Employing life-cycle assessment and comparative analysis to reveal holistic perspectives in regional sustainable development

by

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ABSTRACT

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To combat climate change, rapid population growth, and sprawl, many urban areas are increasing public transit infrastructure. In Seattle, Washington, the first regional extension of a central light-rail line is planned to open its doors in 2023. This study closely examines the climate change mediation potential of the extension, known as East Link. While the system's pollution reduction potential was addressed in an environmental impact statement, it did not include the impact from manufacturing construction and infrastructure materials. Previous studies have shown construction materials to be the single largest source of greenhouse gasses over a transit system's life cycle (Chester and Horvath, 2009; Chester et al 2012). This study aims to fill this gap by conducting a life-cycle assessment of East Link's construction materials. The results of the life-cycle assessment show a vast underestimate of greenhouse gas impacts in the East Link environmental impact statement. Additionally, this study provides a comparative analysis of historic regional transit and development policy in Seattle and Portland, a city that has had success in early adoption of regional light-rail. Together, the life-cycle assessment and comparative analysis provide a more holistic and transdisciplinary understanding of the transit situation in Seattle. The sum of the findings helps to tell the whole story of transit in Seattle from its early history to its future potential.

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Chapter 1: Introduction

Population growth, sprawl, and climate change are three common problems facing urban areas today. Much of the literature on the subject points toward regional sustainable development as a catchall solution to urban environmental problems (Calthorpe, 2012; Haughton and Counsell, 2004; Robinson et al, 2006; Salking, 2009; Shephard, 2011). Transportation is key to sustainable development, especially in urban areas. Emissions from automobiles are a primary contributor to the global climate crisis and transportation infrastructure is closely associated with land-use planning and urban sprawl. Population growth is both influenced by and exhibits diverse effects on climate change, land-use planning, and urban sprawl. These key issues are all closely related to one another.

In Washington State, emissions from automobiles are the single largest source of greenhouse gas (GHG) pollution (Sandin, 2013). Washington is among few states whose largest contribution to climate change does not come from electricity production. The state's large hydropower capacity from the Columbia River and its tributaries and the state's progressive and expanding renewable energy portfolio mislead the total state carbon budget. Currently, there are several large-scale public transportation projects in the Central Puget Sound region of Washington, which is home to Seattle and 54 percent of the state's population (Sandin, 2013). These projects will serve to mitigate climate change, reduce urban sprawl, and prepare the area for a forecasted population boom over then next half-century.

This research shows that sustainable transportation development projects are a sustainable choice for Seattle and Central Puget Sound, but simultaneously the necessity for any mitigation strategy, policy, or project to be understood from an interdisciplinary systems point of view in order to reveal the true environmental potential of sustainable development projects. The primary question driving this research is, “how can a systems approach help reveal a more holistic estimate of the most likely climate-related effects of light-rail development in Seattle?” Two main goals stem from this question. First is the quantification of the true emission reduction potential of the East Link expansion and second is the presentation of a holistic understanding of transit geography in Seattle.

In this research, an interdisciplinary systems point of view is referred to as holistic analysis or holistic planning, when considering sustainable development. The concept of holistic analysis is applied throughout this research as it focuses on sustainable transportation development in Central Puget Sound through an examination of the region’s historical transportation geography and an environmental life-cycle assessment of the East Link light-rail project. Life-cycle assessment (LCA) is a method most often used for quantifying the environmental impact of a project or product.

The idea of holistic analysis and planning regarding sustainable development is somewhat novel. Previous literature (Oktay, 2009) mentions the necessity for holistic strategies towards sustainable urbanism, but the research presented here uses the term holistic analysis as a broader, systems-based lens for understanding the many diverse and interdisciplinary aspects of sustainable development projects. The term holistic planning is meant to be a method for planning that involves holistic analysis and systems thinking. Vocabulary may exist to describe these methods, but a shift in nomenclature was chosen for this study, as the term "holistic" seems most appropriate and reflective of the nature of this work.

This research serves to document sustainable development in Seattle, Washington by presenting a more complete understanding of the emission reduction capabilities of Sound Transit's East Link light-rail extension project. There are two main research components in this study. First is a geographic analysis of historic transportation policy in Seattle. The half-century long struggle towards light-rail development in Central Puget Sound is seen through the lens of a comparative analysis of Portland, Oregon.

Although Portland is significantly smaller in area and population than Seattle, the city and region have been operating a successful and expansive light-rail system for well over 20 years. A more informed understanding of Seattle's transportation situation is obtained through this exercise in comparative geographic analysis by attempting to decipher Portland's transit success and Seattle's delay in adoption. Among the key reasons noted in this chapter are

Portland's strong, cohesive, and popularly elected metropolitan planning organization (Metro) and its ability to affect regional planning law more efficiently that Seattle.

The second component to this research is an environmental life-cycle assessment of materials used in the construction of the East Link light-rail alignment, which runs from downtown Seattle across Lake Washington to downtown Bellevue and north to the Microsoft Campus. East Link is slated to break ground in 2015 and begin full service in 2023. This is the first extension off of the main light-rail line in Seattle, known as Central Link, and the first step towards a comprehensive regional light-rail system in Central Puget Sound. The LCA in this study analyzes estimates of East Link's construction materials and ridership forecasts from Sound Transit to produce a model that shows the system's regional climate change mitigation potential over its expected 100-year lifespan.

Life-cycle assessment is a vital addition to the East Link project's environmental impact statement, which did not account for materials used for infrastructure construction and retrofit in its GHG impact estimates. Previous studies (Chester and Horvath, 2009; Chester and Horvath, 2012; Chester et al, 2012; Chester et al 2013) have shown infrastructure construction to be the most significant source of greenhouse gas pollution during transportation development. Results show that the addition of infrastructure materials raise the greenhouse gas emissions related to the project's construction nearly six-fold.

Together, the geographic analysis and LCA present a holistic story of emerging sustainable transportation development in Seattle. They show the necessity for regional public transit development to curb population growth, urban sprawl, and climate change emissions, but simultaneously the necessity of holistic environmental analysis in any large-scale infrastructure project. Studies of this nature that employ transdisciplinary methods and emerging techniques like LCA are opening the door to more a precise, well-rounded understanding of sustainable development and climate change mediation.

Chapter 2: Literature Review

Introduction

In this chapter, the most influential and crucial concepts from previous research are presented beginning with most broad and concluding with the more specific. This literature review will establish two themes: that a holistic systems approach is necessary when studying climate change and that mediation of the climate crisis is best approached from a lens of regional sustainable development. The literature presented in this chapter are a blend of both qualitative and quantitative methods and cover vital topics including global climate change, sustainable development and land-use planning, levels of climate action, and varying frameworks and methods for examining the problem including life-cycle assessment.

Greenhouse gas emissions, sustainable development, and access to public transportation all systematically affect one another (da Silva, Kernaghan, and Luque, 2012; Chester and Horvath, 2009; Chester et al, 2012; Chester et al 2013; Sheppard, 2011). With GHG emissions on the rise, it is vital that all stakeholders, both public and private, recognize this relationship and begin mitigation and adaptation strategies. However, these strategies cannot be efficiently and effectively completed without a holistic systems approach to the problem of climate change. The following sections help to establish a baseline of thought through previous literature.

Global Climate Change

There is little doubt within the science community that climate change is the most pressing global problem currently facing society. With no “golden key” to readily reverse the effects of climate change, society must mitigate the sources and begin an era of adaptation to the unavoidable consequences of anthropogenic GHG emissions from energy production, transportation, agriculture, and the like. Knowledge of the causes and effects of global climate change have been in the public sphere for quite some time and have been subjected to more scientific review than perhaps any other issue in history (Corfee-Merlot, Maslin, and Burgess, 2007; Robinson et al., 2006). In 1965, President Lyndon Johnson’s Science Advisory Panel acknowledged the potential for anthropogenic GHG emissions to disturb the heat balance of the planet and the importance of working towards reducing these emissions. Despite this observation predating the creation of both the Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration (NOAA), GHG emissions in the U.S. have increased 23 percent since (Brant and Adair, 2010, p. 5).

Electricity production and transportation are the two largest sources of GHG emissions in the United States. Transportation, the focus of this research, accounts for 27 percent of the nation’s total GHG emissions with just under 60 percent of the sector’s emissions coming from passenger automobiles (Environmental Protection Agency, 2013). Despite increased fuel economy standards, the addition of cellulosic ethanol to the fuel stock, and the economic downturn, emissions from passenger cars increased by nearly 20 percent from 1990 to 2011 (EPA, 2013).

In the political and media arenas, climate change is often framed as a scientific problem where its sources, solutions, and implications are still being debated (McCright and Dunlap, 2011; Robinson et al., 2006). The polarization of the issue, however, occurs for the most part in these arenas and not in the scientific realm, where consensus has been constant for quite some time (Cook et al, 2013). Although climate change is scientific in its quantification, it is a social issue at its core given that it is sourced in human behavior and its effects will greatly change human society (Agyeman and Evans, 2003; Robinson et al, 2013; Sheppard, 2011).

The research presented in this paper is not about climate change itself; instead, it is grounded in the idea that climate change is a social issue more so than a scientific issue. This research is a part of the larger body of climate change studies that take a systematic point of view in both identifying the causes of and solutions to the global climate crisis with its central focus on the latter. Climate change solutions are as diverse as the sources and require a systems approach to effectively address its associated problems. Especially when dealing with urban areas, as this research does, it is vital to use a systems approach in order to achieve a more holistic understanding of the problems (da Silva, Kernaghan, and Luque, 2012).

Sustainable Urban Development and Land-Use Planning

Sustainable development in urban areas is often seen as the key answer to the climate crisis (Calthorpe, 2012). While it would be difficult to find someone who disagrees with this, there may be a better way of looking at the issue. Robinson et al (2006) asserts that, because climate change policy and action are often gridlocked in the political realm, it may be best to change the conversation to one of sustainable development in order to progress climate change mediation (Robinson et al, 2006, p. 2). Shifting the conversation to sustainable development bypasses some of the political arguments surrounding climate science while simultaneously progressing environmental, social, and economic goals (Calthorpe, 2012; Robinson et al, 2006). Salkin (2009) reaffirms this idea by showing that climate change can only be effectively addressed through smart growth measures by showing the relationship between environmental justice, land use, and climate change (Salkin 2009). Robinson et al (2006) agrees with Salkin (2009) that the climate change mediation through sustainable development framework is best affected on a local or regional level, where most land use and smart growth policies are in place.

Other literature has pointed to the importance of the relationship between regional sustainable development practices and climate change mediation (Dale, 1997; Milder and Clark, 2011; Dawson, 2007). Land-use change through untamed urban expansion has been said to be both a cause and effect of climate change as it disrupts natural energy flows in ecosystems, increases albedo, and decreases nature's ability to sequester CO_2 (Dale, 1997; Milder and Clark, 2011).

Although they occupy only 3 percent of Earth's land surface, cities are responsible for as much as 80 percent of the anthropogenic GHG emissions on the planet with the majority resulting from electricity production and transportation emissions (Dawson, 2007, p. 3085-6). In the U.S., 80 percent of people live in urban areas where only forty percent did in 1900 (Census Bureau, 1995). The rapid population boom of urban areas has presented a great deal of environmental challenges, but also shed light on some potential solutions.

Research has shown that urban areas present a concentrated opportunity for well-planned sustainable development (Calthorpe, 2012 p. 14; Sheppard, 2011). Haughton and Counsell (2004) document the historical importance of regional planning's relationship with sustainable development. Norman et al (2006) continue this idea by highlighting planning's ability to control population density, affect transit-oriented development (TOD), and enhance transit infrastructure, all key parts of sustainable development (p. 10). This is especially relevant in terms of transportation-related emission reduction. For over half a century, highways, interstates, and single-passenger automobiles have been the paradigm in the U.S. due to the lack of holistic planning and poorly guided federal policy (Hamilton, Hokkanen, and Wood, 2008). Since the 1960s, walkable access to public transportation has decreased by half while the number of houses with garages has increased by about 25 percent (Sakar, 2011 p. 3 and 5).

According to the U.S. Census Bureau, there are over three times as many cars on the road today during rush hour than in 1960 (McKenzie and Rapine, 2011 p. 2 and 3). This is, in large part, the result of many Americans moving away from urban centers during the suburbanization era that followed World War II. Here, it can be seen that land-use policy and transportation go hand-in-hand. Research shows that the poor land-use planning of the 20th century opened the door to urban sprawl, traffic congestion, auto-dependency, and many other problems (Agyeman and Evans, 2003, p. 42; Hamilton, Hokkanen, and Wood, 2008). In the forty years preceding 1990, car ownership in the US grew by 400 percent, over five times more than the percent growth of the population (American Academy of Arts & Sciences, 1992). Dismantling society's auto-dependency problem, rethinking how people get around, and enhancing public transportation efficiency and accessibility are shown to be key parts of affecting urban sustainable development (Agyeman and Evans, 2003, p. 47).

Sheppard (2011) offers an effective example of the importance of sustainable development through transportation by showcasing the successes of Copenhagen, Denmark. Although smaller in area than Massachusetts, Denmark is home to 5.5 million people, 87 percent of which live in urban areas (Sheppard, 2011, p. 68). Sheppard (2011) shows how both the city and nation have redefined themselves as leaders in sustainability by initiating effective programs to eradicate automobile dependency and increase renewable energy. Like many regions in the US, Copenhagen experienced rapid urbanization in the mid-20th century, but responded far more effectively. Both the city and national government took progressive sustainability initiative, linking economic and environmental concerns in the policy arena (Sheppard, 2011). In 1997, the city's 100 percent wind-powered subway system was completed and complements the city's deeply engrained bicycle culture (Sheppard, 2011).

Unlike most other places, public transportation use and cycling are the norm in Copenhagen, despite its generally wet and cold climate. Shepard (2011) found the willingness of the Danish people to change their social behavior and enact progressive climate action not only speaks to their own culture, but to the larger concept of collective action. According to Sheppard (2011), "If sustainability is a rule, individuals are inherently more likely to engage in sustainable activities. If it is only an exception, individuals may feel discouraged from deviating from the norm, risking economic cost or social status to adopt sustainable practices without guaranteed benefit" (p. 72).

Regional and Local Climate Action

As mentioned before, research has shown that cities can be effective laboratories for climate action (Calthorpe, 2012; Haughton and Counsell, 2004; Sheppard, 2007). In her 2011 study on social solutions and sustainable development, Danielle Sheppard affirms,

> …dense population centers represent the apex of environmentally irresponsible behavior, but also perhaps the best geographic and social context in which to enact change. The city is a particularly appropriate arena in which to address climate change for two related reasons. First, cities are sites of high-energy consumption and waste production. Second, it is in cities that authorities can facilitate the greatest response to climate change, either by lobbying national governments or by developing local projects to demonstrate the large-scale costs and benefits of greenhouse gas emission reduction strategies. (Sheppard, 2011, p. 76)

This observation falls in line with other published studies that suggest climate action is most effective at smaller scales (Bulkeley and Betsill, 2003; Dawson, 2007; Kousky and Schneider, 2003). Research has also shown that both the causes and consequences of climate change are local, although the two can be unrelated. Different areas will feel different effects of climate change be it from crop loss due to drought or property loss from sea level rise. Therefore each region, city, and culture will have to adapt in its own way according to its needs and capacity. Likewise, it is necessary to obtain and understand geographical context when working towards sustainable development goals in urban areas.

Mitigation and Adaptation

Two important concepts in the literature dealing with climate change are "mitigation" and "adaptation." As defined by Dawson (2007), mitigation is, "responses…aimed at reducing net GHG emissions (p. 3089)." Mitigation strategies and projects include GHG cap and trade and taxes, carbon sequestering, and increased public transit infrastructure to name a few. Adaptation is defined as, responses to "the impact of climate change through adjustments to social, natural, or built systems" (Dawson, 2007, p. 3089). Adaptation generally refers to behavioral change on the part of society or a system in response to a current or predicted climate change impact. Sustainable development could be seen as both mitigation and adaptation strategy.

The concept of climate change mitigation though sustainable development is especially relevant to the central research of this study. Given that mitigation strategies differ based on local culture, economic feasibility, forecasted effects, and societal cohesion, it is necessary to holistically assess the methods and capacity of an area to respond to climate change. This is often referred to as integrated assessment (IA). This framework can help cities and regions evaluate both potential climate impacts and current emission trends. Dawson (2007) provides both an analysis of the IA framework and a seven-point checklist for successful urban IAs:

1. quantitative evaluation of a wide range of climate impacts, GHG emissions and other resource flows;
2. framing city scenarios and impacts analyses within the context of global climate and socio-economic change;
3. analysis over the extended temporal and spatial scales that are relevant to urban policy-makers addressing the challenges posed by climate change;
4. capturing the interactions and feedbacks between economy, land use, climate impacts, GHG emissions, resource flows and broader issues of sustainability;
5. analysis of both adaptation and mitigation options that can be implemented at a range of scales (e.g. from buildings through to national planning policy);
6. facilitating the construction of multi-sector portfolios of management options and testing their robustness under a wide range of possible future outcomes;
7. use of appropriate visualization and stakeholder participation methods to ensure effective communication of information between policy-makers, scientists and members of the public.

(Dawson, 2007, p. 3092-3)

Each of Dawson's points is necessary for a holistic analysis and all are part of a continuous system of mitigation and adaptation. In practice, sustainable development should be approached as temporally cyclical and evolving with society and situation. If sustainable development is seen as an end goal, rather than a mindset and policy climate, it serves to defeat the initial purpose. Although the primary goal of this study is to decipher a specific quantitative question, its intention is to be a piece of IA and each of the above points have provided substantial influence.

Life-Cycle Assessment

Many environmental problems are complex in both their cause and effect and therefore require an equally complex systems approach to address the problem effectively; climate change is no exception. An emerging tool to deal with this reality is life-cycle assessment. First developed in the 1960s, LCAs examine a product or a conglomeration of products within a system from a number of points of view including cradle-to-grave and cradle-to-gate (Curran, 2006). This process is growing to become a popular method for determining environmental impacts because of its ability to provide a more complete and accurate perspective of a problem. It does so by quantifying the impact of its subject from raw material extraction through processing, product production, and use to its output products (Curran, 2006). Today, LCAs are most often completed using powerful software and databases like SimaPro and ecoinvent3. LCAs are diverse in their applicability and can be effective in dealing with subjects from transit infrastructure to soda cans (Chester and Horvath, 2009; Curran, 2006).

Because of LCA's ability to provide a larger perspective, it is powerful in the policy sphere and has grown influence over the last few decades (Chester and Horvath, 2009).

Within the LCA framework, there are two major sub-framework models: attributional and consequential. The models are chosen based on the scope and overall goal for a project (Pré, 2013). According to Pré (2013), attributional modeling is best used when a project's goal is to obtain an environmental footprint, while consequential modeling is best applied to a project seeking to discover the consequence of a change in proportion it its baseline performance or impact (Pré, 2013). Although some large studies employ both framework models in their analysis (Chester et al 2012), the research presented here works exclusively within the attributional framework model.

To date, the majority of passenger transportation LCA studies have focused separately on fuel sources, tailpipe emissions, and raw materials (Castella et al, 2009; Chester and Horvath, 2009; Chester and Horvath, 2012; Chester et al, 2013; Hawkins et al, 2012). Research of this nature is necessary in understanding the impacts of the parts of the whole system, but when looking at the system itself, especially with considering the relationship between transportation and climate change, small-scale LCAs can be fragmented puzzle pieces with diminished effectiveness:

> In order to effectively mitigate environmental impacts from transportation modes, life-cycle environmental performance should be considered including both the direct and indirect processes and services required to operate the vehicle. This includes raw materials extraction, manufacturing, construction, operation, maintenance, and end of life of vehicles, infrastructure, and fuels. Decisions should not be made based on partial data acting as indicators for whole system performance. (Chester and Horvath, 2009, p. 1)

Passenger transportation LCAs that only provide fragmented information are unable to address the problem effectively because they do not provide a complete view of the situation. That is to say that the research should attempt to match the complexity of the system it is dealing with. This can be particularly problematic when considering new transportation infrastructure, which has both a high initial financial and environmental cost.

Mikhail Chester is one of a few researchers to recognize and directly address this problem. He has spearheaded a number of collaborations that serve as the sole sources of the importance of a comparative systems approach when performing transportation LCAs (Chester and Horvath, 2009; Chester and Horvath, 2012; Chester et al, 2012). This novel research is incredibly significant to the urban climate change conversation. For example, an LCA-based study by Chester and Horvath (2009) revealed that the production-related emissions of a vehicle could be up to 800 times that of its operational impact (p. 4). Depending on ridership and energy source, they found that “total life-cycle energy inputs and greenhouse gas emissions contribute an additional 63% for on-road, 155% for rail, and 31% for air systems over vehicle tailpipe operation” (Chester and

Horvath, 2009, p. 1 and 6).

These more holistic observations are especially important for new rail projects because they require the construction of a significant amount of new infrastructure. In a another study, Chester and Horvath (2012) showed that concrete and steel production alone was responsible for roughly three-quarters of the projected GHG emissions from constructing California's proposed high speed rail system (p. 4). Their research confirms the necessity for a holistic systems approach when considering the true life-cycle impacts of passenger transportation and other sustainable development projects.

Conclusion

Through this examination of the literature related to this study, two themes have been established. The first is that a holistic systems approach is necessary when dealing with climate change strategies and second, that climate change mediation is most efficiently realized through effective sustainable development practices and projects. Additionally, it should be apparent that the research employing LCA is severely lacking. Besides the studies published by Mikhail Chester and his cohorts, there are very few studies that take a systems approach to climate change strategies. This is not to take any worth away from the other research previously reviewed, but to stress the need for more holistic sustainable development studies. The research presented in the following chapters aims to aid in filling this gap and was influenced by each of the authors mentioned above.

Chapter 3: A Geographic Framing of the Transit Situation in Seattle, Washington

Seattle is often viewed as one of the most sustainable urban centers in the United States. Nearly all of the electricity lighting the city is provided by carbon-free sources and its residents enjoy a healthy bicycle culture, many urban parks, good access to fresh local food, and strong social capitol (Sheppard, 2011). However, Seattle is missing a vital facet of a sustainable city: a comprehensive light-rail system. Seattle's smaller neighbor to the south, Portland, has had light-rail for over 30 years, providing the populous with a clean and efficient way to get around town. Seattle has not been so fortunate. Sound Transit's light-rail system will attempt to fill this gap once completed, but until then, it is likely that Seattle will continue to be dominated by its car culture.

To provide a holistic picture of the current and future transit situation in Seattle, it is important to examine the historical geography of transit in the city. The purpose of this chapter is to decipher why Seattle, a city closely associated with progressive urban environmentalism, is so late in hopping on the light-rail train. This will be done in three short discussions with the first being a historical analysis of transit policy in Seattle, then a similar analysis of Portland, and concluding with a comparative analysis of transit policy decisions in Seattle and Portland over the past century. This discussion helps to show where Seattle went wrong by examining what Portland did right. It is not meant to be the sole thesis of this study, but to provide a comprehensive historical geography so that the reader may have a more holistic grasp of the current light-rail expansion in Seattle. This method was chosen in conjunction with life-cycle assessment, a more quantitative-based method, so that a more complete picture could be presented.

Portland was chosen for this discussion for a number of reasons. First, it is the closest American urban hub to Seattle. Vancouver, British Columbia is a close neighbor to Seattle known for its progressive commuter rail system, but was not chosen due to the differing national policies of the two cities. Portland's geography is quite different from Seattle's, but shared a similar desire for light-rail transit (LRT) development in the 1960s and was able to open MAX, the area's light-rail system nearly 30 years before Seattle. Today, Portland has higher transit ridership per capita (Table 1), a comprehensive light-rail system, and strong regional planning government.

A Brief History of Transit in Seattle

1869-1941: The Birth and Decline of Rail Transit

Public transportation has been a part of the Seattle Area's history for quite some time and has played a substantial role in shaping the growth in and around the community (Crowley, 2000). By the time the city was officially incorporated in 1869, ferries and water taxis, known as the "Mosquito Fleet," had been operating across Puget Sound, Lake Union, and Lake Washington for over a decade (Crowley, 2000; King County, 2013). Today, the ferry system is still a vital part

Unlinked Passenger Trips (2012)				
	Seattle (Sound Transit)	**Seattle (Metro)**	**Portland (TriMet)**	**Portland (City)**
Bus	16,012,412	95,592,084	59,509,235	N/A
Trollybus	N/A	18,970,601	N/A	N/A
Light-Rail	8,701,106	N/A	42,227,665	N/A
Streetcar	N/A	750,866	N/A	3,664,739
Total	24,713,518	115,313,551	101,736,900	3,664,739
Comb. Totals		**140,027,069**		**105,401,639**
Per Capita		**45.77**		**56.98**

Table 1: This table shows the per capita ridership of public transportation in Seattle and Portland (National Transit Database, 2013).

of Seattle's transit infrastructure, carrying nearly 10 million passengers and cars each year to and from Seattle (WSDOT, 2013).

Fifteen years after the birth of the city, Seattle saw its first streetcar, a horse-drawn rail car (Figure 1) operated by local entrepreneur Frank Osgood that serviced a line between Pioneer Square and Uptown (Crowley, 2000; Ketcherside, 2012). In 1888, the Seattle City Railway began operating cable car lines that spanned the width of the city on Yesler Way (Ketcherside, 2012). These cable car lines were a well-used facet of early Seattle life and remained in service longer than any other cable car system in the U.S. other than San Francisco's, which still operates today on limited routes (Ketcherside, 2012; King County, 2013).

One year after the opening of the Seattle City Railway, the city saw its first electric streetcars, which were operated by another private transit company (King County, 2013). These were the first electric streetcars in use west of the Mississippi River and their popularity grew quickly; just three years after their debut, Seattle was home to nearly 50 miles of electric streetcar tracks, despite much of the city burning during the Great Fire of 1889 (Crowley, 2000; Ketcherside, 2012; King County, 2013). By 1896, Seattle's streetcar system extended from south of the city center to north of Green Lake, setting the foundation for the system for the next 50 years and beyond the streetcar era (City of Seattle, 2013; Ketcherside, 2012).

Figure 1: Seattle's first horse-drawn streetcar, 1886 (Source: Museum of History and Industry (MOHI, 2014)

At the turn of the century, the streetcars and cable cars in the city were made of fragmented networks (Figure 4) owned by 22 separate private entrepreneurs (King County, 2013). This was the norm at the time as most urban rail networks in the US were privately owned and operated by electric and rail companies. Around this time, an engineering and pseudo-holding company from Boston known as Stone & Webster, Inc. began purchasing many of the urban and inter-urban rail networks around Puget Sound from Bellingham to Tacoma (Ketcherside, 2012; OTS, 1976; Rose, 1987, p. 9).

By 1900, Stone & Webster had purchased the last of the street railways in Seattle and formed The Seattle Electric Company, which won a 40-year contract for the operation of the system (Ketcherside, 2012; King County, 2013). Within ten years, the system expanded to include a number of interurban rail networks that connected Seattle to Everett and Tacoma, known as the Puget Sound Electric Railway (Figures 2 and 3) (King County, 2013). These systems were a part of a larger vision of the financiers of Stone & Webster for a rail network from Olympia to Vancouver, British Columbia known as the Puget Sound International Railway and Electric Company (Crowley, 2000).

Although Stone & Webster was successful in connecting the neighborhoods of Seattle with Puget Sound's other urban areas, the residents of Seattle had become frustrated with the network's substandard maintenance and inconsistent service (Crowley, 2000; Ketcherside, 2012). In 1911, public outcry affected a municipal buyout of the Rainier Avenue line, which ran to Renton (Crowley, 2000). Seven years later, in a controversial and perhaps damning move, then Seattle mayor Ole Hason nullified Stone & Webster's 40 year contract and approved a $15 million buyout of the Seattle Electric Company (Crowley, 2000;

Ketcherside, 2012; King County, 2013).

Over the next twenty years, the system faced a number of hardships due to poor municipal and financial planning, dwindling ridership from the rising popularity of the automobile, and lack of support from the state government (Crowley, 2000; King County, 2013). One of the first problems the new municipal railway faced was debt. The 1918 purchase of the Seattle Electric Company was nearly three times the market value of the system, leaving the organization in debt for the duration of its existence (Crowley, 2000). The city attempted to fix the system's financial problems through general tax revenue, but in 1922 the State Supreme Court ruled against the policy (King County, 2013). At the same time, the state was beginning to expand automobile infrastructure and build highways, but did not have the foresight to include rail infrastructure; in 1928, rail service from Seattle to Tacoma ended with the opening of Highway 99 (Crowley, 2000; King County, 2013). In 1936, the system began operating at a loss and replaced the most derelict lines with gas busses (Figure 5) (King County, 2013).

Without any other options to boost revenue for the system, the city was forced participate in the "Rails to Rubber" conversion sweeping the nation during the late 1930s and early 1940s. This deal, largely orchestrated by behind-doors deals between the federal government and automobile, tire, and fossil fuel producers, offered cities zero-percent loans to convert aging cable car and streetcar systems to trackless electric trollies and diesel busses (Figures 6 and 7) (Crowley, 2000; King County, 2013). Trapped in a financial headlock from state and federal governments, Seattle took the $10.2 million loan and began converting the system; by 1941, the last of Seattle's streetcars and cable cars were removed and sold to Japan for scrap metal (Crowley, 2000).

Figure 2: Seattle/Tacoma interurban streetcar, operated by Puget Sound Electric Railway, near Kent, Washington in 1909 (MOHI, 2014).

Figure 3: Puget Sound Electric Railway streetcar at First Avenue, Seattle circa 1907 (MOHI, 2014).

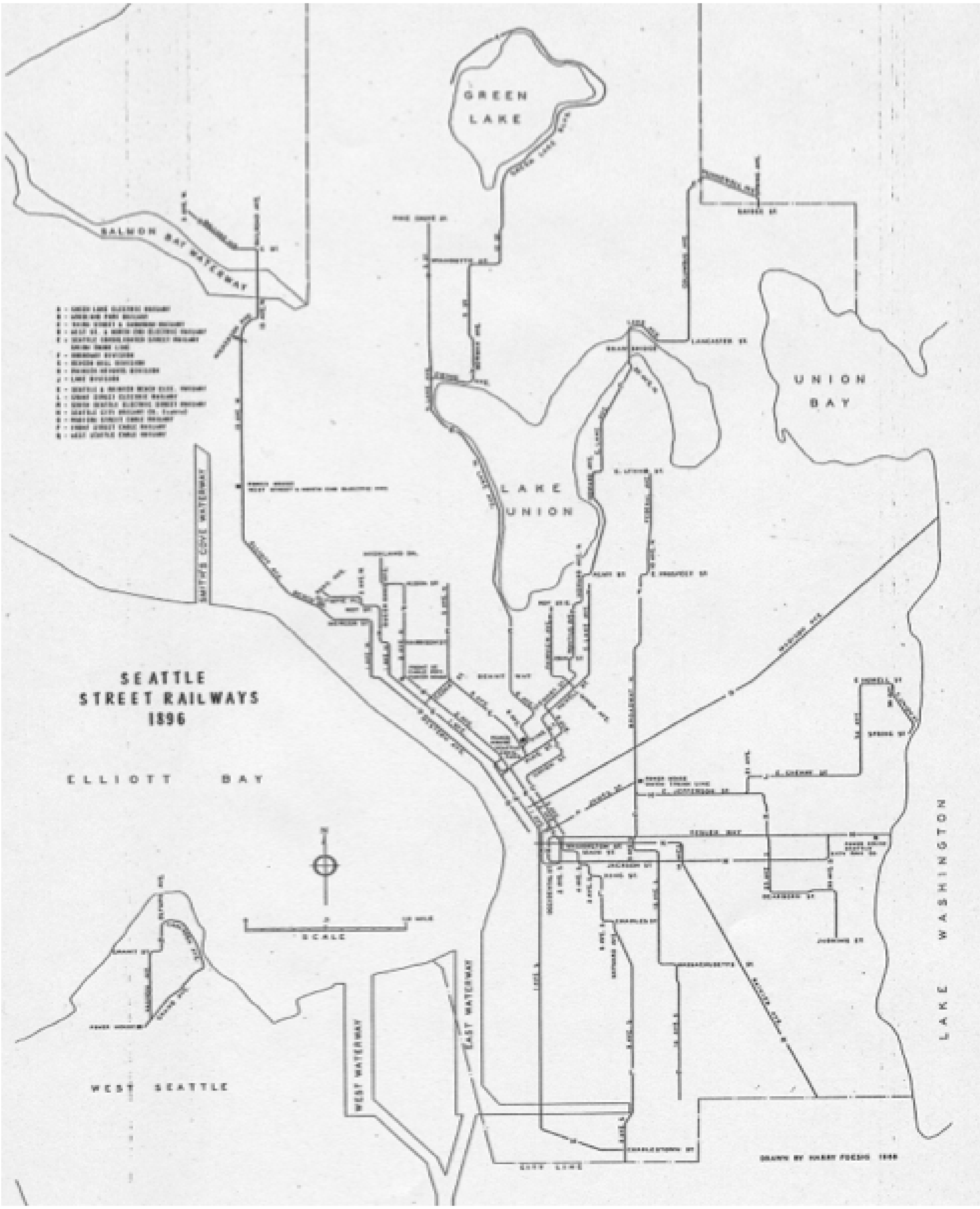

Figure 4: Map depicting citywide private street railways, 1896 (City of Seattle, 2014)

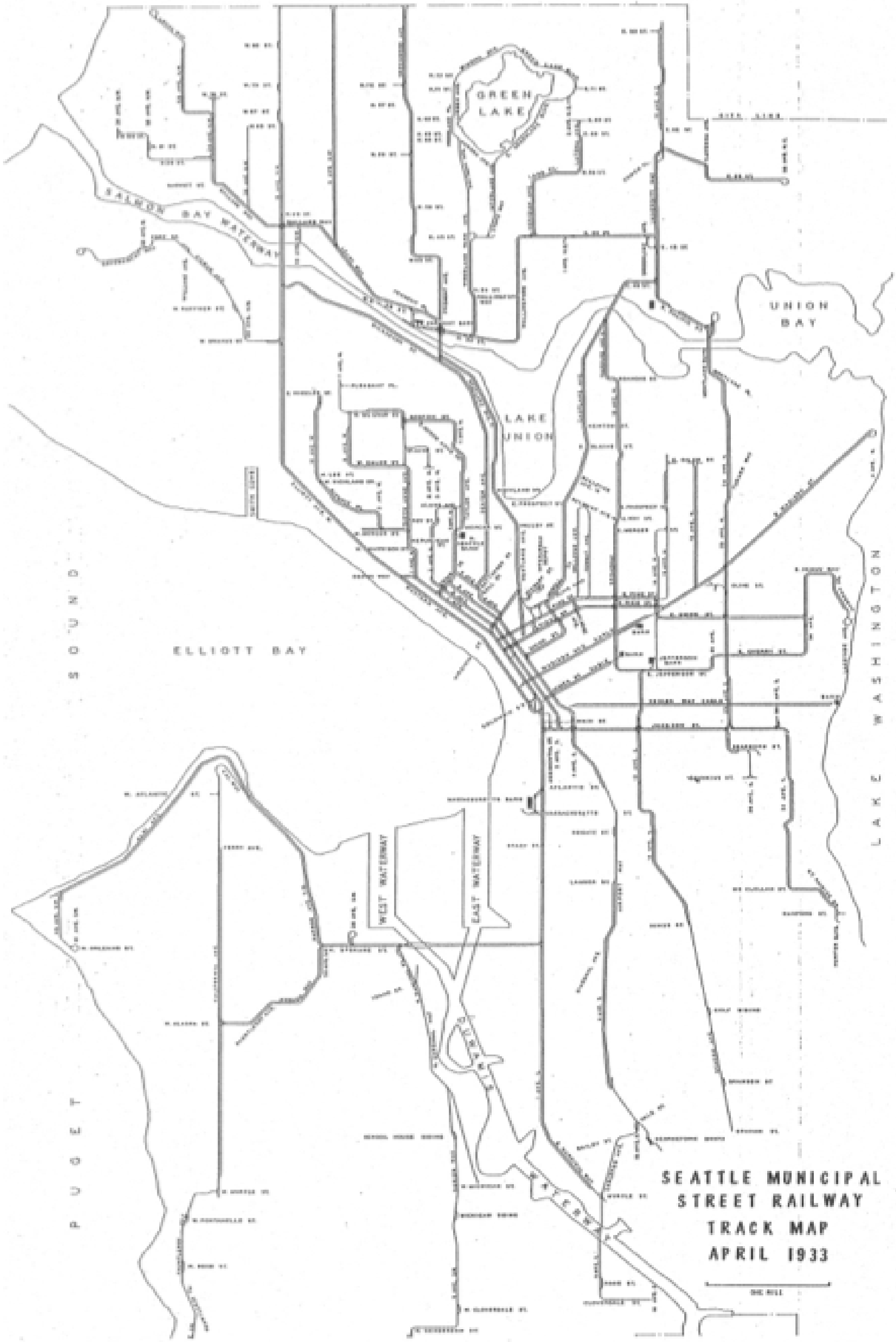

Figure 5: This map depicts the final alignment of Seattle's early 20th century streetcar-dominated public transpiration system (City of Seattle, 2014)

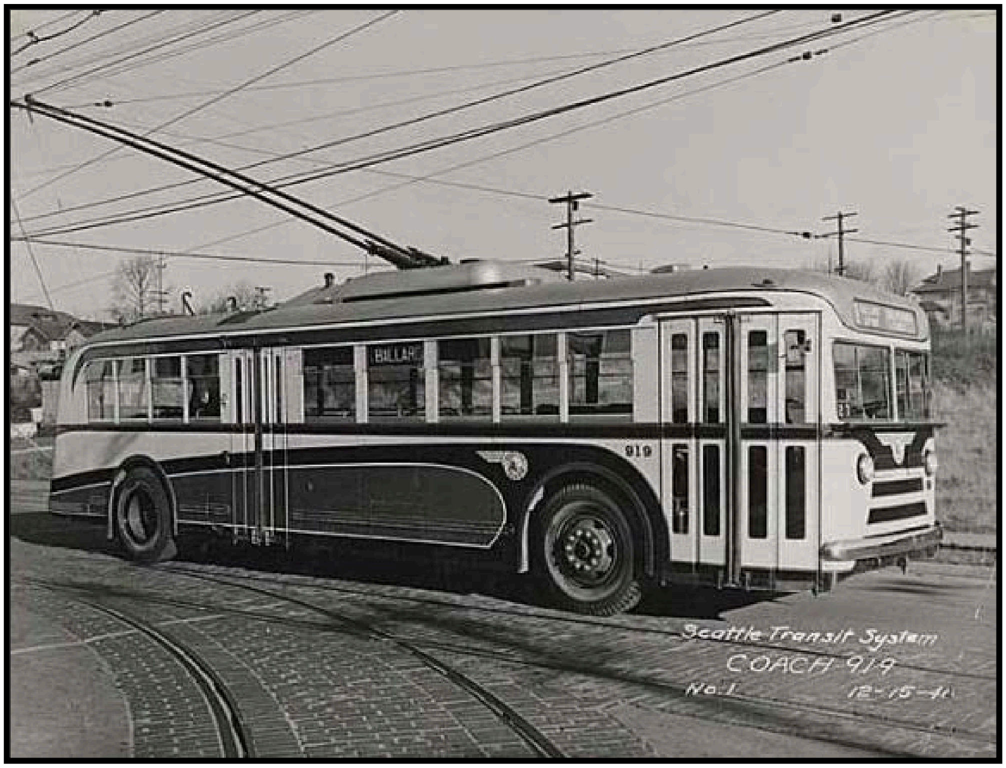

Figure 6: One of the first “trackless trollies” used in Seattle. Although this model is now retired, Seattle Metro uses trackless trollies on many of its current bus lines (Source: Museum of History and Industry (MOHAI, 2014)

Figure 7: Postcard of trolleybus (MOHAI, 2014)

1942-1970: The Age of Rapid Rail Denial

After World War II, Seattle experienced the largest population boom in its history. From 1940 to 1950, the city's population grew from 368,302 to 467,591 (26.9%). This decade also marked the highest ridership in Seattle's transit history (130 million rides in 1944), despite the Rail to Rubber conversion (Figure 8) (King County, 2013). However, this trend would not last long. Throughout the rest of the 20th century, both population and transit ridership dwindled consistently, most likely due to suburbanization, increased popularity in automobiles, and a slew of rejected transit initiatives in the political realm (King County, 2013; OTA, 1976).

Figure 8: School children board the final run of Route 18 through Wallingford, Seattle in 1940 (MOHI, 2014).

The 1950s was one of the most influential decades for transit in Seattle. Perhaps one of the most influential early defeats for transit occurred in 1952 with the rejection of a county charter plan to establish a regional commuter rapid transit system. This plan was defeated in a popular vote due in part to political influence as it was labeled “communistic” by the dissenters (King County, 2013; OTS, 1976). Public and political controversy over public transportation continued throughout the decade and included the denial of a plan to include a 50 foot median on I-5 through downtown Seattle (Figure 9) for rapid rail transit (King County, 2013; OTS, 1976). While the 1950s witnessed the denial of many progressive initiatives and plans, it did lead to the creation of the Puget Sound Regional Transportation Committee to affect detailed studies of transportation in the area (OTS, 1976).

The decade also witnessed multiple attempts to create a stronger regional government. James Ellis, a local lawyer working through the Municipal League of Seattle, made a number of unsuccessful attempts to update King County’s government through the adoption of a countywide metropolitan council (OTS, 1976). This defeat led to the recommendation and eventual creation of the Metropolitan Municipal Corporation Act, a joint effort by Ellis, the mayor of Seattle, and the Board of King County Commissioners (OTS, 1976). This legislation allowed municipalities to create regional bodies of government in order to deal with the problems of suburbanization and sprawl. Additionally, it recommended the creation of Metro, an organization that would oversee transit planning, sewage and water treatment, and parks among others. A subsequent vote on the creation of Metro was shot down by a small margin, but a stripped down version of Metro was passed later that year, which only allowed Metro to govern sewage and water treatment (King County, 2013; OTS, 1976). At the same time, the Puget Sound Governmental Conference was created. This organization was made of elected officials from the various counties of the Seattle metropolitan area, but did not have rule of law and could only provide recommendations, a vital flaw that will be expanded upon in later in this chapter (OTS, 1976).

By 1960, Seattle's population had risen by nearly 100,000 to 557,087, but transit ridership and support continued to dwindle rapidly (King County, 2013). By 1965, ridership in Seattle had dropped to 33.8 million, nearly 90 million less rides per year from 1944 (King County 2012; OTS, 1976, p. 6). The decade also saw a drastic change in the types of rides being made. In 1960, the majority of transit rides were made within the city center, where by 1970, most were made within the suburban ring (OTS, 1976). The decline in transit use and suburbanization seen in the 1960s was not a Seattle-specific phenomenon.

In the previous two decades, the US Congress passed a number of laws that hurt urban transit both directly and indirectly. The Federal-Aid Highway Act of 1944 is often cited as one such law as it provided huge financial incentives for highway construction in urban areas and neglected to fund any public transit (Levin and Abend, 1971). Although this law succeeded in keeping the economy afloat after the industrial boom of World War II ended, it set the stage for a number of other anti-transit federal policies (Levin and Abend, 1971). The

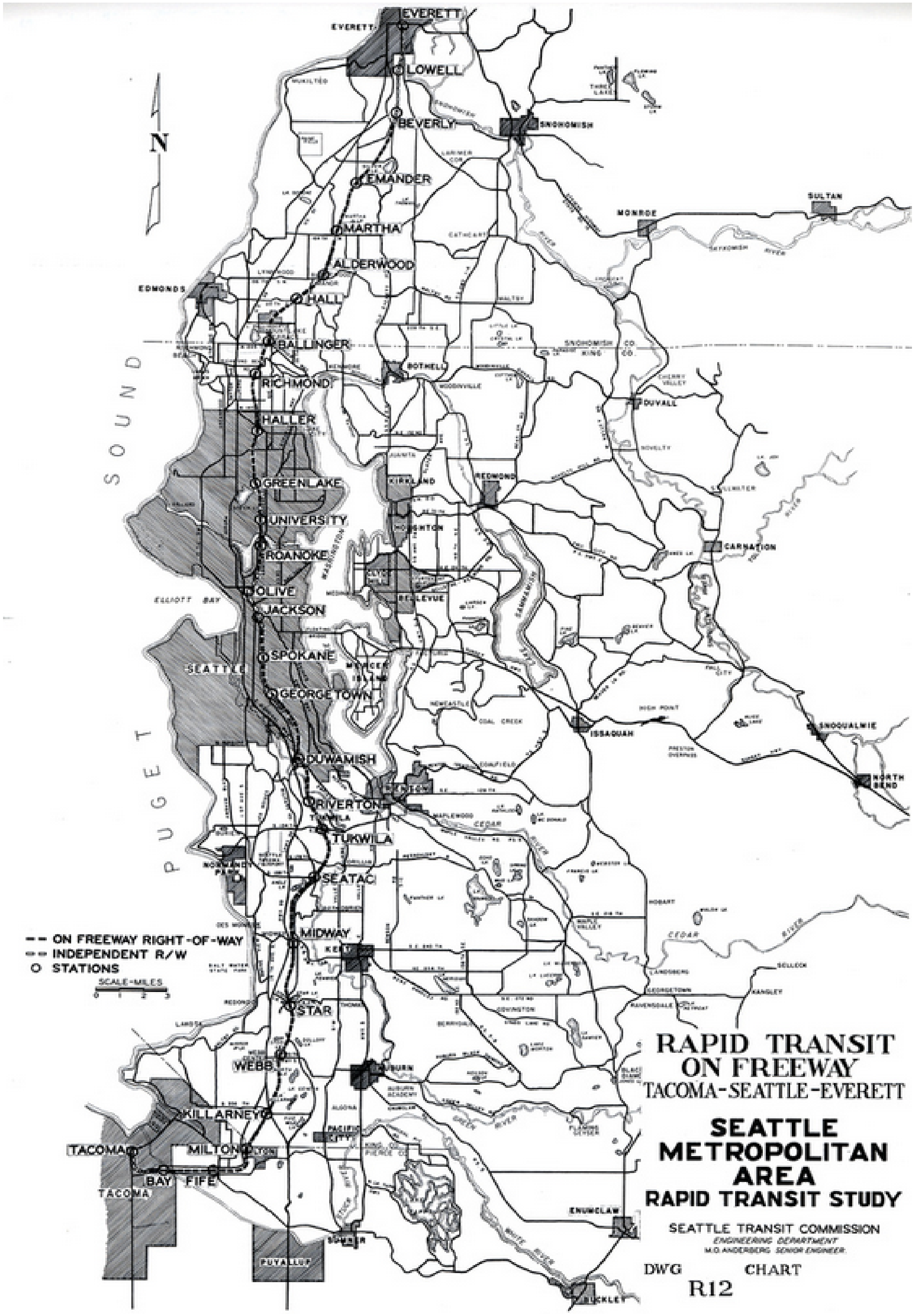

Figure 9: This map shows the failed plan to include rapid light-rail on I-5 through downtown Seattle (City of Seattle, 2014)

Federal Highway Act of 1956 reaffirmed the federal government's commitment to highway construction by offering up to 90 percent of the cost of projects (Hamilton, Hokkanen, and Wood, 2008). It was not until twenty years later that the federal government would offer transit assistance. Even still, the Federal Highway Act of 1976 required that an area's MPO, state governor, and Secretary of Transportation agree to give consent (TriMet and PSU, 1985).

Seattle's transit decline in the 1960s was also influenced by a number of local influences including failed attempts to establish a regional rapid rail system for commuters despite recommendations from advisory organizations and regional governments (King County, 2013; OTS, 1976). Many recommendations were made for transit by the Puget Sound Regional Transportation Study, the Metropolitan Transportation Committee, the Rapid Transit Advisory Committee, and the Citizens' Committee for Metro Transit, but all failed to affect successful transit plans due to political infighting and failed referenda (King County, 2013; OTS, 1976). Among these referenda were attempts to grant Metro the authority to operate transit in 1962, the preservation of trackless trollies in 1964, but perhaps the most influential defeat was that of the "Forward Thrust" plan, created in large part by James Ellis (King County, 2013; OTS, 1976).

The ideas behind Forward Thrust were first proposed during a speech to the Seattle Rotary Club in 1965 when Ellis suggested a number of recommendations to preserve and enhance central Seattle. According to Ellis, a prosperous Seattle should "have a high density of activities, it must be attractive, with open plazas and easy pedestrian access to all facilities, and there must be the capacity to move large numbers of commuters during peak hours" (OTS, 1976, p. 16-17). The last of his three criteria was an obvious call for the rapid rail system that he had been advocating for years at this point. During the same speech, Ellis expanded on the idea of inadequacy of the car in the modern city by saying:

> The only pattern now known which permits both open space and dense development while moving large peak-hour loads is the use of high-rise structures and some form of grade separated public transportation to supplement streets and highways. Rapid transit is the essential link in a balanced transportation system which is missing in Seattle. (OTS, 1972, p. 17)

Unfortunately, this statement would mostly remain true for Seattle today as it is still missing a comprehensive high-speed urban rail system for commuters. Both City Hall and King County were behind Forward Thrust and worked to create the Forward Thrust Committee in 1966 (OTS, 1976).

Over the course of four months, the Committee created a number of recommendations and wrote 18 bills that were given to the State legislature that recommended a Metro takeover of transit and appropriated funding for aspects of Forward Thrust (Figure 10) (OTC, 1976). The next year, the Committee released its final recommendations:

- 47 miles of dual-track, grade-separated rail rapid transit routes with 32 stations. Automobile and bus-to-rail transfer facilities and parking were to be provided at appropriate stations
- A 3-mile, grade-separated busway to west Seattle. To be converted in the future to rail rapid transit
- 24 miles of grade-separated right-of-way for future rail rapid transit
- 90 miles of express bus routes, which would operate on highways
- 500 miles of local bus routes, which would operate on major arterials and serve rapid transit stations (OTS, 1976, p. 18)

Although these recommendations were highly supported by the public (65 percent approval during the pre-election), strong political opposition from various state and local sources including the King County Democratic Party influenced the public to deny the provisions in the special election of 1968 (OTS, 1976; King County, 2013). Two years later, a second attempt was made to fund the system through a 1 percent increase in gasoline tax appropriations and federal grant aid totally $1 billion, but failed in a second special election (OTS, 1976; King County, 2013). The federal money set aside for Seattle's failed Forward Thrust eventually funded Atlanta's successful MARTA rapid rail system (King County, 2013). This was the final loss for Forward Thrust and the Committee dissolved the same year (OTS, 1976).

1972-2000: Bus Expansion and Rail Resurgence

Despite the decline and failures of the past few decades, transit in Seattle made some gains in the 1970s, although both population and ridership continued to decrease throughout the first half of the decade (Crowley, 2000; King County, 2013). In 1972, voters approved a transit expansion of Metro and an accompanying 0.3 percent sales tax for diesel busses, but not electric rail (King County, 2013). The same year, a plan for express diesel bus routes was approved and the city received a total of $86 million for the expansion through the Urban Mass Transportation Act (UMTA) (King County, 2013). In the second half of the decade, ridership began to increase for the first time since the 1940s and nearly doubled from 1975 to 1980, despite the continual decline of the city's population (King County, 2013). More than likely, the OPEC embargo and resulting high prices and the gas pump likely influenced the increase.

In 1980, Metro had its second significant victory when voters approved an initiative that increased Metro's tax share from 0.3 to 0.6 percent (King County, 2013). This likely influenced a number of other achievements for transit in Seattle including a sustained rise in ridership throughout the decade, the first streetcar service since 1940 (albeit the Waterfront Streetcar served to be little more than a tourist attraction), the groundbreaking of the downtown transit tunnel, the approval of a plan for accelerated commuter rail development, and a gain in the city's population (Crowley, 2000; King County, 2013).

Serious gains were also made in the 1990s. One of the most important was perhaps the passage of the 1990 Growth Management Act, which helped Washington play catch up to its neighbor, Oregon, who passed a similar bill (Senate Bill 100) some 17 years before (Cotugno and Benner, 2011; King County, 2013). Another influential state law, the Commute Trip Reduction Act

Figure 10: Map depicting recommended alignment of rapid rail and BRT from the failed Forward Thrust plan of 1968 and 1970 (http://www.flickr.com/photos/95482862@N00/3685408132)

(CTRA), passed in 1991 and has been very successful in promoting public transit for daily commuters to Seattle (Gilmore Research Group, 2011; King County, 2013). One of the most substantial aspects of the CTRA is a provision that incentivizes businesses in the city core to provide transit passes to employees. This is perhaps one of the reasons why ridership increased from 74.6 million in 1992 to 100 million in 2000 (King County, 2013).

Four years after the passage of the CTRA, voters in King, Pierce, and Snohomish Counties accepted the "Sound Transit" plan, effectively creating the regional transit organization that thrives today (Crowley, 2000). Sound Transit currently operates regional transportation through BRT, a commuter heavy rail line known as the "Sounder," a short light-rail line in Tacoma known as "Tacoma Link," and an expanding light-rail line from SeaTac to downtown Seattle called "Light-Link," which is the focus of the life-cycle assessment presented later in this document.

Transit in Seattle has a rich history with many failures and successes. From the early Mosquito ferries providing service to early settlers to the modern Light-Link growing throughout the region, transit has had a significant impact on the life and culture in and around Seattle. This brief and non-comprehensive history of transit in Seattle is simply a tool to provide context for the larger concepts in this study and is not meant to be an exhaustive source, but a starting point for those interested in learning more about Seattle's transit history and the capability of transit to shape the future and affect a more sustainable community.

Regional Transit Planning and Governance in Portland, Oregon

Seattle's regional neighbor to the south, Portland, Oregon, has had a significantly different transit history, despite the two cities sharing similar civic values. Although the Seattle metro area's population is significantly larger than Portland's, the residents of the three counties that comprise metropolitan Portland have access to a comprehensive light-rail system roughly four times the size of Seattle's since 1986. As of June 2013, MAX (Metropolitan Area Express), Portland's light-rail system, carried nearly 100,000 more passengers each day than were carried on Seattle's light-rail (Sound Transit, 2013; TriMet, 2013a). The significant difference between light-rail access in Portland and Seattle is no coincidence; a comparison of the cities' political transit histories helps to reveal the underlying reasons for the disparity between the two.

The most significant reason for the two cities' disparity is not that the City of Seattle has ignored its transit problems or not attempted to develop stronger regional infrastructure, it should be clear after reading the preceding section that Seattle pushed for progress and failed many times throughout the 20th century. The disparity has a lot to do with the presence of a strong, cohesive regional government. Many cities with robust public transit infrastructure including San Francisco, New York City, and Philadelphia, have a consolidated city-county government, which has more power to enact sustainable regional development. Currently, the Portland area's regional government, Metro, is the nation's only popularly elected regional government and oversees a number of land-use issues from transportation to solid waste to habitat protection. Unlike the previously mentioned cities, Metro is a separate level of government not consolidated with the cities it is home to. In terms of transportation, Metro acts as both a decision maker and a purveyor of a round table for member cities and relevant organizations (such as TriMet) to discuss projects and progress. Metro has achieved much notable success over its career (Metro in its current form was established in 1978) and has become one of the most respected and recognized MPOs in the continent (Erickson, 2006).

The following section tells the story of the organizations that preceded Metro and its eventual formation. It begins with early actions by the state and local governments in the 1920s and continues over the next 60 years with the rough and often controversial actions of the most influential MPOs in the Portland metropolitan area. By examining the history of Portland's regional governance and planning, a more holistic understanding of how and why this relatively small metropolitan area has grown to become the poster child of public transportation in the United States. This examination of Portland's transit evolution and success is a vital part of the holistic analysis of this study; through it, a better perspective Seattle's transit evolution can be obtained. This is, however, not to say that the two cities are one in the same. What has and has not worked for Portland may not be identical for Seattle. The succeeding information should be taken as a part of the whole conversation on the experience of public transit evolution through regional planning and policy.

Metro's Predecessors and Beginnings: 1920s-1970s

Portland's history of strong regional government is certainly one of the most influential factors in the city's success with transit development. The story of Portland's success with transit and metropolitan planning goes back nearly a century to the 1920s with the creation of a committee in the Oregon legislature that examined on-going problems with the cohesiveness of development plans and practices of local governments in the Portland area (Cotugno and Benner, 2011). The committee was formed after a number of Oregonians complained that the newly popularized automobile "was allowing rapid and unplanned suburbanization that was outrunning both the provision of services and the pace of annexation to Portland," an observation that was quite ahead of its time (Abbott and Abbott, 1991, p 4). The result of the committee was a recommendation that the city of Portland and Multnomah County be consolidated in order to create a stronger body in charge of development. Although this recommendation was largely ignored, it is regarded by some to be the beginning of the push towards regional government in the Portland metro area (Abbott and Abbott, 1991; Cotugno and Benner, 2011).

Fraught with the Great Depression and World War II, little progress was made towards regional government in the Portland Area until the postwar years when the state government authorized a number of county planning commissions to create and enforce county-wide zoning and planning regulations (Abbott and Abbott, 1991). During this time, many US cities were experiencing a great outward expansion due to the rise in automobile ownership and suburbanization.

Although not a major city at the time, the area's leaders recognized the potential problems and wastefulness associated with "sporadic, scattered, and unregulated growth of municipalities and urban fringes" (Abbott and Abbott, 1991, p. 4). In response, the Metropolitan Planning Commission (MPC) was created to gather land-use and economic data and serve as a viable organization to receive federal funding for regional planning through the Housing Act of 1954, which helped to set the stage for future regional planning organizations (Abbott and Abbott, 1991).

From the 1950s until Metro was created in 1979, the Portland Area had a number of planning organizations including the Portland Metropolitan Study Commission (PMSC), Columbia Region Association of Governments (CRAG), the Tri-County Metropolitan Transportation District (TriMet) and Metropolitan Service District (MSD), the organization that evolved into today's Metro (Abbott and Abbott, 1991; Abbott, 2009; Cotugno and Benner, 2011). The PMSC was created in 1963 after the 1961 state legislature established an Interim Committee on Local Government Problems (ICLGP), which recommended that the legislature fund a metropolitan study commission (Abbott and Abbott, 1991). The ICLGP was created as a response to complaints on the efficiency and effectiveness of local governments by various citizen organizations including Portland's League of Women Voters and Chamber of Commerce (Abbott and Abbott, 1991). The primary goal of the PMSC was to find a solution to the fragmentation of government services in the region; both citizens and the state government were concerned with the ability of the local governments to handle and coordinate regional transportation, safety, sanitary, parks and recreation, and environmental issues that were growing with the urban and suburban populations (Abbot and Abbott, 1991).

After two years of research and analysis, the PMSC approved and created CRAG to succeed MPC (Abbott and Abbott, 1991; Abbott, 2009). Once established in 1966, CRAG oversaw various regional planning responsibilities including transit, land use, water quality, and criminal justice (Cotugno and Benner, 2011). The organization was modeled as a “council of governments” comprised of local elected officials and served the Oregon counties of Multnomah, Washington, and Clackamas as well as Clark County, Washington, which is home to the city of Vancouver just over the Columbia River (Abbott, 2009). CRAG made a number of contributions to planning and transit progress by expanding the demographic and planning data created by MPC, overseeing transit studies, and fulfilling federal requirements for the area to receive federal funding for transit infrastructure (Abbott, 2009).

Despite the moderate successes of CRAG, it was a voluntary organization and lacked the political independence that the current Metro enjoys. A strong degree of political separation can be key in planning organizations; because CRAG was lead by the officials of the cities and counties it served, it’s operational integrity was diminished and led to a number of self-serving studies (Abbott and Abbott, 1991; Abbott, 2009; Cotugno and Benner, 2011). For example, the Portland-Vancouver Metropolitan Area Transportation Study (P-VMATS) recommended highway expansion when TriMet and many of the

Portland Area residents were calling for more investment in public transportation (Erickson, 2006; Abbott, 2009).

Disagreements between agencies, politicians, and the community in general created a stalemate in the policy process and sparked the creation of the Governor’s Task Force on Transportation (GTF) to settle the matter (Cotugno and Benner, 2011). One of their primary tasks was to handle the problems associated with controversial P-VMATS recommendations. At the time, the City of Portland was exploring options to revitalize its downtown and TriMet was pushing towards and enhanced regional transit system (Abbott and Abbott, 1991; Cotugno and Benner, 2011).

Eventually, the GTF canceled two-thirds of the proposed interstate projects including the famed Mt Hood Highway and directed policies towards regional multimodal transit projects (Edner and Arrington, 1985; Cotugno and Benner, 2011). The Mt Hood Highway project was a highly controversial plan that proposed a freeway through downtown Portland, which would have effectively cut the city in half and reduced the city’s residential units by 1 percent (Edner and Arrington, 1985). The decision to cancel the highway was backed by various neighborhood groups and downtown businesses, the GTF, Mayor Goldschmidt, and, eventually, CRAG and helped pave the way of the future decision to build TriMet’s MAX light-rail system (Erickson, 2006). This decision, known as the “Banfield Decision”, will be discussed in greater detail in the following section.

Recognizing that much of the controversy stemmed from the operational integrity of CRAG, the Oregon legislature transformed the organization into a regional planning district in October 1973 (Abbott, 2009). The reformation of the organization gave it the power to enforce regional plans and mandated participation by member counties and municipalities, making it one of only three other mandated council governments in the US at the time (Abbott and Abbott, 1991; Abbott, 2009). The reforms were a sign of progress, but also a point of controversy in the region as CRAG still lacked direct accountability to its constituents. In 1978, CRAG was officially merged with MSD through a referendum, thus beginning Metro as it mostly exists today (Abbott, 2009; Erickson, 2006).

Post 1978: UGB and MAX light-rail

Today's Metro oversees a number of planning and transportation-related issues for the nearly 1.5 million people that make up the three counties of the Portland metropolitan area (Erickson, 2006). As mentioned earlier, Metro acts as both a decision-making organization and point of regional collaboration for transportation issues (Cotugno and Benner, 2011). While TriMet is the organization that actually implements the service of light-rail, streetcars, busses, and commuter trains, transit-related decision making is made by both the Metro Council and the Joint Policy Advisory committee on Transportation (JPACT), which consists of elected officials from Metro and local governments as well as key representatives from transit agencies (Cotugno and Benner, 2011).

Another notable responsibility of Metro is the creation and maintenance of the area's urban growth boundary (UBD). In 1979, the infant organization implemented the area's first UGB as mandated six years earlier by Oregon's Senate Bill 100, which required local land use planning throughout the entire state (Abbott and Margheim, 2008). Seattle would not adopt a comprehensive UGB until 1992 (Oldham, 2006). The UGB has been very influential in the sustainable development of the region in a number of ways, contributing to the early necessity of light-rail in the region as well as promoting greenway construction for motorless travel, expanded wildlife habitat, and the preservation of farmland (Abbott and Margheim, 2008; Cotugno and Benner, 2011; Erikson, 2006). Metro has been able to use the UGB to focus development at the core of each urban center, reducing sprawl and increasing efficiency in planning throughout the region. Portland's urbanized areas have only increased by 10.9 percent since implementing the UGB (Abbott and Margheim, 2008). The success of Portland's UGB has contributed to the notoriety of Metro inside and outside of the industry, becoming a "cultural icon" and inspiring performance art and novels (Abbott and Margheim, 2008). This lends further support to the idea that a strong, cohesive regional government is a key aspect of Portland's developmental success.

Portland's UGB is an ever-evolving policy that is reevaluated every five years per state law (Cotugno and Benner, 2011). This allows Metro to keep a close eye on regional patterns and attempt to stay ahead of growth forecasts. Metro also oversees the creation of long-range plans related to the UGB. In

1995, Metro adopted the “2040 Growth Concept”, which details the organization’s plan to curb the growth of the UGB by merging “land use planning and transportation planning to reinforce the objects of both (Cotugno and Benner, 2011, p. 39).” The 2040 Growth concept allows for a mere 7.3 percent growth of the UGB through 2040 by encouraging “up not out” development, 400 miles of new transit corridors, and 33 new TOD developments (Cotugno and Benner, 2011). Additionally, the plan was created with Metro’s doors and ears open to the public; the designers of the long-range plan paid close attention to the wishes and desires of their concerned constituency (Cotugno and Benner, 2011).

Here again it can be seen that a popularly elected MPO may be more likely to include citizen stakeholders in their decision making as to prevent future backlash and increase trust through transparency and inclusion. Metro’s structure is one that promotes balance: they have the power to tax, mandate, and enforce, but are held directly accountable to the constituency, just as any other government.

Portland’s UGB and the strong, cohesive regional government that oversees its implementation are two key reasons why the area has been so successful in developing a comprehensive light-rail network. Although TriMet[1] was created separately from Metro, it works as the hands of the area’s transportation planning. As mentioned previously, TriMet’s MAX light-rail has been operating throughout the region for nearly 30 years and boasts strong ridership even after recent fare hikes and the elimination of the downtown free

[1] Trimet was originally spelled Tri-Met until a rebranding around the year 2000

ride zone. Since 2000, three new MAX lines have opened nearly doubling its previous ridership to 40 million in 2013 (TriMet, 2013b). TriMet also operates a large biodiesel-powered bus system that has maintained roughly 60 million or more boardings each year since 2000 (TriMet, 2013b).

The decision to build MAX occurred in 1978, the same year CRAG was transformed into Metro (Edner and Arrington, 1985). Known as the Banfield Decision, the process towards planning and building the MAX system was a collective decision on the part of state, regional and local governments and local stakeholders (Edner and Arrington, 1985). It began in 1973 when the Public Utility Commissioner's Railroad Division released a study on Portland area light-rail feasibility (PUC, 1973). The study, created with the help of GTF and at the request of Mayor Goldschmidt, offered a fairly comprehensive plan for five different regional light-rail corridors that employed underutilized freight lines, followed existing roadways at-grade, and borrowed the transit mall concept[1] from Bremen, West Germany for downtown portions (PUC, 1973). Although the corridors presented in the study were not constructed, it served as a starting point for the modern light-rail conversation in Portland (Edner and Arrington, 1985). The study was not intended to be the end-all plan for LRT in Portland, but "to make an informed approach" as to how to proceed with LRT development (PUC, 1973, p. A-27).

[1] Transit malls are areas, usually within an urban downtown core, that prohibit or restrict automobile traffic to allow for expanded use by transit and cyclists. Portions of downtown Seattle become transit malls during weekday afternoon rush hours.

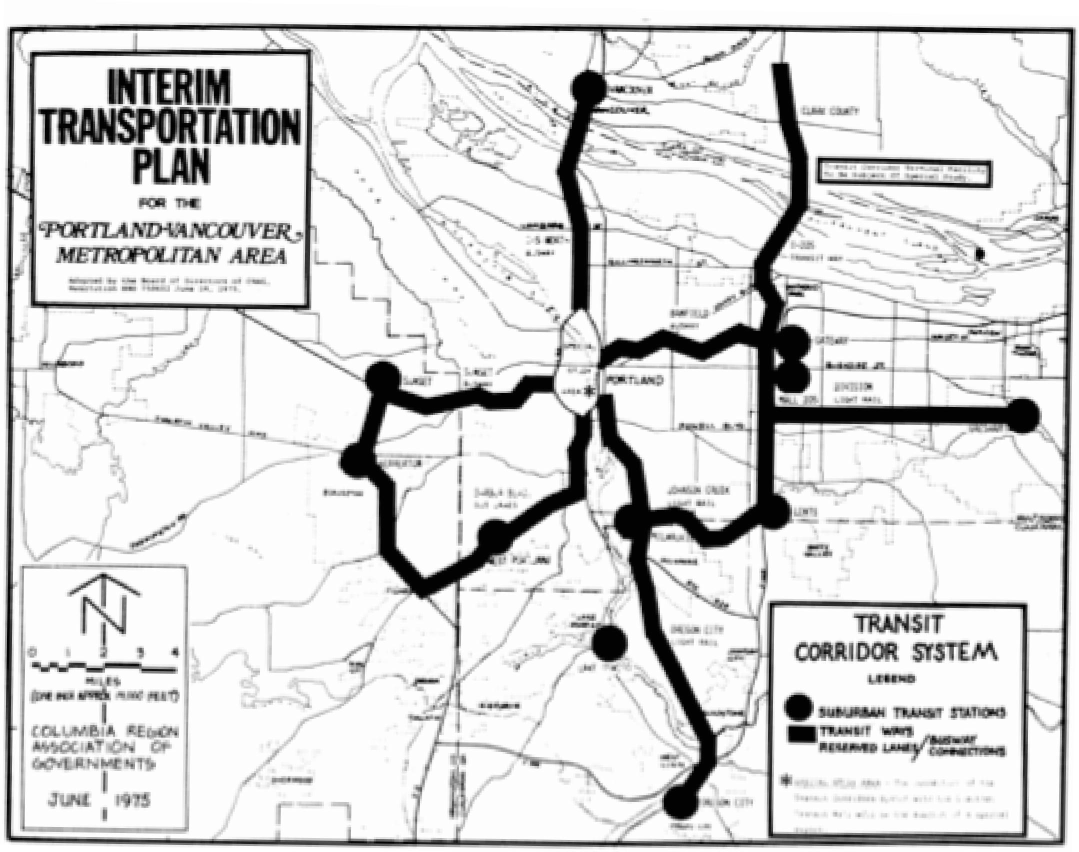

Figure 11: Original plans for the MAX system from the early 1970's (Edner and Arrington, 1985, p. 16)

In 1975, the report caught the attention of the GTF and Mayor Goldschmidt and a formal request was made to the US Department of Transportation to withdrawal the plans to build the previously mentioned Mt. Hood Highway[1] (Edner and Arrington, 1985). The process to pursue LRT began following year stimulated the newly federal funding for multimodal transit by the Federal Highway Act of 1976 and the left over Mt. Hood Funding to boot (Edner and Arrington, 1985). After nearly a decade as a silent partner in the transit policy decision-making process, TriMet released a well-received study that thrust the agency into the lead position on LRT development (Edner and Arrington, 1985). From 1978 to 1980 the plan was reviewed and approved both locally and federally (Edner and Arrington, 1985). Shortly after approval, the city ran into

[1] See Federal Aid Highway act of 1973 Section 103(e)2

problems with the Reagan Administration, but through short negotiations, an agreement was reached to transfer nearly all of federal interstate assistance to the project so long as the city also used the funding on bus improvement (Edner and Arrington, 1985).

By 1982, all funding was set in place and construction on the first segment of MAX began the following year (Edner and Arrington, 1985). Three years later, MAX entered service with 15.2 miles of line running along I-85 and Burnside Street from downtown Portland to Gresham (Demoro and Harder, 1989). This original line had 22 stops and carried about 20,000 riders each day in its first two years (Demoro and Harder, 1989). MAX has expanded significantly in the past decade and now operates four lines (Blue, Green, Red, and Yellow) with over 100,000 daily boardings (TriMet, 2013a).

Comparing and Concluding

It should be evident by now that strong regional government is a key part of why Portland has had more success than Seattle in implementing a regional light-rail system. Now that the relevant histories of the two cities have been presented, it is possible to hone in on a few key factors that may be responsible for the cities' disparity. Both cities struggled significantly through the "dark age" of transit in the mid-20th century, but Portland was able to come out strong with the help of Metro, local stakeholders, responsive and supportive government officials, and its early adoption of a comprehensive UGB.

When the two cities' histories are examined side by side, it is clear that Seattle began its push towards LRT some 20 years before Portland (1952), but Central Link did not open for service until more than 20 years after MAX. Where Portland was able to turn the idea for a transit system (PUC, 1973) into a functioning transit system in 13 years, it took Seattle nearly six decades. The "Seattle way" or "Seattle process" has been cited as the culprit for the lapse in time with credence, but there must be more to the equation (Yardley, 2009). Seattle's "process" of lengthy deliberation on public issues is commonly blamed for many of the issues in the town, but with the example of Portland, it is shown that strong public input is both necessary and valuable (Edner and Arrington, 1985). In Portland, the conversation on LRT development involved both the public and strong MPOs, which provided a venue for public discourse while allowing for progress-centered constraints.

Recall Seattle's twice defeated Forward Thrust plan of 1968 and 1970. The plan was very similar to many of the ideas that were being proposed in Portland at the time: LRT development, downtown preservation, curbing sprawl, and greenspace expansion (OTS, 1976). These ideas were supported by the public (65 percent in favor), the local and regional government, and had a number of transit advocates like James Ellis (OTS, 1976; King County, 2013). In a way, Ellis and Goldschmidt were similar figures, although Ellis lacked the power of the mayor's desk. Still, the LRT provisions of forward thrust failed on Election Day.

Figure 12: Two MAX trains at the Hollywood Station, November 1986
(Hare, 1989, p. 55)

Here, it could be argued that timing killed early LRT development in Seattle. Forward Thrust was snuffed six years before the federal government amended the Federal Highway Act to include public transportation funding. The plan had won a federal grant of $1 billion, but even with this the plan still required a 1 percent hike in the gasoline tax (OTS, 1976; King County, 2013). The argument for timing has some weight to it, but if the region had had a strong MPO with the power to tax, there would have been no need for a vote on the tax to fund Forward Thrust. The region was home to a number of MPOs, but all were either advisory committees or temporary studies without any real planning power.

Despite the passing of the Sound Transit plans and LRT expansion underway in the city, Seattle still lacks a strong regional government. The Puget

Sound Regional Council, the area's MPO, has provided a "vision" of the future in Seattle as far as growth management, economic development, and transportation goes, but does not have the same power as Portland's Metro to affect change in an efficient manor. Recommendations can only go so far if the public is responsible for deciding whether or not to fund a project and choose not to. Seattle has proved this for quite a while.

Unfortunately, there are no other MPOs like Metro in the US with to compare it at this time. This may take away from the credence of this argument to some extent. Yes, Portland's success and Seattle's tardiness may be purely local phenomena, but the similarities between the two cities' values and many closely failed referenda Seattle suggest that strong regional government is a key reason.

What has been presented here is not the end-all be-all of the conversation on MPOs and their structure and policy in Seattle or urban areas as a whole. Where this chapter leaves off, a new study could begin. This chapter is not meant to be the thesis of this study, but a catalyst to enhance the interdisciplinary approach on the part of the author, and the effectiveness of the interdisciplinary research as a whole. It has provided a strong contextual geographic history of Seattle. Now that the city's holistic historic transit policy has been presented, the following research will be able to be understood from a broader and more complete perspective.

Chapter 4: Methodology, Results, and Discussion

Study Area

Both Seattle and the Central Puget Sound Region are growing quickly; the area's population is increasing 30 percent faster than the national average (Drewel, 2011, p. 136). Within the region, a number of regional transit projects have been proposed to meet population growth and reduce VMT of single occupancy vehicles. This study focuses on the East Link expansion of Sound Transit's light-rail system. East Link is the first and largest of a number of plans to evolve the existing Central Link light-rail line from a single north/south route into a viable regional commuter system. This extension takes light-rail across Lake Washington to Bellevue and will eventually continue north to the Microsoft campus in Redmond, funding permitted (Sound Transit, 2014). Eventually, light-rail in Central Puget Sound will extend throughout the region providing commuters with a new mode of transit that will reduce VMT and serve as a foundation for regional sustainability.

Currently, there are twelve stations planned for East Link light-rail (Figure 13). Ten of these stations have received funding and are on schedule to begin construction in 2015 (Sound Transit, 2011; Sound Transit, 2014) Sound Transit (2011) estimates that the system will open sometime in 2023. The East Link alignment begins in Seattle at the International District/Chinatown Station on the Central Link alignment. From there, the line continues east making its only stop within the Seattle city limits in the Rainier neighborhood. East Link crosses Lake

Washington over the I-90 Bridge with a stop on Mercer Island and at the current South Bellevue Park-and-Ride. Here, the line turns north towards downtown Bellevue, stopping at 112th Avenue SE and Main Street at the East Main Station before reaching the Bellevue Transit Center Station, located at NE 6th Street downtown. Bellevue Transit Center Station will serve as a central hub for East Link as it is located very close to the existing transit center. East Link continues on an elevated route to Hospital Station, located at NE 8th Street and 116th Ave NE, and then turns east on NE 16th Street making stops at 120th Avenue Station and 130th Avenue Station via elevated route. After 130th Avenue, the route travels at-grade northeast where it becomes elevated just before reaching Overlake Village Station at 152nd Avenue NE and NE 31st Street. The last funded station of East Link is the Overlake Transit Center, located near NE 40th Street and 156th Avenue at the Microsoft campus.

Data and Methodology

Both data collection and analysis undertaken in this study are somewhat novel and exploratory. A number of previous research and LCA guides influenced the scope and methods, but no one source was a sole provider of methods (Chester and Horvath, 2012, Chester et al, 2013, Transportation Authorities Greenhouse Group, 2013). The scope and methodology of this study, although grounded in previous works, was adapted to fit time, financial, and data availability constraints. This section details the scope, methods for data collection, and the LCA procedure and analysis conducted in the study.

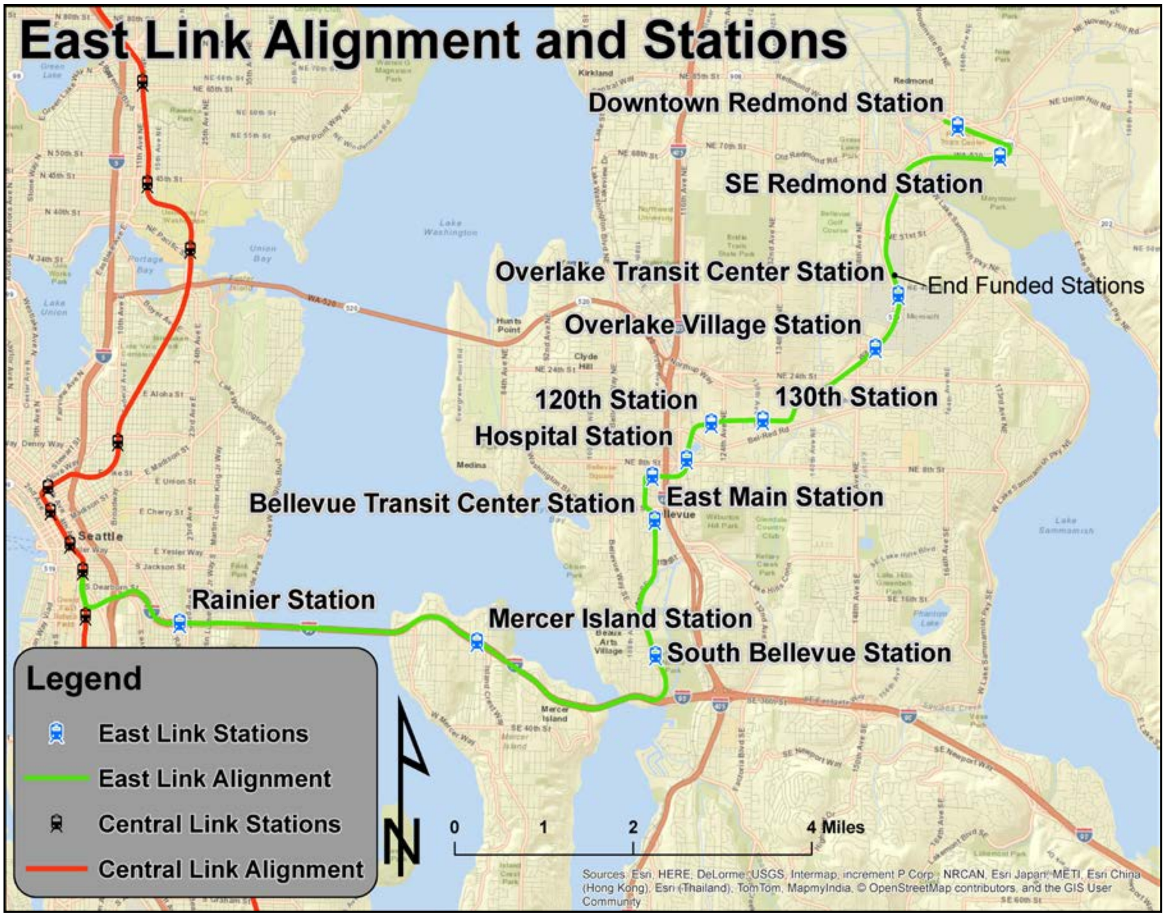

Figure 13: Map showing East Link alignment and stations

Definition of Life-Cycle Inventory Scope

Although this study presents an opportunity to examine sustainable development with up-and-coming methods, there were some constraints on the scope that it could pursue. Like all studies, time and data availability played a significant role in defining the scope of this research.

The amount of time allotted for the full completion of this work was limited to roughly ten months, a relatively short time when considering LCAs. Additionally, timing of the study limited the scope; this entire work was completed before the final design of the East Link alignment was completed, which will inevitably affect the accuracy of the results. Still, it is more useful for a study of this kind to be produced beforehand as it can provide insight into the environmental potential of a future sustainable development project.

Data availability was by far the most limiting factor on the scope of this study. This work began several months before much of the data analyzed in the following chapters were produced by their sources. Therefore, the scope of the study was defined by the data that was available and able to be analyzed within the given time limitations. The scope was defined to include any and all materials used in the construction of the East Link light-rail expansion that met the following criteria:

1. Materials must be able to projected as an amount of weight or volume
2. Materials must be created off of the construction site (i.e. dirt and backfill gathered from the construction site were not included)
3. The base or source of a material should be able to be specifically defined (steel, Portland cement, polyethylene, etc.)
4. Materials with complex composition must be able to be accurately sub-divided into base material parts

Although these criteria provided some limitation on what was included in the final LCA analysis model, they made it possible to complete the study within the given time and data availability constraints.

Data Collection, Materials, and Procedure

Data was collected between July 2013 and May 2014. Quantitative data for the life-cycle assessment came from a number of sources including Sound Transit, Puget Sound Regional Council, the City of Seattle, and WSDOT. At the time of this study, East Link was in the “60 percent design” phase of the project, meaning that the materials analyzed in this study were estimates on a bid report. All available bid reports (four in total) were collected from Sound Transit via Public Request for Records with the help of members of Sound Transit’s Community Outreach and GIS teams. Each of the four reports represented a different bid, all of which were authored by Jacobs Engineering of Bellevue in January 2014.

The materials from the bid reports were compiled in a spreadsheet and categorized based on the primary components used in the production of the material. Six categories were established and included metals, plastics, earthen composites (concrete, cement, and gravel), wood-based, miscellaneous (rubber, tar, and artificial adhesives), and not applicable to scope (NAS). In total, 228 materials of the 338 total were deemed appropriate for the scope of this study (Table 2). Those designated as NAS were done so for a variety of reasons including an inability to be identified, obscurity of dimensions and units (common among stormwater features), and the complexity of an item being too high for the study (electrical breaker boxes, combination air valves).

After the inventory of materials was established, totals were summed and converted to a common unit of weight or volume using conversion formulas from relevant industry and government sources. Formulas were gathered from local industry and government sources when available. Among the most complex materials analyzed were bridge girders and decks. While their complexity bordered the appropriate scope of the study, it was necessary that they were included in the analysis due to their large numbers. Bridge components were converted into weight of steel and volume of concrete with the assistance of the WSDOT Bridges and Structures Office and Concrete Technology Corporation, a Tacoma-based manufacturer.

It is important to disclose that the bid reports provided by Sound Transit represented only six of the ten funded stations for the East Link alignment as well as the downtown Bellevue Transit Tunnel. According to Sound Transit (2014), the bids that represented the remaining alignment and stations were late and therefore unavailable. This issue was addressed during data analysis by using a multiplier (1.666667) on the total of each material group in order to project for the unavailable alignment and station materials.

Other information relevant to the life-cycle assessment was available at the onset of the study. Demographic data, GIS layers, and ridership forecasts were provided by PSRC. Sound Transit's East Link Final EIS (2011) provided estimates of the system's 2030 regional emission reduction potential (p. 5.6-14) and incomplete estimates of the GHG impacts from construction (p. 4.6-15 and 4.6-16). The construction-related estimates from the EIS included emissions from construction equipment, construction of the track alignment, stations, and facilities, and the waste and transportation associated with construction materials (Sound Transit, 2011, p. 4.6-16). This was shown to contribute 121.60 kton CO_2e to the project (Sound Transit, 2011, p. 4.6-16). The EIS did not, however, include estimates of the impact of the construction materials themselves, a gap that this research aims to fill through LCA.

Procedure: Life-cycle Assessment

Materials were analyzed for their estimated CO_2e impact using SimaPro 8 software. SimaPro 8 was chosen for its compatibility with this study, common usage among other similar studies (Chester and Horvath, 2012), access to diverse databases, and integrated normalization, weighting, and statistics capabilities. A temporary SimaPro 8 lab was established at The Evergreen State College Computer Applications Lab in Olympia, Washington where research and analysis were conducted from March 2014 through May 2014. The software was purchased with funds made available by the Evergreen Clean Energy Fund.

An Impact Assessment analysis of the estimated East Link materials was conducted using the Greenhouse Gas Protocol (V1.01) method to determine the total estimated CO_2e impact of the project. Attributional modeling was applied throughout the analysis process. Within SimaPro 8, a model was created and East Link materials were allocated to common unit materials provided in the ecoinvent3 database (Table 2). In addition to the East Link materials, an average of Sound Transit's estimated CO_2e emissions from construction processes was added to the model after analysis (Sound Transit, 2011, p. 4.6-26).

Allocated ecoinvent 3 Materials	Amount	Associated East Link Materials
Copper {GLO}| market for | Alloc Def, U	187.03 kg	Copper pipes
Cast iron {GLO}| market for | Alloc Def, U	683832.41 kg	All iron materials
Steel, low-alloyed {GLO}| market for | Alloc Def, U	137481890.26 kg	All steel materials
Polyester-complexed starch biopolymer {GLO}| market for | Alloc Def, U	5316.02 kg	Geotextile reinforcing
HDPE pipes E	517904.90 kg	HDPE Pipes
PVC pipe E	1259384.12 kg	PVC Pipes
Glass fibre reinforced plastic, polyamide, injection moulded {GLO}| market for | Alloc Def, U	11087.63 kg	Fiberglass
Polypropylene, granulate {GLO}| market for | Alloc Def, U	71962.86 kg	Polyprop. rope, geocomposite drain board, polyprop. fabric, geotextile fabric
Polyethylene, high density, granulate {GLO}| market for | Alloc Def, U	451.82 kg	Plastic sheeting, safety fence, backer rod
Concrete, normal {GLO}| market for | Alloc Def, U	277641.27 yd^3	Shortcrete, quickcrete, walls, slabs, flow fill, girders and decks (reinforcing accounted for as steel)
Gravel, crushed {GLO}| market for | Alloc Def, U	1107879861.59 kg	Gravel
Sand {GLO}| market for | Alloc Def, U	16631.75 kg	Sand
Pre-cast concrete, min. reinf., prod. mix, concrete type C20/25, w/o consideration of casings RER S	8061429.72 kg	RCP, manhole components
Cement mortar {CH}| production | Alloc Def, U	1020674.39 kg	Grout
Cement, Portland {US}| production | Alloc Def, U	56538.89 kg	Cement
Brick {GLO}| market for | Alloc Def, U	144242.66 kg	Bricks
Liquid epoxy resins E	33.07 kg	Epoxy cartridges (packaging not incl'd)

Synthetic rubber {GLO}| market for | Alloc Def, U	1692.14 kg	Concrete waterstop
Bitumen seal {GLO}| market for | Alloc Def, U	1559.75 kg	Tar for coating (coal tar illegal in Wa – assumed bitumen)
Dry rough lumber, at kiln, US PNW/US	5498053.67 kg	Lagging, blocks, and fence – species undefined
East Link Construction	(1)	Construction emissions (Sound Transit, 2011)

Table 2: This table shows the allocated ecoinvent3 materials used within the LCA model as well as the associated materials from the East Link bid report and their weight or volume.

Five processes were applied to the model in order to allocate for the production of usable goods from raw materials and included steel processing for beams and rebar, copper processing for pipes and wire, iron working, extrusion for plastic film production, and plastic polymer foaming (Table 3). The majority of East Link materials was compatible with existing unit materials within the database and did not require allocating a process (RCP and PVC pipes, etc.). Unlike many other LCAs, this study did not employ grouping of materials within the model, as this option was rendered unavailable by feedback loops within the model itself.

The LCA output was weighted and normalized so that the results could be expressed as single CO_2e value. All relevant impact categories were included in the model: Fossil CO_2[1], Biogenic CO_2[2], Land Transformation CO_2[3], and CO_2 uptake from natural processes (Table 4). Result tables from the SimaPro 8

[1] Fossil CO_2 refers to GHG emissions from burning fossil fuels or processes related to burning fossil fuels.
[2] Biogenic CO_2 refers to GHG emissions from natural processes
[3] Land Transformation CO_2 refers to GHG emissions from altering natural habitats and landscapes and therefore reducing their natural capacity to sequester CO_2

Impact Assessment were exported to Microsoft Excel and analyzed using a 100 year model that accounted for total system build emissions and compounded average forecast of the system's regional GHG reduction potential as provided by Sound Transit (Sound Transit, 2011, p. 4.6-14).

Both electricity and the construction of rail cars were omitted from the model for a number of reasons. First, the majority of electricity supplied to the area where the system will be in operation is produced from carbon-free sources like hydro (Sound Transit, 2011). The portion of the alignment within Seattle's city limits is supplied by 100 percent carbon-free energy (Seattle City Light) and the part outside of Seattle is just under 50 percent carbon-free (Puget Sound Energy). Although the majority of the East Link alignment is located outside of Seattle, it is unknown what Puget Sound Energy's electricity supply will be in 2023 when the system opens.

The rail cars were omitted from the study as they did not meet the defined scope. This was mainly because, after some investigation, their material composition was unable to be accurately determined and could not be analyzed. Additionally, previous studies (Chester and Horvath, 2009, p. 4; Chester et al, 2012, p. 31) have shown that light-rail vehicle manufacturing contributes a relatively insignificant amount of CO_2e compared to infrastructure construction and other inputs.

Process	Amount	Associated material
Metal working, average for copper product manufacturing {GLO}| market for | Alloc Def, U	1875.03 kg	Copper pipe production
Metal working, average for steel product manufacturing {GLO}| market for | Alloc Def, U	137481890.26 kg	All steel materials
Metal working, average for metal product manufacturing {GLO}| market for | Alloc Def, U	683832.41 kg	All iron materials
Extrusion, plastic film {GLO}| market for | Alloc Def, U	77595.53 kg	Polyester, Polypropylene, and Polyethylene (minus backer rod)
Polymer foaming {GLO}| market for | Alloc Def, U	135.16 kg	Polyethylene backer rod production

Table 3: Shows ecoinvent3 processes associated with East Link bid report materials and their total weight

Impact Category	Total CO_2e	Most Significant Sources (kton CO_2e)
Fossil CO_2e	688.24 kton	Steel Processing – 288.45 kton Steel (low-alloyed) – 274.42 kton Concrete – 93.11 kton Gravel – 21.90 kton
Biogenic CO_2e	27.39 kton	Steel Processing – 21.68 kton Steel (low-alloyed) – 3.63 kton Concrete – 1.56 kton
Land Transformation CO_2e	1.7 kton	Pre-cast concrete – 0.95 kton Steel Processing – 0.50 kton Steel (low-alloyed) – 0.18 kton
CO_2e Uptake	-20.62 kton	Dry Lumber – -10.57 kton Steel Processing – -6.13 kton Steel (low-alloyed) – -3.16 kton

Table 4: Detail of LCA Impact Analysis showing categories, associated CO_2e impact, and the most significant sources of impact within each category

Results

The primary goal of this study is to complete a GHG life-cycle assessment of the East Link light-rail expansion in Seattle and to discover when the regional GHG reduction benefits will outweigh the GHG cost of constructing the system. To accomplish this goal, estimates of construction materials were complied, converted to weight and volume values, and analyzed for their GHG impacts using SimaPro 8 LCA software. The Impact Assessment outputs from SimaPro 8 were analyzed using a 100-year model that shows the system's long-term emission reduction capabilities and emission payback timeline.

The results from the LCA impact assessment analysis are discussed in terms of total impact from the project and impact from the most significant sources of GHG emissions within the project. Finally, this section will detail the results from the 100-year model and provides a discussion based on the findings.

LCA Impact Assessment

Using the Greenhouse Gas Protocol (V1.01) method in SimaPro 8, an impact assessment was produced for the East Link materials model. This method estimates total CO_2e from the sum of Fossil CO_2e, Biogenic CO_2e, Land Transformation CO_2e, and CO_2e uptake associated with the model. Additionally, it shows the relationship among all significant materials and processes (Figure 15). The estimate of the total CO_2e impact from the construction of the system was shown to be 818.31 kton CO_2e with 696.71 kton CO_2e attributed to construction materials and 121.60 kton CO_2e from Sound Transit's construction emissions estimate (Sound Transit, 2011, p. 4.6-16). Of the four impact categories, Fossil CO_2e was the by far the largest emission source at 688.24 kton CO_2e or 98.78 percent of total emissions from materials (CI_{95}: $\overline{6.92E+08} \pm SE\ 0.003$). CO_2e emissions from fossil sources were expected to be the most significant source of the four. Biogenic CO_2e emissions were shown to be 27.39 kton CO_2e with small standard error (CI_{95}: $\overline{2.77E+7} \pm SE\ 0.006$) and emission from land transformation was shown to be 1.7 kton CO_2e with small standard error (CI_{95}: $\overline{1.7E+6} \pm SE\ 0.0055$) (Figure 14).

Significant Materials and Processes

Certain materials presented a significantly larger impact than others. Of all materials analyzed, Steel, Concrete, and Gravel were by far the most significant sources of CO_2e emissions in the Impact Assessment model. Steel represented some 275.07 kton CO_2e, slightly less than 40 percent of total material emissions from the construction of the system. Concrete accounted for 94.29 kton CO_2e or 39.48 percent of the total material emissions. Gravel, although a minimally processed material, accounted for some 22.04 kton of CO_2e emission. This was due perhaps due to its very large amount of 1107.88 kton, making it the most abundant material in the bid sheets.

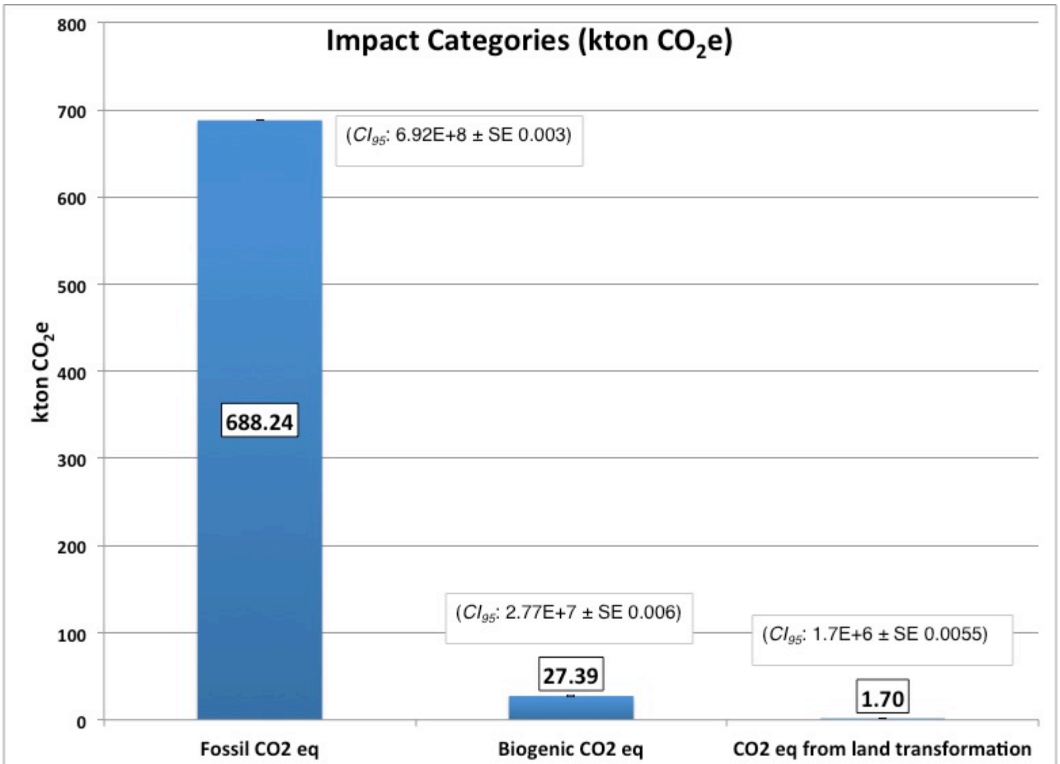

Figure 14: Detail of categories from LCA impact analysis using Greenhouse Gas Protocol methodology. Exact amounts are seen in the white boxes. All categories show very low standard error.

Surprisingly, manufacturing processes as a group represented the largest source of GHGs associated with East Link construction (43.94 percent). Of all processes and materials analyzed in the model, steel metal working processes were the most significant source of emissions at 304.5 kton CO_2e (43.70 percent of total material emissions). This was because of the energy-intensity methods of processing raw steel into goods ready to be used.

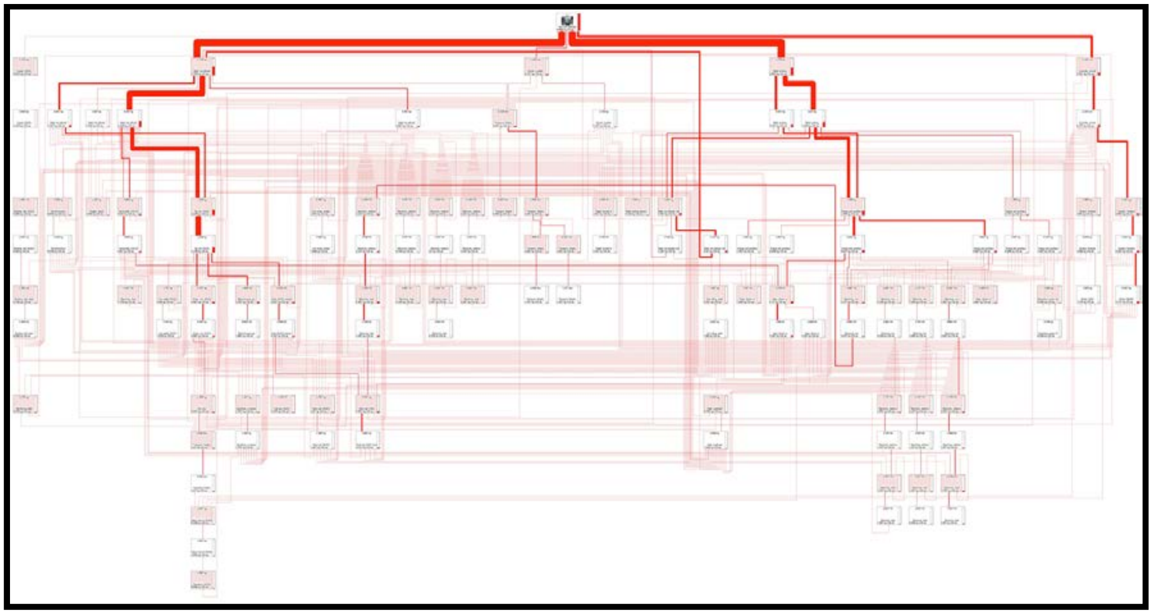

Figure 15: The East Link model LCA output expressed as a network of all materials and processes at one percent relevancy. Lines connecting the network are weighted by impact amount.

100-Year Impact Model

Construction materials, processes, and annual system CO_2e reduction forecasts were modeled over 100 years starting in 2023, the projected open date for the East Link alignment (Sound Transit, 2011). Sound Transit estimated the 2030 average annual reduction benefits to be 25.19 kton CO_2e over the Central Puget Sound Region (Sound Transit, 2011). Although this number is likely to change over the century-long estimated lifetime of the system, it was used as a constant within the model as it was the only forecast available at the time of this research.

Using the reduction constant of 25.19 kton CO_2e per year and total system construction cost estimate of 818.31 CO_2e, the model showed the East Link alignment to pay achieve carbon neutrality in May of 2054, some 31 years after its open date (Figure 16). The model also showed the system's total lifetime GHG reduction capability, which is estimated to be 1700.19 kton CO_2e, roughly two times the CO_2e cost to build the system.

Discussion

There are several important implications stemming from the results of the LCA analysis. This section discusses important insights from the 100-year model and the necessity of holistic environmental impact assessments for large sustainable development projects like East Link. Limitations of the results are discussed throughout the section.

100-Year Impact Model

The main purpose of the 100-year model is to show the regional CO_2e reduction capability over the lifetime of the East Link extension. The estimates in the model show that although the system is responsible for a large amount of GHG pollution from its construction (818.31 kton CO_2e), it has the capacity to be a significant regional carbon sink over its estimated century-long lifespan (Sound Transit, 2014). According to this model, it will take just over 30 years (May 2054) for the system to become carbon-neutral and start showing regional GHG reduction benefits (Figure 16). Additionally, the model shows a net-carbon sink over its lifespan and estimates regional a GHG savings of 1,700.19 kton CO_2.

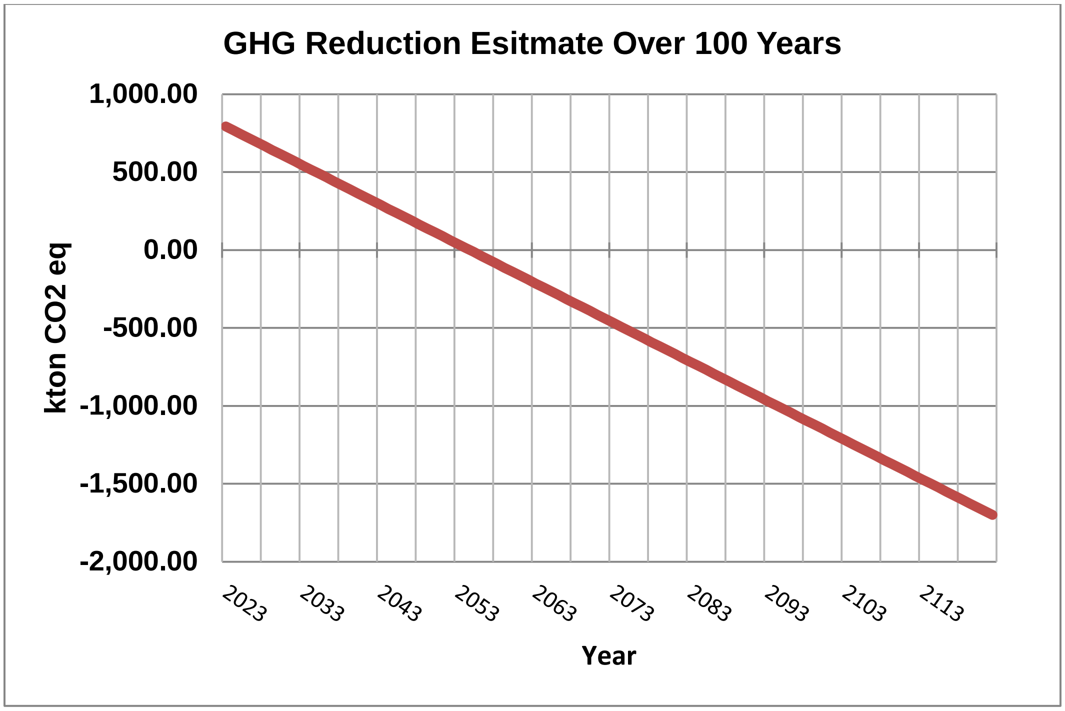

Figure 16: East Link's GHG reduction benefit is estimated over 100 years using both Sound Transit's construction emission estimates and the results of the LCA. This figure shows East Link will become carbon neutral in May of 2054 and will be a carbon sink for the majority of its expected 100-year operation.

While these estimates used the best available data at the time of this study, there are several factors that could affect its long-term accuracy. Perhaps most evident is the estimated annual CO_2e reduction capacity of the system. This figure, provided by Sound Transit, was based on a number of factors including an anticipated reduction in regional VMT from drivers switching to transit, increased efficiency of automobiles from reduced traffic congestion, and anticipated transit oriented development (TOD) around the system (Sound Transit, 2011, p. 4.6-11-4.6-14). Although not mentioned by Sound Transit in the East Link EIS, it is possible that the system's regional reduction capacity will grow over time and therefore alter the trajectory of the 100-year model. Current and future regional transit projects could significantly increase the ridership of East Link by increasing the connectivity of the system. Central Link is currently expanding towards the north and south and Sound Transit is exploring the possibility of a northwestern light-rail extension from downtown Seattle to the more residential neighborhoods of Queen Anne, Ballard, and Freemont[1]. Once these projects are running, light-rail will be a more appealing travel option in Seattle.

It should also be noted that transit ridership could decrease over the next 100-years due to an advent in transportation technology. An increase in affordable electric automobiles may change ridership of transit; this is especially relevant to Seattle as its residents pay less than 70 percent of the national average electricity bill (United State Energy Information Administration, 2013). If this were the case, it could take longer than this model estimates for the system to pay off its GHG costs. This may be more of a speculative idea, but it is important to approach the issue from all sides. It is true that transportation in the U.S. has not evolved as quickly as other facets of life like personal computers, but it is an issue worth considering and should be given more thought in impact statements from MPOs and developers.

[1] See this link for more information on the Ballard Transit Expansion Study

Construction Emissions and East Link EIS

Perhaps the most significant insight provided by this study is the large difference in Sound Transit's estimated construction emissions in the East Link EIS and the estimate of construction emission from the materials LCA. While Sound Transit estimated total construction-related emissions to be just over 121 kton CO_2e, the LCA of East Link material estimates an additional 696.71 kton CO_2e emissions. Here the importance of holistic analysis of sustainable development projects is easily seen. Using only Sound Transit's estimate, the system could pay itself off in less than six years, but the holistic estimate that includes LCA shows it more than likely will take over five times as long.

Previous studies have highlighted the necessity of employing holistic modeling and analysis for sustainable development projects in other parts of the country (Chester and Horvath, 2009; Chester et al, 2013). Although the estimates in this study show that the East Link alignment will be able to reduce regional CO_2e emissions over its lifetime, it is vital to understand its true potential at the project's onset. If sustainable development projects are pursued for the purpose of mitigating climate change, their potential to do so should be fully analyzed and understood in order to maximize effectiveness.

Unfortunately, this is not standard operating procedure in most environmental impact statements (Chester and Horvath, 2009; Chester et al, 2013). The results of this study should serve as a wake up call for anyone involved in sustainable development projects and climate change mitigation.

Climate change is the most pressing environmental problem facing society today and if we are to mitigate it effectively, we must attain a complete understanding of both the problem and the solution before proceeding. No environmental issue, be it local or global, can be solved without a holistic systems approach to the source of the problem. It is recommended that projects not only begin to incorporate life-cycle assessment, but also include contextual briefing to establish a geographic point of view on the project.

Chapter 5: Conclusion

Two main goals were established at the onset of this research: quantify the true emission reduction potential of the East Link extension and present a holistic understanding of transit geography and context. Through a life-cycle assessment of East Link's construction materials and a geographic comparative analysis of transit in Seattle and Portland, both of these goals were met. Several key insights can be drawn from this research. First and foremost, the results reaffirm findings from previous LCA studies (Chester and Horvath, 2009; Chester and Horvath, 2012; Chester et al, 2012; Chester et al 2013) by showing that infrastructure materials are the largest contribution to a transit project's lifetime GHG emissions. While Sound Transit (2007) estimated total construction emissions to be 121.6 kton CO_2e, this research showed that the addition of infrastructure materials to the EIS contributed an additional 696.71 kton CO_2e. The impact estimate from this research is some 676 percent larger than that of East Link's EIS. This analysis confirms the necessity of holistic LCA analysis when producing impact statements for large-scale sustainable development projects.

Second and equally important, this research shows that the East Link light-rail system is estimated to provide a lifetime regional CO_2e reduction (1700.19 kton CO_2e) nearly twice as large as the estimated CO_2e cost to build the system (818.31 kton CO_2e). Using just the Sound Transit (2007) construction emission estimates, the system would have been able to pay itself off in just under five years. When including the LCA of this study, the payoff time for the system is shown to be just over thirty years, with carbon neutrality achieved in May of 2054. Again, these results show the necessity of holistic LCA analysis in finding the true environmental benefits and drawbacks to sustainable development projects.

Additionally, this research shows the importance of a strong and cohesive regional government in affecting sustainable transportation development. Seattle made a number of attempts to develop light-rail infrastructure throughout the 20th century, but all failed in elections or for other political reasons. Portland, on the other hand, was able to build the expansive MAX system in large part because of Metro's political structure. Although Seattle began working towards a comprehensive light-rail system many years before Portland, Metro's ability to function as a strong, autonomous government allowed the region to progress with less political resistance than in Seattle.

Together, these key results affirm that transportation is a transdisciplinary issue that requires transdisciplinary methods and analysis. While the results from this paper are able to stand alone in their significance to the issues of sustainable development and climate change, their collective impact shows the importance of holistic analysis when considering development and mediation projects and ideas. This study surpasses a simple examination of the GHG reduction potential of a development project or the results of historic political decisions and reveal a whole story of the transit situation in Seattle. In many cases, a strong understanding of a current situation greatly benefits from a strong understanding of historical and geographic context. Likewise, plans for the future are enhanced by in-depth knowledge of the past. These are common truths that can be applied to many different situations.

The research is not meant to be a singular source of the story of transit in Seattle, but to enhance the current conversation on sustainable development in the region and serve as an example for future research. Additionally, there are places where this research could be enhanced and used by future studies. Some questions regarding the story of transit in Seattle are left unanswered. What would have been the GHG reduction potential of the Forward Thrust plan if it had been enacted? How would transit in Seattle be different today if its MPO shared the political structure of Portland’s? How could building with recycled or less-impactful infrastructure materials reduce emissions from construction? How will future light-rail expansion projects in Seattle alter the reduction potential of East Link? All of these are important questions that could progress the conversation on sustainable development and climate change mediation in Seattle and other urban areas.

The story of public transportation in Seattle continues with a bright future. Seattle and the Central Puget Sound region are among the most environmentally progressive areas in the United States and the completion of East Link will reaffirm the region’s national leadership in urban sustainability (Sheppard, 2011). As the region’s population grows, so should its preparedness, ingenuity, and creativity in mediating climate change and urban sprawl. Developing transit infrastructure in Seattle is a step in the right direction for the region, but understanding the holistic sustainability implications is necessary for development to make a positive impact.

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