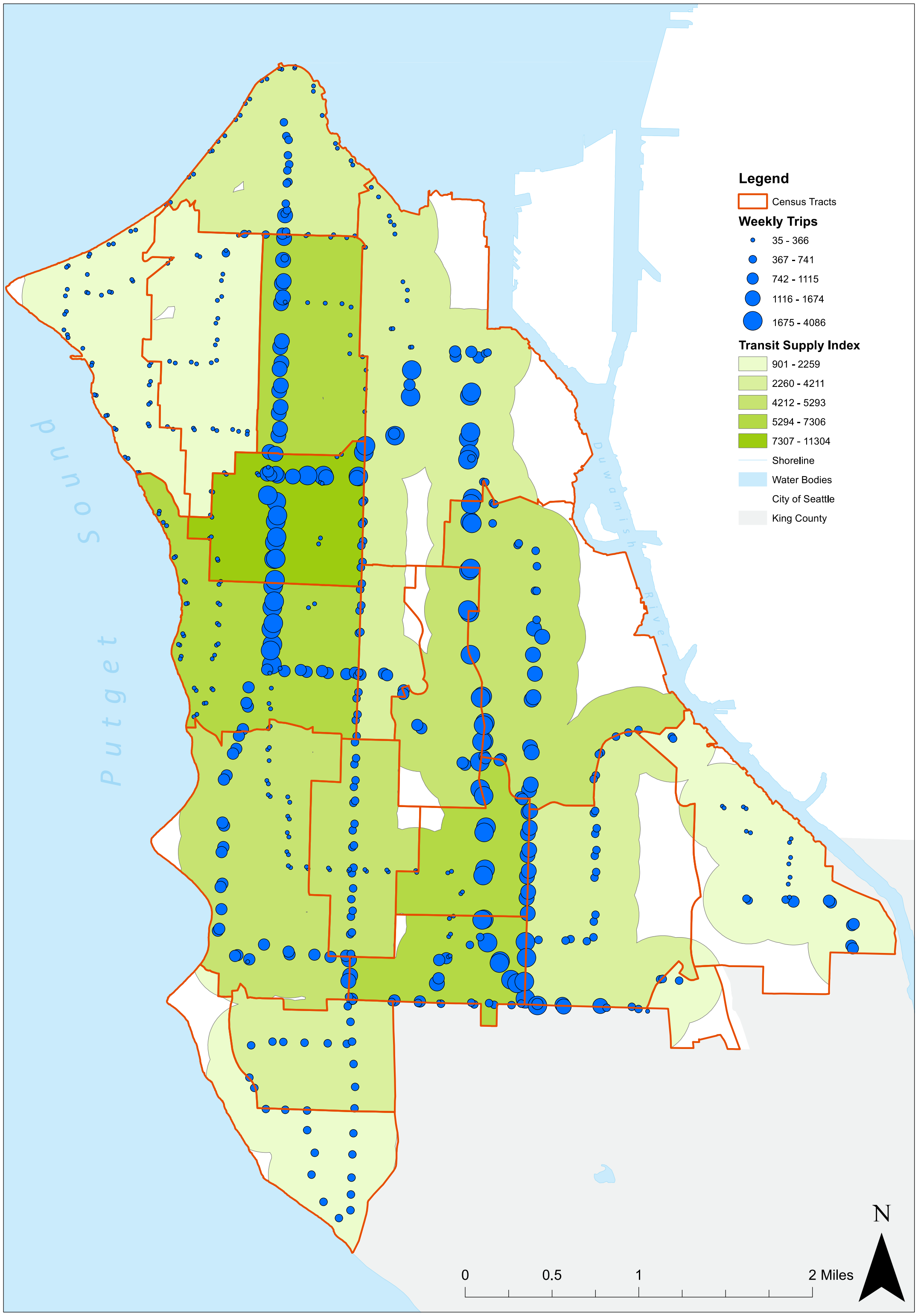


Figure 7. Weekly Trips and Transit Supply Index: Scenario 2

It is difficult to discern clear differences from these maps, however, because most of the positive impacts accrued to tracts that already had high SI scores, while the negative impacts were generally borne by tracts with low SI scores. It is much easier to see the geographic distribution of impacts by looking at the percentage change in total SI score between the two scenarios, as shown in Figure 8. This shows that, not surprisingly, the change towards a frequent, core route network causes the most service to be lost in tracts towards the edge of the study area, while most of the gains are concentrated towards the center. This finding supports the notion that some geographic coverage is lost, so mitigation alternatives that enable residents at the outside of the service area to reach the frequent service in the core could potentially offset some of the lost service.

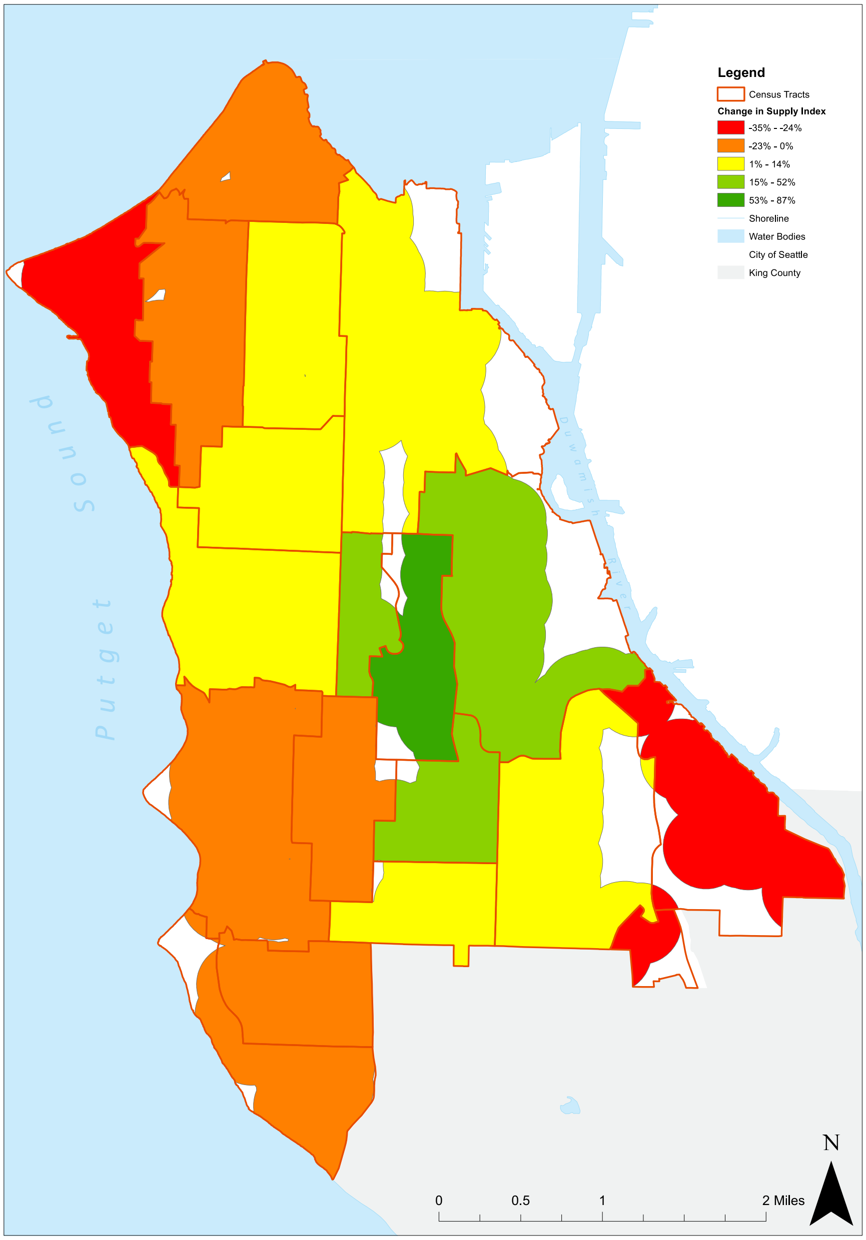


Figure 8. Percent change in Transit Supply Index

4.2 Distribution of Impacts

The following sections include a close analysis of the demographic makeup of tracts that suffered a decrease in the transit supply index in order to evaluate potential adverse equity effects. This process uses the results from the percentage change in transit supply index, along with GIS mapping to identify the quantity and location of census tracts with high densities of transport disadvantage that lost transit supply. The primary purpose of this step is to identify whether the service change had a disproportionate effect on the transport disadvantaged, and identify the spatial location and specific populations that could benefit from mitigation in order to offset the negative impacts. Densities for each population group higher than the study area average are considered "high", while concentrations at or below the average are considered low. The average percentages for each population in the study area are shown in Table 7.

Table 7. Study Area Average concentrations of transport disadvantages

	Total Populat ion	Poverty	People of color	Over 65	Under 18	Households w/o car
Average % of Tracts		11%	31%	11%	19%	9%
Total (households)	39454	3541.8				3125
Total (population)	88475		24602	10286	16329	

Source: US Census 2010, accessed from King County GIS Portal, 2012

The following sections describe the analysis and findings for each population group.

4.2.1 Poverty

The average percentage of households below the poverty line in the study area is 10.75 percent, with range between 2.5% and 40% (a difference of 37.5), as shown in Figure 9

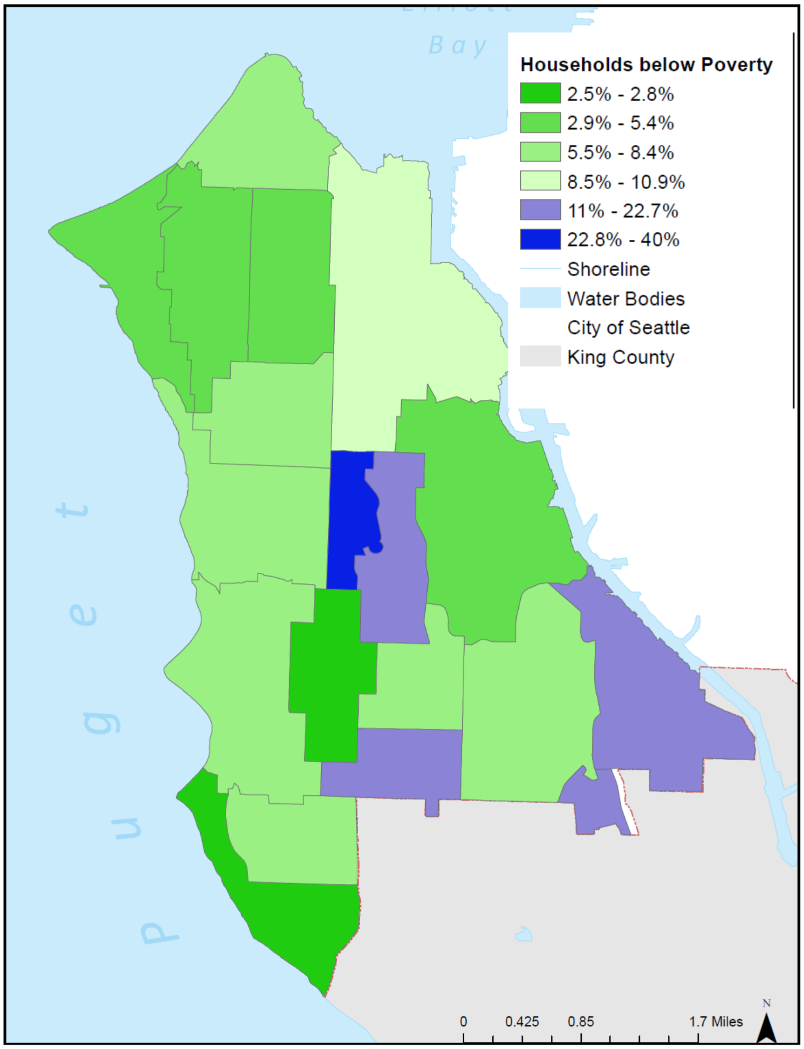


Figure 9. Map of Households below Poverty

Six census tracts fall above the study area average, as shown in Table 8. Overall, high poverty tracts experience a nearly 17% increase in SI, while low poverty tracts gain only 9%. This indicates that in answer to the first question (whether there is a disproportionate impact to high poverty tracts) it appears that high poverty tracts actually gain more than low poverty tracts.

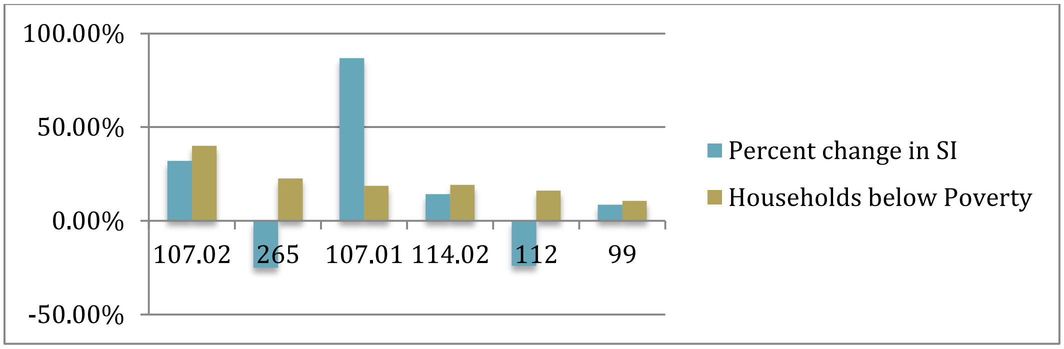
Table 8. Poverty data summary

	Census Tract	Scenario 1 SI	Scenario 2 SI	Percent Change	Number households	Households below Poverty	Percent Households below Poverty
High Poverty	**107.02**	2663	3513	31.92%	1058	422.9	40.0%
	265	1724	1291	-25.12%	1101	249.4	22.7%
	107.01	2553	4770	86.84%	1099	205.8	18.7%
	114.02	6093	6955	14.15%	1792	342.8	19.1%
	112	2592	1968	-24.07%	1292	208.2	16.1%
	99	3876	4211	8.64%	2404	253.6	10.6%
	High Sub-Total	19501	22708	**16.45%**		0.0	
Low Poverty	**105**	10420	11304	8.48%	2918	244.4	8.4%
	96	3616	3351	-7.33%	2757	206.9	7.5%
	120	3666	3665	-0.03%	1485	113.7	7.7%
	113	3723	3996	7.33%	2352	173.2	7.4%
	106	5950	6785	14.03%	3611	238.9	6.6%
	114.01	4356	6604	51.61%	1794	119.6	6.7%
	116	4937	4689	-5.02%	2784	179.6	6.5%
	98	6388	7306	14.37%	2964	157.0	5.3%
	97.01	1394	901	-35.37%	2974	141.8	5%
	108	3291	4650	41.29%	1621	87.0	5.4%
	97.02	2037	1913	-6.09%	2263	110.8	4.9%
	115	5508	5293	-3.90%	2029	57.7	2.8%
	121	2260	2259	-0.04%	1156	28.5	2.5%
	Low Sub-Total	57546	62716	**8.98%**			
	Study Area Average			**11.00%**			**10.71%**

Source: Census tract and population data from US Census 2010, accessed through King County GIS Portal, 2012. SI data based on data from King County Metro, 2012, unpublished.

However, as seen in Figure 10, two high poverty tracts – 265 and 112 – lose nearly a quarter of transit service, as measured by the supply index. These two tracts should be targeted for mitigation to reduce the impact of reduced fixed route transit, using strategies that are appropriate for low-income populations. This could include subsidies to reduce the cost of other modes of transportation, but will be discussed further in subsequent sections.

Figure 10. High proportion poverty tracts



4.2.2 Age: Youth

The average percentage of the population under 18 for the study area is 19.24%, with a high of nearly 30% and a low of 13% (or a range of 17 percentage points), as shown in Figure 11.

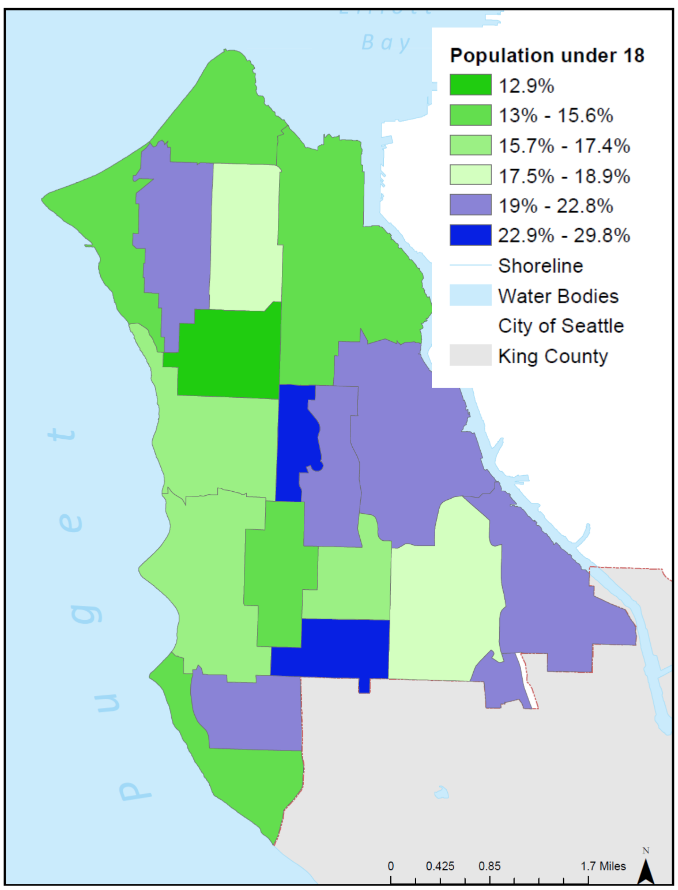


Figure 11. Map of Population Under 18

Eight tracks contain above average percentages of youth population, shown in

Table 9. The range of variation is smaller for youth than for poverty, as youth are unlikely to concentrate in the same way as poor households. Still, the average SI increase for high-youth tracts is 17.7%, compared to 7.93 for low-youth tracts, indicated there is not a disproportionately negative effect on high-youth areas.

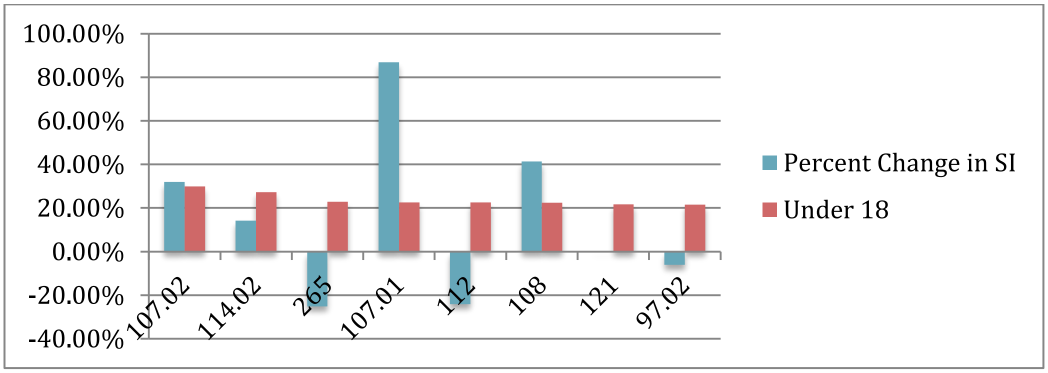
Table 9. Youth data summary

	Census Tract	Scenario 1 SI	Scenario 2 SI	Percent Change	Total Pop.	Pop. under 18	Percent under 18
High Youth	**107.02**	2663	3513	31.92%	2620	782	29.8%
	114.02	6093	6955	14.15%	4193	1146	27.3%
	265	1724	1291	-25.12%	2905	663	22.8%
	107.01	2553	4770	86.84%	2622	593	22.6%
	112	2592	1968	-24.07%	4102	927	22.6%
	108	3291	4650	41.29%	4683	1047	22.4%
	121	2260	2259	-0.04%	2565	557	21.7%
	97.02	2037	1913	-6.09%	5186	1118	21.6%
	High Sub-Total	23213	27319	**17.69%**			
Low Youth	**98**	6388	7306	14.37%	6127	1159	18.9%
	113	3723	3996	7.33%	5527	1039	18.8%
	106	5950	6785	14.03%	7087	1233	17.4%
	114.01	4356	6604	51.61%	3919	644	16.4%
	116	4937	4689	-5.02%	6304	1007	16.0%
	115	5508	5293	-3.90%	4152	646	15.6%
	120	3666	3665	-0.03%	3632	541	15%
	97.01	1394	901	-35.37%	5622	824	14.7%
	96	3616	3351	-7.33%	5714	833	14.6%
	99	3876	4211	8.64%	5091	740	14.5%
	105	10420	11304	8.48%	6424	830	12.9%
	Low Sub-Total	53834	58105	**7.93%**			
	Study Area Average			**11.00%**			782

Source: Census tract and population data from US Census 2010, accessed through King County GIS Portal, 2012. SI data based on data from King County Metro, 2012, unpublished.

Still, three tracts (112, 265, and 97.02) with above average youth populations experience a reduction in the transit supply index, while 5 are neutral or gain transit. These tracts should be targeted for youth-appropriate mitigation. Programs that rely on driving, such as car sharing or subsidies for car travel would probably not be appropriate for youth, many of whom would be under the legal driving age. Policies and programs to provide alternatives through bicycling should be explored.

Figure 12. High proportion youth tracts



4.2.3 Age: Over 65

The average percentage of the population 65 and above for the study area is 11.03%, with a high of 21.40% and a low of 5.24% (for a spread of 16.6 percentage points), as shown in Figure 13. This is range is very similar to the range for the population under 18, which is perhaps not surprising, given that in a geographic area as large as a census tract age distribution may be likely to closely mirror average.

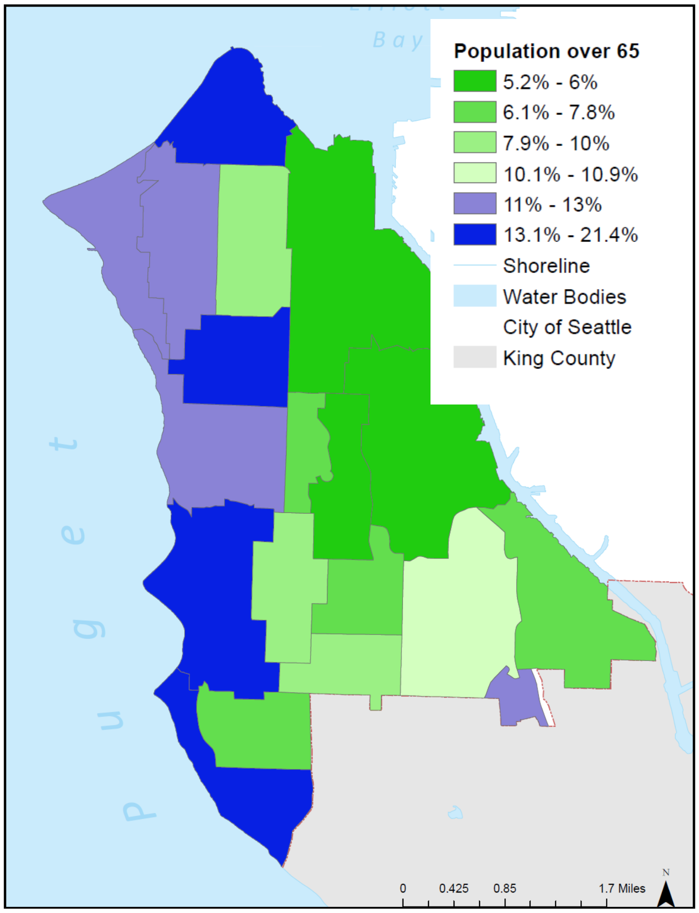


Figure 13. Map of Population over 65

Eight tracts in the study area have above average populations of people aged 65 and above (

Table 10). The overall change in SI for tracts with high proportions of people over 65 is 1.71%, compared to 19.25% for tracts with low proportions of people over 65. This indicates that although there is not a disproportionately negative impact to tracts with a larger proportion of elderly citizens, most of the benefits accrue to tracts that are lower in this population group.

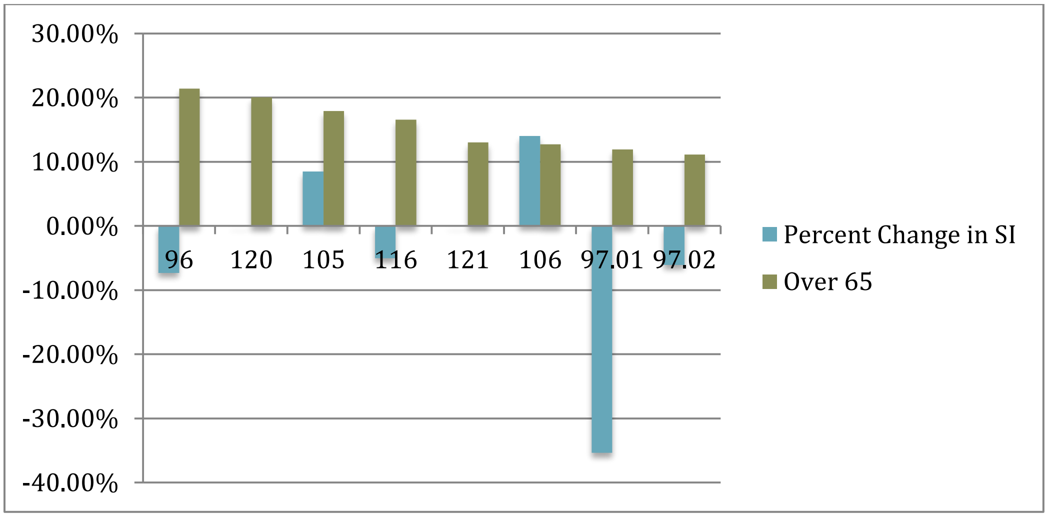
Table 10. Over 65 data summary

Group	Census Tract	Scenario 1 SI	Scenario 2 SI	Percent Change in SI	Total Pop	Pop Over 65	Percent Over 65
	96	3616	3351	-7.33%	5714	1223	21.40%
	120	3666	3665	-0.03%	3632	728	20.04%
	105	10420	11304	8.48%	6424	1151	17.92%
	116	4937	4689	-5.02%	6304	1043	16.55%
	121	2260	2259	-0.04%	2565	334	13.01%
	106	5950	6785	14.03%	7087	902	12.73%
	97.01	1394	901	-35.37%	5622	670	11.92%
	97.02	2037	1913	-6.09%	5186	576	11.11%
High 65+	**High Sub-Total**	34280	34867	**1.71%**			
	113	3723	3996	7.33%	5527	602	10.89%
	98	6388	7306	14.37%	6127	612	9.99%
	115	5508	5293	-3.90%	4152	388	9.34%
	114.02	6093	6955	14.15%	4193	364	8.68%
	112	2592	1968	-24.07%	4102	318	7.75%
	114.01	4356	6604	51.61%	3919	297	7.58%
	265	1724	1291	-25.12%	2905	202	6.97%
	107.02	2663	3513	31.92%	2620	177	6.76%
	108	3291	4650	41.29%	4683	280	5.98%
	107.01	2553	4770	86.84%	2622	152	5.80%
	99	3876	4211	8.64%	5091	267	5.24%
Low 65+	**Low Sub-Total**	39044	46561	**19.25%**			
	Study Area Average			**11.00%**			**11.03%**

Source: Census tract and population data from US Census 2010, accessed through King County GIS Portal, 2012. SI data based on data from King County Metro, 2012, unpublished.

As Figure 14 shows, several tracts with a high proportion of people over 65 experience a significant decline in SI including 96, 116, 97.01 and 97.02. These tracts should be targeted for mitigation appropriate for an older population. Something similar to paratransit or flexible transit might be more appropriate than programs to support the use of other modes.

Figure 14. High proportion Population over 65 tracts



4.2.4 Race: People of Color

The average percentage of people of color (non-white) in the study area is 31.29%, with variation from 65.40% to 11.29%, shown in Figure 15. The range is the highest of all variables so far, at 54%.

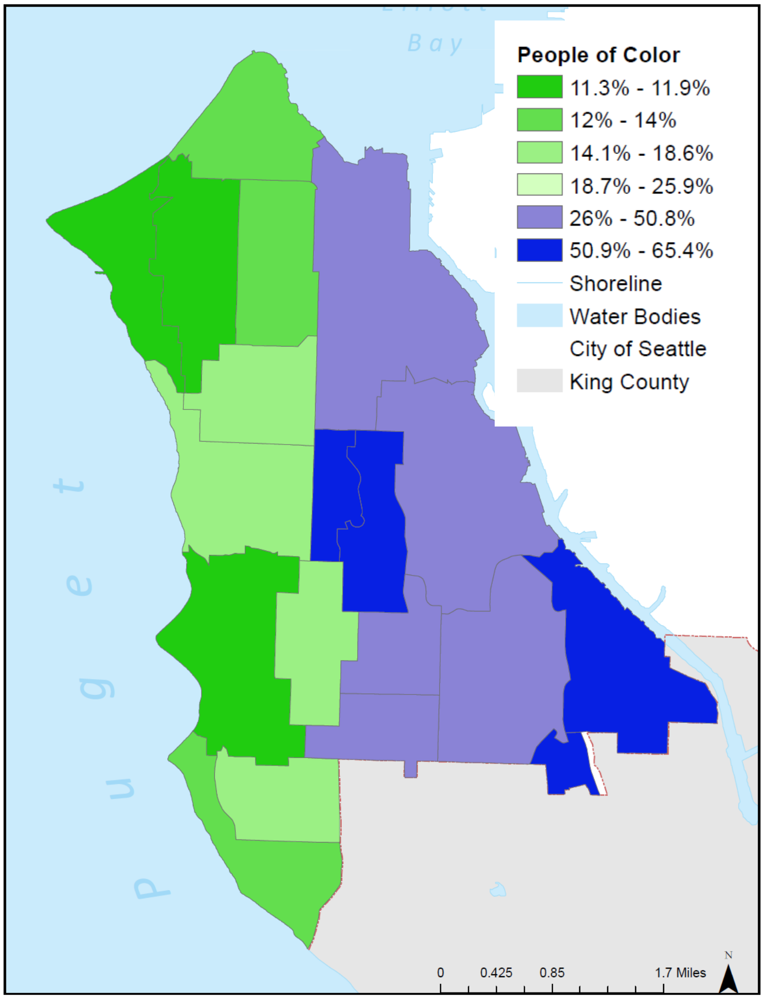


Figure 15. Map of People of Color

Eight tracts have above average concentrations of people of color, with an average transit supply gain of supply gain of 25.01%. Low percentage people of color tracts have an average gain of 3.25%. It would therefore 3.25%. It would therefore appear that tracts with a high percentage of people of color are not only are not not only are not disproportionately burdened by the service change, but instead accrue a greater proportion of greater proportion of the benefits on average (

Table 11).

Table 11. People of Color data summary

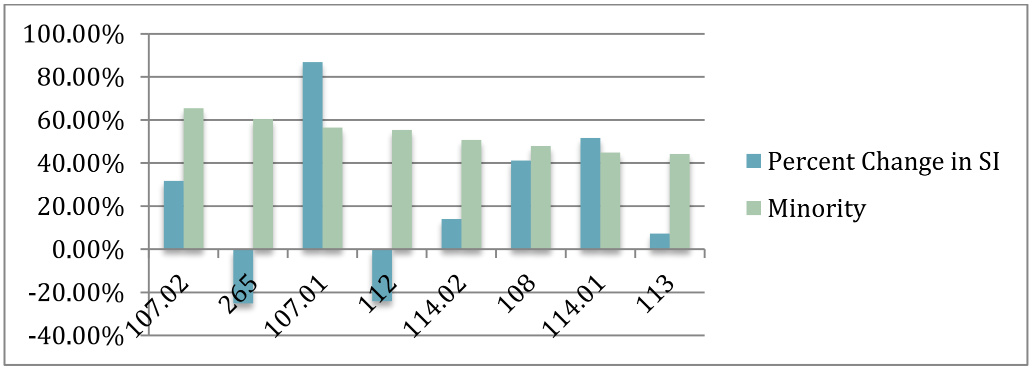
	Census Tract	Scenario 1 SI	Scenario 2 SI	Percent Change in SI	Total Pop.	Pop. People of Color	Percent People of Color
High People of Color	**107.02**	2663	3513	31.92%	2620	1713	65.40%
	265	1724	1291	-25.12%	2905	1754	60.36%
	107.01	2553	4770	86.84%	2622	1482	56.51%
	112	2592	1968	-24.07%	4102	2273	55.40%
	114.02	6093	6955	14.15%	4193	2131	50.81%
	108	3291	4650	41.29%	4683	2241	47.85%
	114.01	4356	6604	51.61%	3919	1760	44.90%
	113	3723	3996	7.33%	5527	2443	44.20%
	High Sub-Total	26995	33747	**25.01%**			
Low People of Color	**99**	3876	4211	8.64%	5091	1338	26.28%
	115	5508	5293	-3.90%	4152	771	18.56%
	120	3666	3665	-0.03%	3632	620	17.08%
	106	5950	6785	14.03%	7087	1144	16.14%
	105	10420	11304	8.48%	6424	995	15.48%
	121	2260	2259	-0.04%	2565	360	14.02%
	98	6388	7306	14.37%	6127	838	13.68%
	96	3616	3351	-7.33%	5714	737	12.89%
	116	4937	4689	-5.02%	6304	753	11.94%
	97.01	1394	901	-35.37%	5622	664	11.81%
	97.02	2037	1913	-6.09%	5186	585	11.29%
	Low Sub-Total	50052	51677	**3.25%**			
	Study Area Average			**11.00%**			**31.29%**

Source: Census tract and population data from US Census 2010, accessed through King County GIS Portal, 2012. SI data based on data from King County Metro, 2012, unpublished.

In looking at the high-people of color tracts specifically (

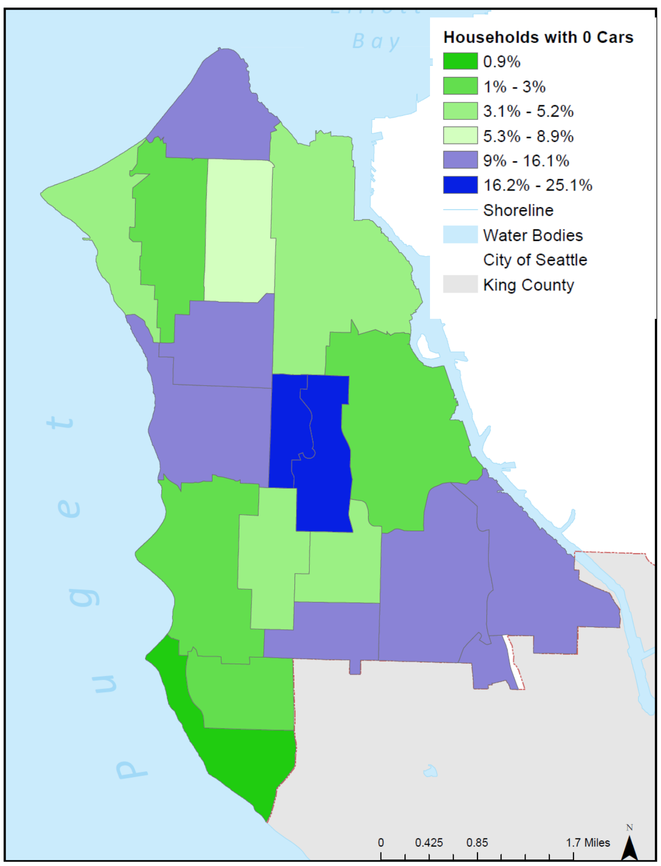
Figure 16), there are only two that have reduced transit supply – tract 265 and tract 112. Mitigation alternatives for these tracts should be targeted towards the needs of the unique communities within the non-white population.

Figure 16. High proportion minority tracts



4.2.5 Car ownership

The average level of car ownership is 8.62%, ranging from 0.87% to 25.14, or a range of 24.27 percentage points.



A total of nine tracts are above the average, with an average gain of 11.69% in the transit supply index. Tracts with low carelessness experience an average change of 10.02%, suggesting that the distribution is relatively evenly spread between tracts with high car ownership and tracts with low car ownership.

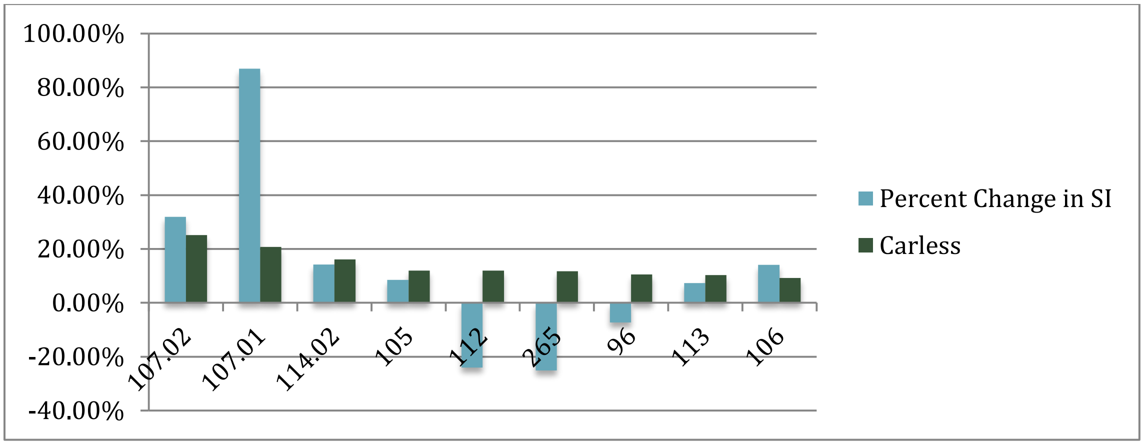
Table 12. Car ownership data summary

	Census Tract	Scenario 1 SI	Scenario 2 SI	Percent Change in SI	Number households	Households with 0 Cars	Percent with 0 Cars
High Households with 0 Cars	**107.02**	2663	3513	31.92%	1058	266	25.14%
	107.01	2553	4770	86.84%	1099	228	20.75%
	114.02	6093	6955	14.15%	1792	288	16.07%
	105	10420	11304	8.48%	2918	349	11.96%
	112	2592	1968	-24.07%	1292	154	11.92%
	265	1724	1291	-25.12%	1101	129	11.72%
	96	3616	3351	-7.33%	2757	291	10.55%
	113	3723	3996	7.33%	2352	241	10.25%
	106	5950	6785	14.03%	3611	331	9.17%
	High Sub-Total	39334	43933	**11.69%**			
Low Households with 0 Cars	**98**	6388	7306	14.37%	2964	216	7.29%
	99	3876	4211	8.64%	2404	125	5.20%
	97.01	1394	901	-35.37%	2974	136	4.57%
	114.01	4356	6604	51.61%	1794	77	4.29%
	115	5508	5293	-3.90%	2029	81	3.99%
	108	3291	4650	41.29%	1621	49	3.02%
	116	4937	4689	-5.02%	2784	73	2.62%
	120	3666	3665	-0.03%	1485	36	2.42%
	97.02	2037	1913	-6.09%	2263	45	1.99%
	121	2260	2259	-0.04%	1156	10	0.87%
	Low Sub-Total	37713	41491	**10.02%**			
	Study Area Average			**11.00%**			**8.62%**

Source: Census tract and population data from US Census 2010, accessed through King County GIS Portal, 2012. SI data based on data from King County Metro, 2012, unpublished.

Looking at the tracts with high proportions of carless households, three lose transit supply index in Scenario 2 – tracts 112, 265, and 96. While mitigation for the hypothetical service change developed here could include measures targeted at this specific population – for example subsidies for the cost of driving would probably not be a viable option, it is also likely that mitigation for this group would not be required.

Figure 17. High proportion carelessness tracts



4.3 Summary of Impacts

This analysis found that, on average, none of the transport disadvantaged groups studied had a disproportionately negative impact from the transit service change from Scenario 1 to Scenario 2. In fact, for four out of five of the socio-demographic groups studied, the average benefits to tracts with high disadvantage were greater than for non-disadvantaged tracts. The exception was for tracts with a high population over 65, where benefits for tracts with a low population were much greater than those with a high population. This finding suggests that with the exception of the population over 65, shifting to a high-frequency core service network may meet an egalitarian, or even Rawlsian, definition of equity.

4.3.1 High-impact, High-transport disadvantage tracts

However, there were several individual tracts with high concentrations of each of the transport disadvantaged population groups that experienced significant reductions in transit supply, as measured by the transit supply index. There was significant overlap between the tracts that fell into this latter group – of 14 total high-impact tracts with high concentrations of the different transport disadvantages, two tracts with high impacts had high concentrations of each population group, as shown in Figure 17. Several of these tracts did have very high reductions in the transit supply index, ranging from around negative 25% for tracts 112 and 265 to negative 35% for tract 97.01.

Table 13. High-impact high-transport disadvantage tracts

Tract	Households below Poverty	Under 18	Over 65	Minority	Households w/o car
265.0	x	x		x	x
112.0	x	x		x	x
97.02		x	x		
96.00			x		x
116.0			x		
97.01			x		

Source: Census tract and population data from US Census 2010, accessed through King County GIS Portal, 2012. Other data based on data from King County Metro, 2012, unpublished.

Figure 18 shows a map of these six tracts, which have a decline in SI and above average percentages of one or more of the four primary disadvantaged groups (car ownership, as mentioned previously, has a more complicated relation to transport disadvantage).

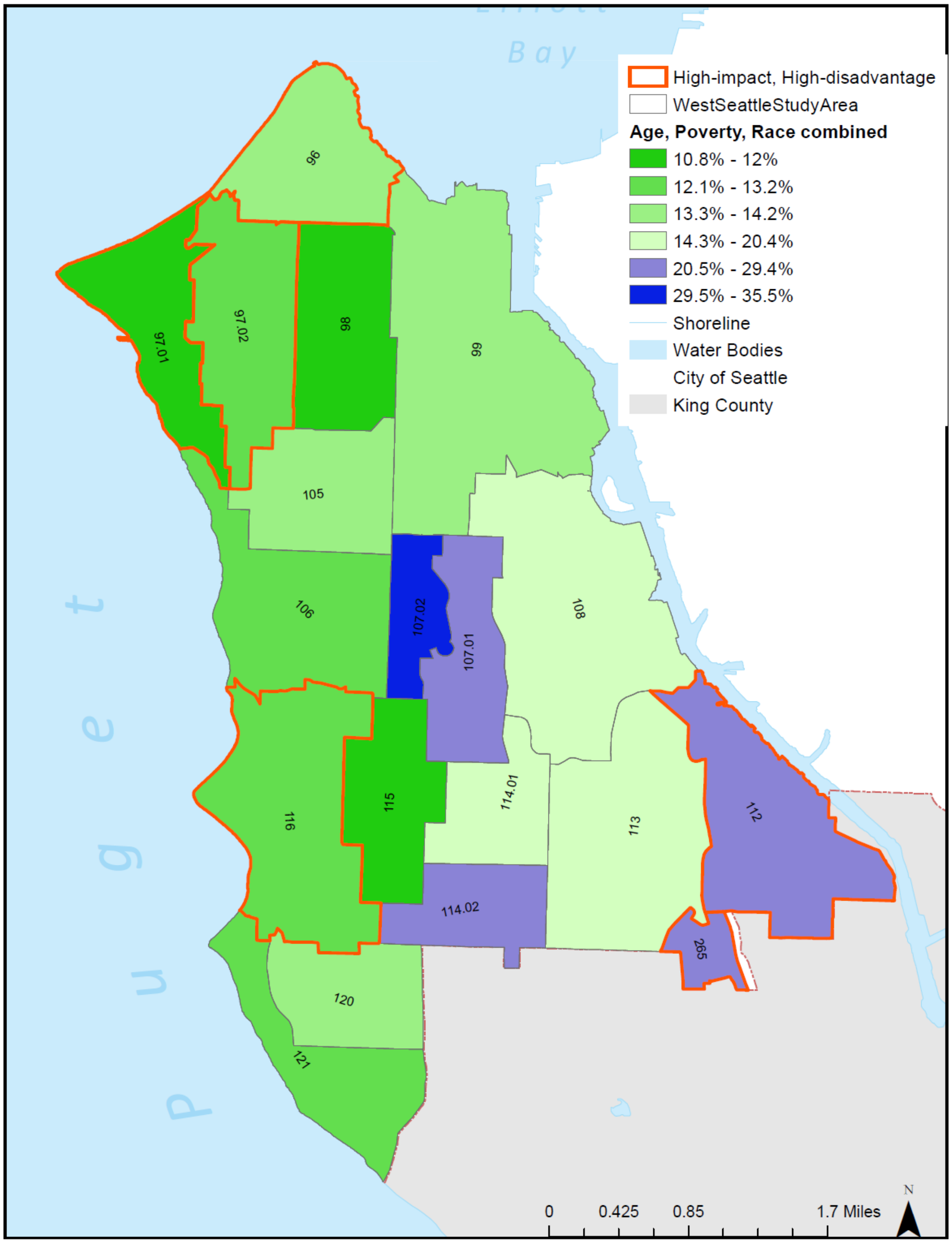


Figure 18. Map of high-impact, high-disadvantage tracts

While on the one hand the overlap between tracts suggests that a more nuanced route restructure could avoid some of the negative impacts by retaining service within these tracts – as a transit agency might typically do – there are also several areas where the populations of interest are spread between different tracts. For example the census tracts with high impact and high concentrations of people over 65 do not share any overlap with the tracts that are high impact and high minority.

5 Discussion

The purpose of this study was to find out what the potential equity effects might be from a shift away from transit service that emphasizes geographic coverage and local routes, towards service that emphasizes productivity and service along core, frequent routes The findings presented in Chapter 5 generally suggest that there may be positive equity implications associated with a shift in service provision towards increased frequency on high-productivity routes and decreased service on low productivity routes. At the same time, some geographies with high concentrations of specific transport disadvantaged populations could lose service, which would require mitigation or reconsideration of the restructure design in order to counteract negative equity impacts.

5.1 Findings

There are several possible explanations for the finding that moving from Scenario 1 (current service) to the hypothetical Scenario 2 carries, generally speaking, the most benefit for the most transit disadvantaged communities. For one, routes that received increased service in Scenario 2 were those that measured the highest in a combined measure of productivity citywide and relative to the study area. Given that, by definition, transport disadvantaged communities are more likely to rely on public transportation due to disadvantage in access to all modes (and indeed serving these communities is one of the primary purposes of public transit systems) it is not surprising that high ridership might be found in areas with high transport disadvantaged populations. Compounding this factor could be that Metro already incorporates equity into service planning, therefore it is highly possible that Metro purposefully provides high frequencies to transport disadvantaged communities, and frequency in turn increases transit quality, further increasing ridership.

The geographic distribution of transport disadvantaged communities may also play a role, in that in an urban context, transport disadvantaged communities may be more likely to live in areas with dense population compared to non-disadvantaged communities, who have the opportunity expend more resources for additional square feet of housing in lower density areas or in time and money spent commuting to job centers. Although this study did not analyze population density per say, population density is the single most important predictor of transit ridership, which in turn increases transit productivity. If transport disadvantaged communities are spatially concentrated in areas of high population density, they are likely to be served by routes with high productivity. However, for those populations that live outside of the core service area, a reduction in transit service could be potentially severe. In other words, a majority of both transport disadvantaged and non-transport disadvantaged populations may gain service, but for those who lose service, some high-transport disadvantaged areas may be left with even fewer alternatives, compounding transport disadvantage. The potential for this kind of outcome warrants serious evaluation of mitigation alternatives.

Ultimately, it appears that at the very least the equality/egalitarian model of equity introduced in section 2.1.2 is being met in that any negative impacts are not disproportionately distributed towards transport disadvantaged communities. In fact, even the stricter Rawlsian notion of equity may be met by shifting towards a network structure with greater emphasis on productivity, in that most of the transport disadvantaged communities studied in this research experience greater benefit than non-transport disadvantaged areas, on average. However, for equitable outcomes for all census tracts, the negative impacts to “high-impact high-disadvantage” tracts would need to be addressed. Fortunately, Metro’s process for evaluating equity as part of Title VI reporting ensures that service reductions to at least some types of transport disadvantaged communities are identified and addressed. Additionally, further development of new tools for mitigation could provide alternative, cost-effective strategies to replacing lost transit service.

5.1.1 Comparison to Metro service revision

The high-frequency, core route scenario developed in this study was developed using a very simple methodology – service was cut from the lowest productivity routes and added to the highest productivity routes. In reality, Metro would used a more nuanced toolbox that could include cutting service or adding service to individual stops instead of entire routes, restructuring and merging routes, and adjusting frequencies for certain time periods only. This is evidenced in Table 14, which shows that the Metro restructure includes a significant of revisions to routing, in addition to revision of trip frequencies.

Table 14. West Seattle Restructure Comparison

Key:

Reduced frequency/number of trips	Increased frequency/number of trips

West Seattle Routes	Study methodology	Metro planned restructure
21		Revise routing
22		Revise routing
23		Discontinue
51		Discontinue
53		Discontinue
54		Discontinue
55		No changes to routing, peak only
56		Discontinue
57		Revise routing
60		Revise routing
85		Discontinue
113		
118		
119		
120		Revise routing
125		Revise routing
128		Revise routing
131		Revise routing
132		Revise routing
133		
134		
116EX		No changes
118EX		
119EX		
21EX		No routing changes
37EX	EX	
54EX	EX	Discontinue
Rapid Ride C		New route

Source: King County Metro, 2012d.

Although the routes I selected for service additions or reductions are not the same as those selected in the Metro restructure, both exchange service on a high number of routes for service additions on fewer, high-frequency routes, suggesting that this aspect of the scenarios used in this study is somewhat realistic.

5.2 Limitations and generalizability

5.2.1 Data sources

One of the primary limitations of this study is due to the level and types of data used, particularly the use of census tract data. While this enabled inclusion of a large study area and improved reliability (due to the high margin of error for data collected in the American Community Survey at anything below a census tract level), census tract data is limited in other ways. For example, the study assumed even distribution of population within tracts, which is extremely unlikely. Some of the tracts towards the Eastern boundary of the study area are part of the Duwamish industrial area and likely have low population. It is also possible that the density of transport disadvantaged groups is outside the walkshed of the individual bus stops that receive increase service, as this study relies on the average change in Transit Supply Index across the entire tract. Census Blocks or Block Groups would give much more accurate data on population density, however they would have had very limited reliability for demographic traits such as income and car ownership.

Another limitation was the fact that I was not able to include disability among the variables considered as transport disadvantaged, due to the fact that this data has not been released at the Census Tract level for 2010. Disability is an important factor for public transit agencies, particularly becuase public transport may be the only transportation available to some members of this group. However, the Americans with Disability Act is a powerful piece of legislation, which includes mandates regarding alternative public transportation options for qualifying people with disabilities. King County Metro operates Dial-A-Ride-Transit (DART) services to specifically meet these obligations and serve people with disabilities. More study would be required to fully analyze the overall impact to transit access and mobility of a service change such as that suggested here.

5.2.2 Methodology

The methodology used involved several simplifications of complex factors regarding public transportation service. For one, the use of the Transit Supply Index as a measure of transit quantity and quality is a very simplified measure in light of the many variables that ultimately affect the usefulness of service – including on and off-board travel time, ability to reach desired destinations, transit comfort, cost, service span, reliability, availability of real-time arrival information, and others. However it is still slightly more advanced than the weekly trip measure used in the Metro methodology for Title VI analysis.

Another issue is the use of "weekly trips" as a common currency for reallocating service. Weekly trips may not be an accurate proxy for the overall cost of service, since cost is much higher for long routes (in terms of time required to complete one cycle) and one-way peak service that requires deadheading in one direction. In the end, the number of trips added in Scenario 2 was not exactly equal to the number of trips that were reduced, though the difference was less than one percent of total weekly trips in the study area (100 total trips).

5.2.3 Transferability

The findings of this study are likely to be similar in other parts of Seattle. As a dense urban area, transportation disadvantaged populations may be concentrated in center-city neighborhoods that were historically home to economically and socially disadvantaged groups. If this is true, these populations are likely to benefit from transit investments that increase frequency along core routes with high ridership. However, two factors could limit the potential positive benefits of this finding. The first is that, as was found here, some transportation disadvantaged groups may be concentrated towards the outer edges of the city, perhaps particularly at the Northern and Southern boundaries (the Eastern and Western periphery of Seattle, in contrast, is along the water and therefore tend to be high-income). These areas could lose transit service in a restructure that is based purely on productivity. Secondly, as development and gentrification occur in inner-city neighborhoods, it is possible that transportation disadvantaged groups will be forced to move not only to the periphery of the city, but to further suburbs or rural areas. This has the potential to significantly exacerbate their transportation disadvantage and at the same time decrease the positive equity impacts of increasing service to dense inner-city areas. Several recent studies have evaluated the relationship between gentrification and public transportation infrastructure investments such as light rail or rapid bus technology (Plevak 2010; Pollack, Bluestone, and Billingham 2010; Sage 2012).

5.3 Mitigation Alternatives

Mitigation is an important component of transportation packages that have the potential to reduce transit access for some. At the county level, an ordinance approved by the King County Council in August of 2011 included a call for Metro to “right-size” some of the fixed-route transit service in south and east King County in order to cut operating costs. The primary objective was to provide a more efficient and appropriate level of service that would continue to meet the community’s mobility needs. The ordinance called for between 5,000 and 20,000 annual hours of traditional fixed route service to be “right sized” by June 2012 (King County Metro 2012c, 3). As part of this effort, Metro recently published a *Five-year implementation plan for alternatives to transit service delivery* report. King County Metro already operates several types of alternate service, including Dial-A-Ride-Transit (DART), which could expand service beyond qualified citizens with disabilities, serving as a replacement for very low productivity fixed-route service in rural areas. The Metro “family” of services and their respective boardings and costs are shown in Figure 19.

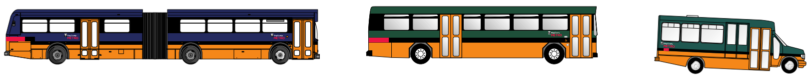
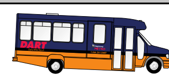
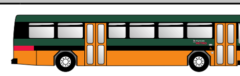
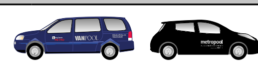
Current products, usage, and budget[2]			
Fixed-route service (60-, 40-, and 30-foot coaches; transit vans)			
			
Annual boardings	**Average operating cost/boarding**	**Annual operating cost**	**Average fare revenue/boarding**
109,583,654	$4.03	$442,147,051	$1.13
Dial-a-Ride-Transit (DART) service (transit vans)			
			
Annual boardings	**Average operating cost/boarding**	**Annual operating cost**	**Average fare revenue/boarding**
817,030	$7.30	$5,964,808	$1.13
Custom bus (40- and 30-foot coaches)			
			
Annual boardings	**Average operating cost/boarding**	**Annual operating cost**	**Average fare revenue/boarding**
193,464	$7.74	$1,496,885	$4.40
Vanpool/Vanshare, MetroPool (commuter vans)			
			
Annual boardings	**Average operating cost/boarding**	**Annual operating cost**	**Average fare revenue/boarding**
2,849,585	$1.69	$4,810,170	$2.06[3]
Taxi scrip			
Annual boardings	**Average operating cost/boarding**	**Annual operating cost**	**Average fare revenue/boarding**
32,502	$9.98	$323,134	50% of meter
Community Access Transportation			
Annual boardings	**Average operating cost/boarding**	**Annual operating cost**	**Average fare revenue/boarding**
250,369	$4.59	$1,149,193	$0 to $0.50
Access paratransit service (transit vans)			
			
Annual boardings	**Average operating cost/boarding**	**Annual operating cost**	**Average fare revenue/boarding**
1,229,039	$38.64	$48,795,947	$0.25

Figure 19. Metro Service Family *Source*: King County Metro, 2012f.

This table highlights the fact that there is an incredible range of operating cost per boarding for different services, from a low of $1.69 for the vanshare/vanpool/Metropool programs to a high of $38.64 for Access paratransit service. It should be noted that these services may also have widely varying infrastructure costs, not reflected in the number shown in Figure 19. Metro's challenge is to improve cost-efficiency, while at the same time meeting legal obligations with respect to paratransit and providing mobility throughout the service area.

Although the focus of June 2012 Alternative Service Delivery report is on rural areas, it includes an overview of best practices used in both urban and rural areas throughout the country. Several other studies have evaluated pilot programs and other efforts to develop successful alternatives to fixed route transit service that meet the needs of people facing transport disadvantage. Some of these tools may be more appropriate for specific groups; as was discussed in previous chapters, six census tracts in the study area had high concentrations of one or more high disadvantage groups and high negative impacts from the change of service in Scenario 1. Therefore solutions appropriate for households below poverty, young people, people over 65, minority groups, and households without cars should be explored.

There are a number of alternative types of transit delivery, including flexible route transit, jitneys, and more. However these programs have been well documented in reports such a paper from the Transit Cooperative Research Program, *A Guide for Planning and Operation of Flexible Public Transportation Services* (Potts et al. 2010). Instead, the following strategies focus on two types of mitigation. The first group consists of automobile-based programs, including the potential for partnership between transit agencies, private providers, volunteers, non-profit organizations, and private citizens. The second group describes potential programs to encourage bicycling, which may be particularly well suited to an urban context, as the distances are not as great as in rural environments and bicycle facilities can be provided cost-effectively. Both types of programs also have the potential for significant environmental benefits, as carpooling is one of the most fuel-efficient modes of transport, while bicycling uses no fuel at all Several possible strategies are highlighted below, though this list is not comprehensive.

5.3.1 Auto-based programs

As shown in Figure 19, King County Metro's van sharing programs have the lowest cost per boarding in addition to the highest revenue per boarding. Van sharing and car sharing programs have significant potential to carry riders cost-effectively, particularly for commute patterns not well served by fixed route transit. Such programs can be run and operated by Metro or provided privately through car-sharing services such as Zipcar, or through more informal car-sharing and carpool programs.

- **Auto loans**: Some programs may directly aim to increase automobile ownership. For example, one California program helped provide low-interest loans for automobile purchase or repair to low-income parents and welfare recipients, in order to assist the transition from welfare to work. Although controversial, the program demonstrated effectiveness in reaching the target audience including women and particularly single mothers, and found that gross income improved 36.9% by the end of the loan term (Cervero and Tsai 2003)
- **Car sharing:** Car sharing allows the cost of automobile ownership, including capital costs and maintenance costs, to be shared among drivers. There are several program models, including for-profit subscription programs and co-operative arrangements where car-sharing is provided by a private entity as an amenity to members - such as an car-sharing for an apartment building, resort, or university (Katzev 2003; Billard-Ball et al. 2005). There is some evidence that members of car-sharing programs, as implemented thusfar, tend to be well-educated and not low-income (Billard-Ball et al. 2005). However, car sharing as part of a public transportation system is a possibility that has not been greatly explored, particularly in the United States (Billard-Ball et al. 2005). Such a program could be integrated into the transit system in a similar manner as bike-share programs, with cars available at major stations for short-term loans. Discounts or subsidies could be provided to low-income drivers. In order to increase the participation among transport-disadvantaged communities, it might be worth exploring the rates of licensed drivers in different communities and barriers to licensing.

- **Informal carpooling:** Metro does not directly offer resources for private carpooling, but does provide links to a WSDOT program, RideshareOnline.com. This service is commute-oriented, though it does allow for ridematching for special events or private trips. Further research on the success and adoption rate for this program could provide insight as to how well this program meets the needs of transit disadvantaged populations and what might encourage increased use. Emerging technology could help facilitate ridesharing for trips that may benefit especially from auto use, such as trips to large grocery stores. Increased private carpooling could take advantage of excess capacity in private vehicles and improve mobility especially for those who are not able to drive themselves. Low-income auto-mobile owners could benefit from carpooling by avoiding tolls and/or saving time in carpool-only lanes, and from cost-sharing for fuel.
- **Taxi subsidies:** Metro currently operates a taxi scrip program, which covers 50% of the cost of up to six taxi rides per month for qualified participants. However this program is quite costly, at nearly $10 per boarding.

5.3.2 Bike programs

Transit restructures that increase frequency on one or more core routes may improve service enough that the potential ridership area expands beyond the quarter-mile walkshed used in this study. One of the new transportation needs that emerges when a new high frequency line is built is the “last mile”, getting local riders to the trunk line where they either transfer from local bus service to the frequent network, or arrive by another mode. Bicycles have a huge potential to provide this “last mile” connection, particularly since all Metro buses are equipped with bicycle racks (DeMaio 2009). However secure parking at transit stations is also key to accommodating higher bicycle volumes than could be carried on bus-mounted racks. **Error! Reference source not found.** shows heavily-used bicycle parking at a rail station in Groningen, the Netherlands. Some of the potential programs for encouraging bicycling as an alternative to fixed-route transit are described below:

- **Bike library:** A bicycle library program allows participants to borrow a bicycle for a short-term or long-term period. This type of program could be well suited for helping introduce new populations to bicycling, providing mobility when an automobile is out of service, and as an interim if a full bicycle share program is not available.
- **Bike sharing:** Bicycle sharing has perhaps the most significant potential to meet the needs of communities without physical mobility limitations that lose some fixed-route transit service. Bicycle share programs allow short-term bike rental at relatively low cost and high flexibility, as bicycles can typically be checked out from any station and returned to another (DeMaio 2009). One option that Metro could explore is the potential for integrating payment with the ORCA card system and allowing citizens who currently qualify for the Regional Reduced Fare Permit (RRFP), youth, and potentially other groups to access the bicycle share system for free or at a reduced cost.
- **Bike ownership:** A recent survey of Seattle residents found that only 40% of respondents reported having access to a working bicycle (SDOT 2012, unpublished). Although there are currently some bicycle exchanges and giveaway programs operated by non-profits in the Seattle area, it may be worthwhile for Metro to consider whether the long-term costs of providing free or subsidized bicycles could be worthwhile in terms of improved mobility for transit reliant populations.

As cities continue to develop a more robust and varied system for delivering sustainable and equitable transportation alternatives to the private automobile, research in this area will likely continue to expand (Goldman and Gorham 2006; DeMaio 2009; Rietveld and Daniel 2004; Billard-Ball et al. 2005). The existing research suggests that there are many promising possibilities for future development of automobile and bicycle-based alternatives to low-productivity fixed-route service, even in urban areas.

6 Conclusions

6.1 Potential for future study

This topic may prove an increasingly important area for research in the future, if transit agencies continue to face budget shortfalls that force service restructures to support the most productive transit service at the expense of less productive local service. Additionally, as many North American cities work towards significant infrastructure upgrades to provide rapid/high capacity bus or rail service, local transit service networks will need to be restructured so that they provide more local connectivity to the core network in the place of direct service to destinations outside of the local area.

One potential avenue for further study would be a city-wide study using the methodology developed in this thesis in Seattle or another city, in order to determine whether my findings hold true for different geographic areas, which may have different distributions of transit service and transit disadvantaged populations. For example, there may be some areas where the highest concentrations of transit-disadvantaged populations are also in low-density areas that are very difficult to serve effectively with fixed route transit. Although this is more likely to occur in suburban or rural areas, it is possible such a structure would exist in other parts of Seattle, or even in other urban areas in the country.

Perhaps most interesting would be a more detailed study of potential mitigation alternatives within an urban context, including the potential for innovative car-sharing and bicycle programs. Much of the current work has focused on flexible route transit and alternatives for rural areas, which are some of the most difficult to serve efficiently with fixed-route transit. Additionally, because geographic isolation is far from the only barrier to mobility, there are other population groups, including (but not limited to) those studied here, that may not cluster spatially and therefore could be better served by mitigation alternatives that are not tied to spatial location – for example a program to provide free or subsidized bikes to students throughout the city. The potential for new, innovative solutions also raises some interesting questions about the role of public transit agencies in the future with respect to what may become an increasingly multi-modal transportation system.

6.2 Summary of Findings

This thesis defined transport disadvantaged communities in West Seattle as those census tracts with higher than average densities of people under age 18, over age 65, people of color, households below the poverty line, and people without cars. In a scenario where weekly transit trips are reduced from the routes with the lowest productivity and reallocated to the routes with the highest productivity, overall transit supply (measured by the Transit Supply Index) increases more for all transport disadvantaged groups than for non-disadvantaged groups, with the exception of the population over age 65. This supports the potential benefits of the type of strategic planning and service guidelines recently adopted by Metro and the frequent network advanced in Seattle's TMP.

Still, in a relatively simple network restructure such as this, there are some severe impacts to a handful of census tracts with high concentrations of one or more of the transport disadvantaged communities. These impacts could be mitigated or obviated by a more complex service restructure, such as an alteration of the routing so as to reduce negative impacts to high priority areas, or through mitigation approaches that encourage the use of other modes, such as walking, bicycling, or driving.

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