URBAN TRANSIT MODE COMPARISON AND SELECTION

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To my friends, family, and loved ones

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LIST OF ABBREVIATIONS

AG	Automated Guideway
APTA	American Public Transportation Association
BRT	Bus Rapid Transit
CB	Commuter Bus
CC	Cable Car
CO_2	Carbon Dioxide
CPT	Cable Propelled Transit
CR	Commuter Rail
DR	Demand Response
DT	Demand Response Taxi
EIA	Energy Information Administration
FB	Ferryboat
FT	Funitel
FTA	Federal Transit Administration
GD	Gondola
HR	Heavy Rail
IP	Inclined Plane
JT	Jitney
LR	Light Rail
MB	Motorbus
MDG	Monocable Detachable Gondola
MG	Monorail / Automated Guideway
MMF	Major Mechanical Failures

MO	Monorail
MPO	Metropolitan Planning Organization
MV	Maglev Rail
NEPA	National Environmental Protection Act
NTD	National Transit Database
NTS	National Transportation Statistics
OMF	Other Mechanical Failures
PB	Publico
PRT	Personal Rapid Transit
RB	Bus Rapid Transit
SR	Streetcar Rail
TB	Trolleybus
TR	Aerial Tramway
TRSMF	Total Revenue Service Mechanical Failures
VAMS	Vehicles Available in Maximum Service
VOMS	Vehicles Operated in Maximum Service
VP	Vanpool
WB	Water Bus
WT	Water Taxi
YR	Hybrid Rail

SUMMARY

The motivation behind this research is to support more informed decision making when it comes to transit mode selection, to help cities and communities thrive. In this thesis, a variety of innovative and conventional transit modes are described and compared across several different dimensions related to performance, environment, social, and economic factors. This information can be used to inform and guide transit mode selection processes in the United States and beyond. Tools and guidelines are proposed to inform more logical and inclusive mode selection processes for transportation planners, engineers, and others to use in identifying transit mode options that would best align with their purposes and the needs of the communities they serve. The author did not seek to identify a single best mode for any particular purpose, but rather to provide information and guidance to help decision makers narrow the field of urban transit modes to several appropriate options for further investigation.

This thesis presents background on urban transit modes, including a brief history of transit and a literature review summary for the U.S. and beyond, followed by transit mode definitions, research methods used, and organization of the report. After the introduction, the thesis is presented in three parts. Part I focuses on the *Transit Mode Selection Survey* that was administered to gain insights about processes and priorities for choosing transit modes to use for system expansion and enhancement in the U.S. and Puerto Rico. Part II presents data that was collected and analyzed relating to urban transit modes from national data sources and international case studies. Part III includes a proposed transit mode selection process, as well as a summary of recommendations and future research opportunities. Additional tools and information, including a process checklist and urban transit mode summary sheets, are provided in the appendices.

CHAPTER 1

INTRODUCTION

This thesis is a compilation of research over the past two years, which has been focused on identifying and comparing urban public transportation modes across many different dimensions. Chapter 1 provides an introduction to the research, including the motivation behind it, a problem statement, objectives, background, methodology, and organization of the report.

1.1 Motivation

Multi-modal transportation networks are critical for thriving and productive cities. Public transit is an amenity provided in most urban areas to facilitate jobs access and efficient movement of people through congested corridors, yet effective transit planning in the United States remains a challenge. Heavy reliance on buses and limited adoption or expansion of other transit modes over the last several decades has led to a lack of expertise among transit planners and decision makers in the U.S. with respect to modes other than bus. As a result, our transportation mode selection processes often exclude innovative modes, such as cable-propelled transit (CPT), automated guided transit (AGT), and maglev rail (MV).

For example, although CPT systems, which include aerial tramways (TR), funitels (FT), and aerial gondolas (GD), have been widely used to transport people in various places around the world for decades (especially on ski resorts), they have only recently gained popularity for use in urban settings. Many seasoned transportation professionals have not heard of, used, or given serious consideration to CPT as a mode of mass transit. This is regrettable, since CPT has proven itself over decades to be very safe, user-friendly, and efficient. Many cities, including Portland and New York, but more often cities in South America, Asia, and Europe, such as Medellin and London, already have CPT systems incorporated into their urban transportation infrastructure, and many more systems are planned. This is just one example of a transit mode that is being deployed in cities around the globe at a much faster rate than in U.S. cities, but as new modes emerge this trend will likely continue, unless we update our transportation planning processes to include new options as they become available.

If U.S. cities are to be globally competitive, their leaders must consider new technologies as they develop, so that the most appropriate, efficient, and sustainable systems may be implemented for meeting current and future needs. The motivation behind this research is to support more informed decision making when it comes to transit mode selection, to help cities and communities thrive. In this thesis, a variety of innovative and conventional transit modes are described and compared across several different dimensions. This information can be used to inform and guide transit mode selection processes in the U.S. and beyond. Ultimately, the goal of this research is to encourage more logical, creative, and objective thought and decision making with regard to transit mode selection.

1.2 Problem Statement

There seem to be more choices than ever for moving people throughout urban environments, and new transportation modes continue to be created and developed. Transportation innovations may struggle to gain traction in the U.S. due to a lack of understanding of new technologies among community leaders and key makers, as well as many other possible reasons. Transportation planners and engineers in the U.S. often focus on conventional transit modes, but may still find it challenging to objectively evaluate different technologies for their particular purposes and context. When the fundamental differences in these technologies and the lack of information about many of the lesser-known modes are taken into account, it is no wonder that planners and engineers don’t propose innovative transportation solutions more often. The risks and uncertainty may be viewed as too great, which would limit creativity and willingness to try new modes. This research seeks to bring less conventional transit modes into more transit mode selection processes, and ultimately into more cities, especially when these modes offer strategic advantages over other options.

1.3 Objectives

The objective of this research is to comprehensively evaluate existing and emerging forms of urban transportation, with particular emphasis on more sustainable transit modes. Further, tools and guidelines are proposed to inform more logical and inclusive mode selection processes for transportation planners, engineers, and other interested parties to use in identifying transit mode options that would best align with their purposes and the needs of the communities they serve.

The goal of this research is not to identify a single best mode for any particular purpose, but rather to help decision makers narrow the field of urban transit modes to several appropriate options for further investigation. While the researcher has worked to adhere to the highest standards of academic rigor while producing this thesis, this report is written with non-academic audiences in mind, so that it can be useful for anyone from senior transportation engineers and transit agency executives to community groups and concerned citizens.

1.3.1 Research Questions

The research questions addressed in this thesis include the following:

- How do decision makers choose which transit mode to use for a project?
- How do urban transit modes, including unconventional modes, compare to each other, and under what conditions should each mode be used?

1.3.2 Significance

This project will help to bring viable innovative transit modes into more planning processes and cities around the world. An overarching goal of this effort is to create a mode selection framework that is streamlined and flexible enough to integrate new transportation technologies as they come to market. Tools and guidelines developed to aid in this process will help decision makers in the U.S. and beyond to more creatively and objectively identify and evaluate urban transit modes. These tools will give lesser-known but useful urban transit modes a better chance for market deployment, and offer cities more affordable and sustainable options for expanding and enhancing their public transit systems.

1.4 Background

1.4.1 History

This section provides an overview of the history of public transit around the world, with a focus on the United States.

1.4.1.1 Pre-1800s

Before the industrial revolution, people typically traveled through cities by walking and with the help of animal labor. One of the earliest ferry services in the world dates back to the mid-1100s in England, although the first royal charter for ferry service wasn't issued until 1330 (Mersey Ferries, 2013). The reputed first publicly operated ferry service in the U.S. opened in 1630 in Boston (APTA, 2007). Inclined plane (or funicular) rail and other modes were being used in the 16th and 17th Centuries, but primarily for hauling cargo (Azema, 1997). Horse-drawn hackney carriages appeared on the streets of Paris and London in the early 1600s (Gilbey, 1903). One of the earliest public bus lines was launched in Paris in 1662, but a fare increase and subsequent decline in ridership led the service to cease operations after only 15 years (Histoire generale des transports, 2014). Almost a century later, in 1740, the first ox carts for transporting passengers were used in New York City (APTA, 2007).

1.4.1.2 First Industrial Revolution (1800-1839)

The world's first railway service was converted to carry people between Swansea and Mumbles in Wales on March 25, 1807, as shown in Figure 1.1 (Rogers, 2000).

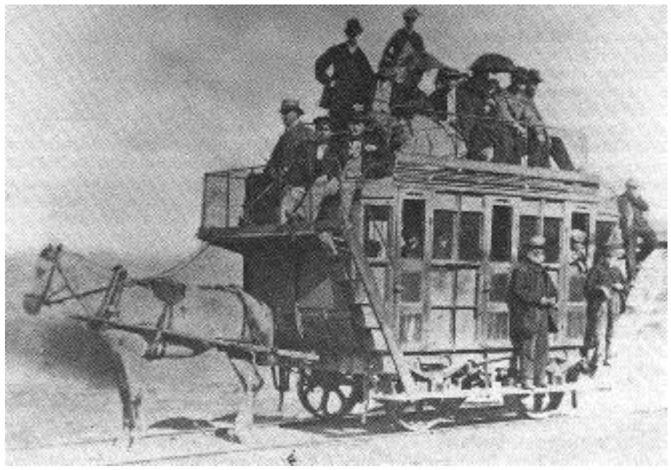


Figure 1.1 – The Mumbles Train (world's first passenger railway service)

Just a few years later, in 1811, the first steam-powered ferry service began operating between New York City and Hoboken, New Jersey (Doan, 1909). In the 1820s and over the decades that followed, the horse-drawn omnibus, a pre-cursor to the modern bus, emerged in France (Histoire generale des transports, 2014), and soon spread to other countries including the United States (APTA, 2007). In 1825 the first passenger-carrying monorail opened, which was powered by a single horse (Monorails in History). Steamboat services were also to be found on the Seine River in Paris around this time (Histoire generale des transports, 2014). The following year, the first cable car began operating in England (Hazard, 1827).

The 1830s brought several advances in public transportation. The first U.S. railroad opened in Baltimore in 1830 (APTA, 2007). In 1832 the first (horse-drawn) streetcar rail system, the New York and Harlem Railroad Fourth Avenue Line, began service. New Orleans then began operating their streetcar system in 1835 (Bellis). Steam-powered buses also emerged in England in the early 1830s (Centenary of the Omnibus, 1933). At least two other major breakthroughs took place in 1834. This was the year that the New York City MTA opened the Long Island Rail Road, a commuter rail line that is the oldest still operating under its original name (Long Island Rail Road - General Information). Further, this was the year in which the steel cable was invented in Germany, sparking a wave of innovation in cable-propelled transit technologies (Creative Urban Projects, 2013). The first commuter fares collected for rail travel were for the Boston and West Worcester Railroad in 1838 (APTA, 2007).

1.4.1.3 Transition Years (1840-1869)

The period between the first and second industrial revolutions saw a decline in transit innovations, yet some progress was made during this era. Double-decker buses made their first appearances on the streets of Paris (Gould), London (Webb, 2009), and elsewhere. Advances in steel manufacturing led to widespread deployment of steel railroads for moving goods and people, beginning in the 1860s (Grubler, 1990). The first passenger-carrying funicular began operating in 1862 (Histoire generale des transports, 2014). London debuted the world’s first underground railway, which would later become part of the London Underground but was then called the Metropolitan Railway, in 1863 (TfL). Five years later the West Side and Yonkers Patent Railway in New York City opened the first cable car in the United States, but mechanical, financial, and legal problems led to the shutdown of this system by 1870 (Christiano, 1995).

1.4.1.4 Second Industrial Revolution (1870-1919)

Although gondolas did not become a common mode of transportation until many decades later, the detachable gondola grip was invented in 1872 in Austria (Creative Urban Projects, 2013). Despite the failure of the first cable car system in the U.S., this mode proliferated across the country and in many other parts of the world during the second industrial revolution. The first line in San Francisco’s famous cable car system, the Clay Street Hill Railroad, began operating in 1873 and is shown in Figure 1.2 below (Friends of the Cable Car Museum, 2004).

Figure 1.2 – Clay Street Hill Railroad

This period brought expansions of many different types of rail transit modes. Inclined plane rail (or funiculars) were being built across North America and the world during the second industrial revolution, including the first in the U.S., which opened in Pittsburgh in 1870. Then, the first steam-powered elevated rail line opened in New York in 1871 (APTA, 2007). Monorails made a good deal of progress in 1876, when General LeRoy Stone’s steam-driven monorail was demonstrated at the U.S. Centennial Exposition. Further, this was the year that Sonoma Prismoidal opened 3.5 miles of monorail track between Norfolk and Sonoma, California (Monorails in History). Siemens debuted the first electric railway (with power supplied through the rails) at the Berlin Trade Fair of 1879 (Siemens AG, 2002).

Progress continued through the 1880s and 1890s. The first electric streetcar debuted in Berlin in 1881 (Vuchic, 2007). The world's first trolleybus, called the Elektromote, began operating in 1882 and is shown in Figure 1.3 below (Siemens AG, 2002).

Figure 1.3 – Siemens Elektromote (world's first trolleybus)

In 1886 the Enos Electric Railway became the first suspended monorail test track in the world. Monorail went beyond the test phase two years later, with the opening of the Listowel and Ballybunion Railway in Ireland (Monorails in History). Steam-powered streetcars began operating in Munich, Germany in 1883 (Wellige, 2003). Electric streetcars gained popularity in urban areas in the United States and around the world during the second industrial revolution, with the first electric streetcar line in the U.S. opening in Cleveland in 1884 (APTA, 2007).

In the 1890s, several more notable developments in public transportation took place. The City and South London Railway opened in 1890 as the first electric-traction rapid transit railway in the world. The first practical subway line in the U.S. was opened in 1897 in Boston (Encyclopedia Britannica, 2015). Wilhelm Bruhn invented the taximeter in 1891 (Mcardle, 2012). Electric taxicabs were operating on the streets of New York City by the late 1890s, and the first gasoline-powered taxicabs, as shown in Figure 1.4, also appeared in Stuttgart and Paris around this time (English, 2012). Furthermore, the first interurban (streetcar) lines opened in Ohio and Oregon in 1893 (Vuchic, 2007).

Figure 1.4 – Early Model Gasoline-Powered Taxicab (English, 2012)

In 1895 the world's first petroleum-powered omnibuses, from Benz & Co. in Mannheim, Germany, began operating (Mercedes-Benz). The world's first documented goods and passenger cableway, called an "aerial railway" at the time, was built and began operating at Gibraltar in the 1890s, as shown in Figure 1.5 below (Lesser Columbus, 1893).

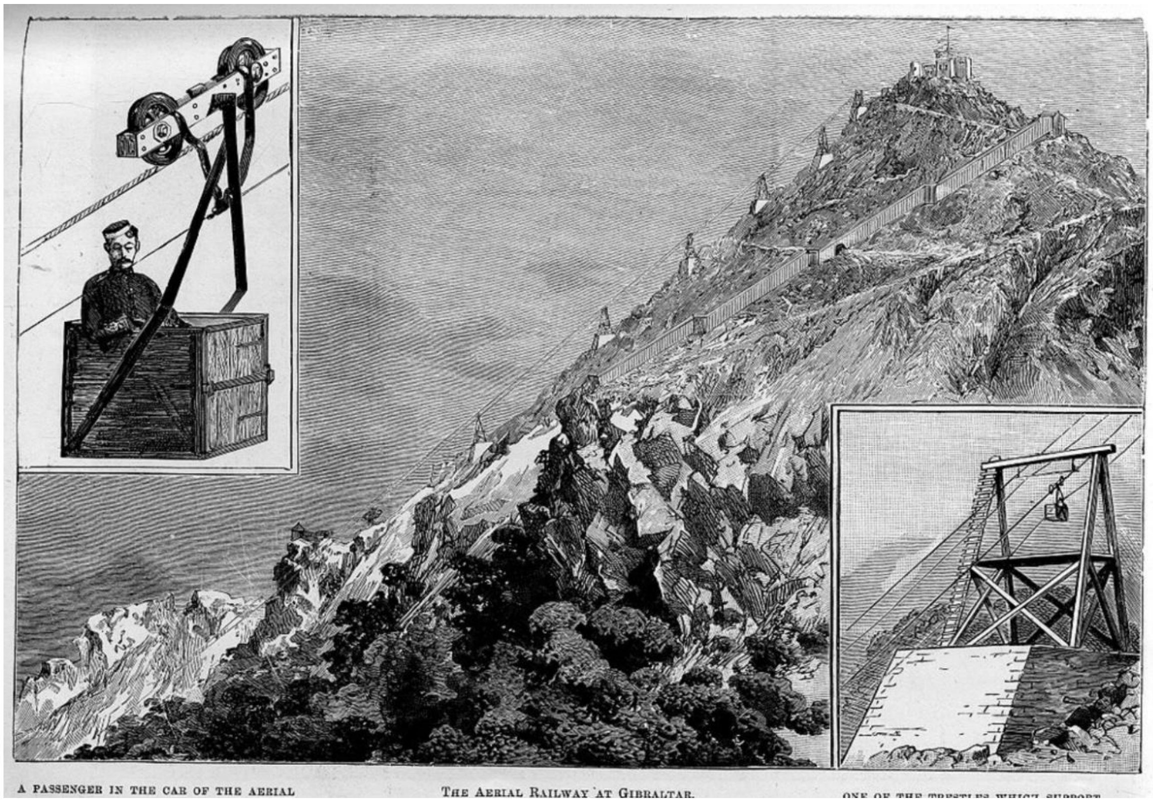


Figure 1.5 – World's First Passenger Cableway (Lesser Columbus, 1893)

In the 1900s, as motorized omnibuses were replacing horse-drawn omnibuses in Paris and many other cities across the globe, the first passenger-carrying trolleybuses were put into operation, advancing this mode beyond the "Elektromote" experiment in Berlin (Dunbar, 1967). The first successful monorail opened in Wuppertal, Germany in 1901 (Vuchic, 2007). In New York City, the subway system opened as the first electric underground heavy rail system in the U.S. in 1904. The following year the first bus line in in the U.S. opened, also in New York City (APTA, 2007). A U.S. Patent was issued to German inventor Alfred Zehden in 1905 for his "electric traction apparatus", a linear motor-propelled train, which was a critical step toward the later demonstration of the first maglev train (Zehden, 1905).

A few years after the release for Ford's Model T in 1908 (A&E Television Networks, LLC, 2016), Jitneys first appeared in cities across the United States (Cozza, 2012). In 1910 the Laurel Canyon trolleybus in Hollywood, California was the first trolleybus service to open in the U.S. (APTA, 2007). The following year, the William H. Boyes Monorail was demonstrated in Seattle, making it the first monorail demonstration in the U.S. (Monorails in History). In 1913, Emile Bachelet demonstrated a prototype magnetic levitating railway car in New York City (Skerrett, 1913).

The early 20th Century was considered to be the "Golden Age of Tramways", with nearly every major city in the world operating a tramway until their eventual decline, which began in the 1920s (Taplin, 1998). In 1917, the last horse-drawn streetcar service closed down in New York, as automobiles began to take over the urban environment (APTA, 2007).

1.4.1.5 Interwar Period (1920-1939)

As the second industrial revolution came to a close and World War I came to an end, the Interwar Period began, which marked a dramatic shift from rail to bus modes for public transit. The first bus not based on a truck chassis, the Fageol Safety Coach, was released in 1920, and by 1923 cities in the U.S. were replacing all of their streetcar lines with bus lines (APTA, 2007).

The first successful trolleybus line in the U.S. began operating in 1921 in New York City (APTA, 2007). Trolleybus lines also opened in Toronto, Philadelphia, Salt Lake City, Chicago, Seattle, and elsewhere in the 1920s and 1930s (Grava, 2003). Another sign of the times that pointed to an increase in bus usage was the opening of the first street with a designated bus lane in the U.S., which took place in 1939 in Chicago (APTA, 2007).

One of the first detachable grip passenger gondolas in the world opened in Freiburg, Germany in 1930, with the first aerial tramways in North America being built later in the decade (Creative Urban Projects, 2013). The first urban aerial tramway, the Grenoble-Bastille Cable Car, opened in 1934 in Grenoble, France (Jay, 2014).

Meanwhile, streetcars and light rail systems were in decline. The biggest developments in rail transit technology during this period were the issuance of three German patents (GR643316, GR44302, and GR707032) for magnetic levitation (maglev) trains, awarded to Hermann Kemper from 1937 to 1941 (Maglev train, 2014).

1.4.1.6 World War II and the Civil Rights Era (1940-1969)

As World War II began, San Francisco became the last U.S. city to operate cable cars, while bus ridership exceeded street railway ridership for the first time in history. Public transit ridership hit a high point in 1946 when it reached 23.4 billion trips in one year (APTA, 2007). In 1957 when Dunedin, New Zealand shut down their cable car system, San Francisco was left with the last remaining on-street cable car system in the world (Rice, 2008).

Automobiles, taxis, and full-size buses gained widespread popularity and use throughout this era, replacing light rail and streetcar systems in many cases. However, the first modern articulated streetcar was introduced in Germany in 1955. The first rubber-tired metro was introduced in Paris in 1956 (Vuchic, 2007). Monorail made some advances during this time, including demonstration of the ALWEG Monorail test track in Fuhlingen, Germany, shown in Figure 1.6. Another technology, the Skyway Monorail, also had a test track debuted in Houston, Texas in 1956. The ALWEG system, which is the most successful monorail technology to date, was the basis for the 1957 Disney Monorail and the 1962 Seattle Monorail. Monorails were built in New York City, Turin, Italy, and in Nihon and Tokyo, Japan in the 1960s as well (Monorails in History).

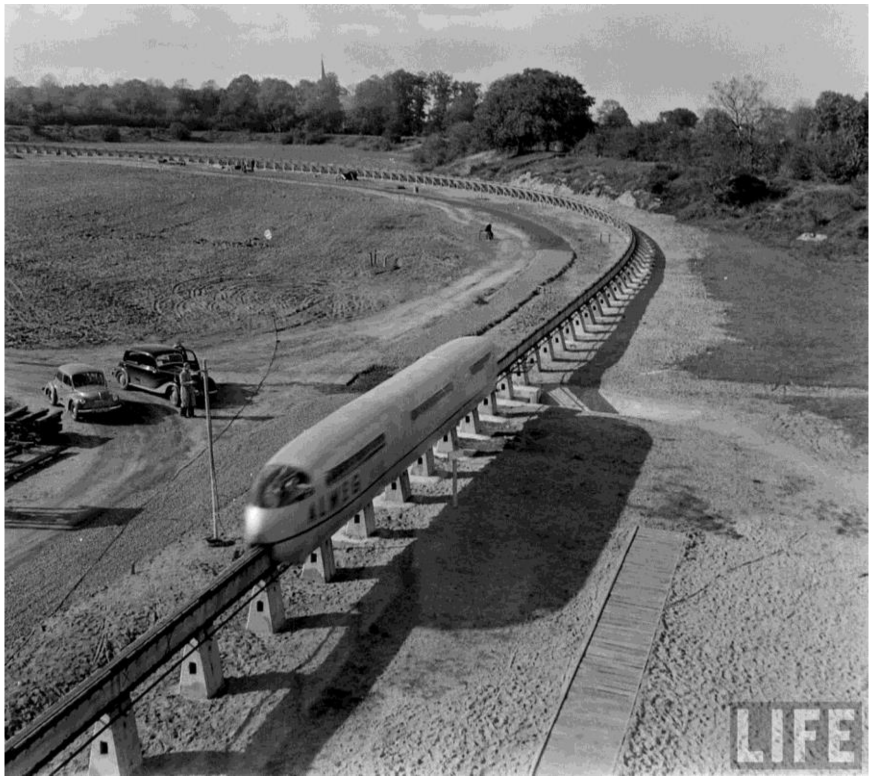


Figure 1.6 – ALWEG Monorail Test Track (Photo by Ralph Crane, LIFE Magazine, October 1952)

The first gondola erected in the U.S. was built in 1957 at Wildcat Mountain Ski Area (Wildcat Mountain, 2016). The 1950s were a peak period for the implementation of trolleybus systems worldwide, though this technology began to decline in use in the 1960s (Grava, 2003). Modern articulated buses and trolleybuses emerged in West Germany in the late 1950s (Vuchic, 2007).

Chicago became the last city to operate an interurban (streetcar) line in the U.S. in 1963 (APTA, 2007). On the other hand, many innovations in public transit emerged in the 1960s. The “light rail revolution” was just taking off in Europe (Taplin, 1998). In the United States, this was the period when research and funding for automated guideway transit systems began, with the first automated heavy rail line, the New York Grand Central Shuttle, opening in 1962. The first automated people mover was demonstrated in Pittsburgh in 1965 (Vuchic, 2007). The first modern heavy rail system in the U.S. replaced a former rail line in Philadelphia in 1969. This was also the year that the first transitway in the U.S., the Shirley Highway in Washington, D.C., opened (APTA, 2007).

1.4.1.7 First Digital Revolution (1970-1999)

The first digital revolution was the dawn of the Information Age. Public transit use in the United States hit its lowest point (6.6 billion trips) in 1972 (APTA, 2007), but two major energy crises sparked renewed interest in the energy efficiency of our national and local transportation systems, boosting public transit usage in urban areas. Many innovations in transportation emerged around the globe during this period.

While trolleybus service ended in many U.S. cities, the 1970s was mostly a decade of new beginnings. Although traditional streetcar rail was still in decline, with only Boston, Cleveland, Newark, New Orleans, Philadelphia, Pittsburgh, and San Francisco operating streetcar lines in the U.S. in 1974 (APTA, 2007), this was the beginning of a streetcar revival through modern railcars and technologies (Spivak, 2008). The “light rail revolution” that started in Europe in the 1960s was spreading across the Americas, Australia, and Asia, with the light rail concept introduced in North American literature in 1972 (Thompson, 2003). This was also the year that the first computer-controlled heavy rail transit system in the United States, the Bay Area Rapid Transit District (BART) in San Francisco, began operating. Commuter rail was beginning to make a resurgence in the U.S. around this time as well (APTA, 2007).

Innovations in rubber-tire transit service, technology, and operations were also prevalent in the 1970s. The first “dial-a-ride” demand response transit agency began operating in 1970 in Fort Walton Beach, Florida. In 1974 federal legislation required the some public transit service be made available for disabled people throughout the United States. Most likely in response to this mandate, in 1977 San Diego led the way in implementing wheelchair-lift-equipped fixed-route bus service in the U.S. (APTA, 2007).

Bus Rapid Transit (BRT) also began to take off as a mode, with the first BRT system launching in 1974 in Curitiba, Brazil (Weinstock, Hook, Replogle, & Cru, 2011). Not to be left too far behind, the first BRT system in the U.S. was unveiled in 1977 in Pittsburgh (Lotshaw, 2011). The first low-floor buses were tested in Hamburg, Germany in 1979 and put into wide use in the following decades. Low-floor (65%) light rail transit vehicles appeared in Geneva in 1985, followed by 100% low-floor rail cars in Bremen in 1990 (Vuchic, 2007).

New urban transit modes emerged, including the first fully automated guided transit network at the Dallas-Fort Worth Airport in 1974 (Vuchic, 2007). The following year, the first automated guideway transit agency in the U.S. opened the Morgantown People Mover to serve the campus of West Virginia University (APTA, 2007). The Roosevelt Island Tramway began operating in 1976, making it the first urban aerial tramway in the U.S. This system originally opened as a temporary solution for connecting Roosevelt Island with Manhattan in New York City (Ferretti, 1976). As construction of the planned subway line fell further behind and popularity of the aerial tramway grew, the system was converted to be a permanent part of the urban transportation system (Richman, 2012).

The digital revolution made many advances in automated guideway, monorail, and maglev rail possible, such that these modes began to proliferate and, in some cases, converge. The first maglev train licensed for passenger transportation opened in Hamburg, Germany in 1979. Several high-speed systems were built in Germany and Japan throughout the 1970s and 1980s, breaking speed records repeatedly through research, development, and testing of both manned and unmanned vehicles. The world's first commercial automated maglev system was a low-speed shuttle between Birmingham International Airport and the Birmingham International railway station in the United Kingdom, which opened in 1984 and operated until 1995 (Maglev train, 2014).

The Vancouver SkyTrain, an automated guideway (AGT) heavy rail system that uses linear induction motors for propulsion, opened as an “Expo Line” in 1986 (Mason, 1989). Successful deployment of AGT systems in Vancouver and Morgantown, along with developments in automation and digital technologies, helped to spark a “renaissance” of automated guideway transit that gained momentum in the 1990s. Monorails were also seeing renewed interest during this period (Monorails in History).

While 1987 marked the end of the Boston “El” elevated railway (The Elevated), other elevated or aerial modes were just beginning to take off around this time. Doppelmayr built the world’s first 8-passenger gondola in 1986 at the Steamboat Ski Resort (Fetcher, 2010). A few years later, Jan Kunczynski patented the quad monocable funitel in 1989 (Kunczynski, 1989). The world’s first funitel was installed at Val Thorens ski resort in France in 1990 (Val Thorens). A photo of the Val Thorens funitel is shown in Figure 1.7.

Figure 1.7 – World’s First Funitel, at Val Thorens (Photo by Two Owls, 2015)

Light rail began to appear in the United States again during the 1980s and 1990s, with the San Diego Trolley as the first completely new light rail system in decades opening in 1980, and additional lines opening over subsequent years, including Los Angeles (1990), Baltimore (1992), Saint Louis (1993), Denver (1994), and Dallas (1996). Miami opened the first new commuter rail line in several decades in 1989 (APTA, 2007).

By the end of the 1980s, computer aided dispatching had been introduced, which would become very useful for taxi companies and public transit agencies. Trolleybuses also advanced, with batteries and supercapacitors allowing for “off-line” operation to improve the flexibility of trolleybus systems (APTA, 2007). Maglev deployment also spread during this time, with a system opening in South Korea in 1993 (Maglev train, 2014).

1.4.1.8 Second Digital Revolution (2000-present)

The vast improvements in technology seen around the early 2000s, especially related to wireless digital communications, led to even more rapid advances in public transportation, but mostly in the area of Intelligent Transportation Systems (ITS). Amenities such as real-time arrival information are now offered directly through smartphone applications, in addition to displays at transit stations, for example. These advances led to deployment of a second wave of more advanced BRT systems, such as the TransMilenio in Bogota, Colombia, which debuted in the year 2000 (TransMilenio S. A., 2016). Modern BRT systems use real-time vehicle tracking systems, automated data collection, transit signal priority, and central control, among other strategies to ensure reliable service.

Advanced modern rail systems have continued to be deployed, including new streetcar systems in Portland, Tampa, Atlanta, and many other cities around the world. Modern light rail systems have also gained in popularity in recent decades, with the opening of light rail systems in Minneapolis, Charlotte, Seattle, and elsewhere in the U.S. and around the globe. Maglev trains like the one shown in Figure 1.8, have continued to be deployed, mostly in Asia and Europe, including the Japanese maglev system that set a world record in 2015 by traveling 375 miles per hour during a test run (McCurry, 2015).

Figure 1.8 – Transrapid Maglev Rail in Shanghai, China

Aerial gondolas appeared in the urban environment with the completion of the first MetroCable line in Medellin, Colombia in 2004. Since then, dozens of urban gondola lines have been constructed in South America, Europe, Asia, and Africa. However, the only new aerial system built in an urban environment in the U.S. so far has been the Portland Aerial Tram (which is an aerial tramway, not a gondola). With new urban gondola cabins being made available since 2010, this mode is rapidly gaining popularity for deployment in urban settings (Creative Urban Projects, 2013). Monorails have also been gaining popularity in recent years, with systems built or under construction in

China, India, Saudi Arabia, South Korea, and Brazil (Trevisani, 2011). The first new heavy rail system (as opposed to extensions of existing systems) in the U.S. in many years is also under construction in Honolulu, Hawaii.

Several new transit concepts have been proposed recently, as well. Ride-sourcing services, such as Uber and Lyft, emerged in the late 2000s, offer alternatives to traditional taxis. Amphibious buses have also emerged, in the Netherlands to provide transit service across water bodies without the need to transfer vehicles or build bridges, as shown in Figure 1.9 (DAT). With unmanned aerial drones and automated vehicles already in use, and mass-transit concepts like Hyperloop in development, the future of transportation is uncertain. What is clear is that many U.S. cities are growing and densifying, and well-planned and operated transit systems of a variety of modes can help to make our urban areas more accessible.

Figure 1.9 – Amphibious Bus (Photo by The ALK3R Post)

1.4.2 Literature Review Summary

While a great deal of information is available on one or more of a variety of urban transit modes, surprisingly few resources provide a comprehensive comparison of all modes that might reasonably be considered for deployment in a modern city. While the mode-specific research is discussed in Chapters 4 and 5, this literature review summary is focused on the most relevant comprehensive research identified in the review.

Vuchic produced some of the most comprehensive information on urban transit systems in the new millennium. His 2002 paper, entitled *Urban Public Transportation Systems*, described a classification system for modern transit systems, as well as key characteristics of the following transit modes: bus, trolleybus, rail, streetcar, light rail, metro, automated guideway, regional rail, commuter rail, and special technologies. He described three classes of transportation:

- Private transportation
- Paratransit or for-hire transportation
- Urban transit, mass transit, or public transportation

Vuchic also described transportation as being either for individuals or for groups of unrelated individuals. He describes transit right-of-way as falling into one of three categories: A, B, and C. Category A transit has right-of-way that is fully separated and physically protected, such that vehicles traveling in this type of right-of-way do not compete with other modes for space. Category B transit ways are partially separated from traffic, but may encounter other modes when attempting to pass through at-grade intersections. Category C transit shares public streets with general traffic (Vuchic, 2002).

Transit technology was described by Vuchic as relating to features such as support, guidance, propulsion, and control. Transit services were grouped into types based on the routes and trips served (short-haul, city, or regional), stopping schedule (local, accelerated, or express), and time of operation and purpose (all-day, regular, peak-hour commuter, or special). Modes were similarly grouped into street transit, semirapid transit, and rapid transit modes. Street transit was said to include buses, trolleybuses, and tramways or streetcars, which generally operate within Category C right-of-ways. Semirapid transit included modes operating mostly in Category B right-of-way, such as light rail transit and bus semirapid transit. Rapid transit was described as having Category A right-of-way and including rail rapid transit (metros), rubber-tired rapid transit, light rail rapid transit, automated guided transit, and monorails (Vuchic, 2002).

Bus transit is described as the most widely used transit technology, present in almost every major city with transit service. Buses offer the advantages of being easily-implemented and flexible. However, their flexibility can be viewed as a drawback, due to the lack of physical presence and permanence of bus routes. Bus service is labor-efficient when compared to paratransit modes, but labor-intensive when compared to rail transit. A driver is needed to operate each bus in service. Buses come in a variety of sizes and shapes, including 15-40 passenger minibuses, 50-100 passenger regular buses, and articulated or double-decker buses that accommodate up to approximately 150 passengers. Buses may be operated in a variety of right-of-way categories, from public streets to exclusive busways (Vuchic, 2002).

Express (or commuter) bus is described as having: large stop spacing and higher travel speeds; route portions on reserved bus lanes, high-occupancy vehicle lanes, or freeways; higher comfort; and higher fares than regular bus service. Express buses may operate only during peak commuting periods, or throughout the day. Bus semirapid transit (often called bus rapid transit) is also described as an upgraded (faster, more reliable, and higher capacity) bus service using Category B right-of-ways (Vuchic, 2002).

Trolleybuses are said to be similar to regular buses, only powered by electricity via overhead power lines. They offer a stronger image than buses without overhead infrastructure, as well as higher acceleration, improved climbing ability, quiet travel, and no exhaust. Disadvantages include higher investment costs and limited ability to reroute service (Vuchic, 2002).

Rail transit systems are distinguished based upon four characteristics: guided vehicle technology, rail technology, electric traction, and separate rights-of-way (Category A or B). Advantages of rail transit include simple and reliable guidance (rails), comfort and durability, rapid acceleration and deceleration, safety, low noise, no exhaust, and fixed tracks that offer a sense of presence and permanence even when vehicles are not present. Disadvantages are the requirement of separate right-of-way and extensive infrastructure, high investment costs, and lack of flexibility. Rail modes are seen as offering higher-quality service than bus modes, and said to be more appropriate for high passenger volume situations. Rail or bus modes could be appropriate for serving medium-level passenger demand, but buses are generally preferable for low-demand situations. One or more large rail vehicles may be used in a train, and articulated and double-decker rail vehicles are available. Rail modes may be operated in any right-of-way category, as long as there are two steel rails to run on (Vuchic, 2002).

Streetcars or trolleys ("trams" using English / French designation) are typically operated in Category B or Category C right-of-ways, making them prone to delays due to traffic congestion. Dedicated lanes, protected stop areas, and signal priority can be used to avoid traffic congestion to some extent, which helps to improve service reliability. Light rail transit is most often operated in Category B right-of-way, and sometimes Category A, making it less impacted by traffic than streetcar in many cases. Up to four articulated cars may be used to accommodate 150-800 passengers per train (Vuchic, 2002).

Rapid transit or metro systems are electric rail systems with multi-car trains, operated in Category A right-of-way with high efficiency and travel speeds. Offered capacity of rapid transit systems range from 20,000 spaces per hour to as high as 80,000 spaces per hour for a single line. This mode is well-suited to dense urban environments, which could not be effectively served by buses or jitneys due to chronic traffic congestion (Vuchic, 2002).

Automated guided transit (AGT) is electricity-powered, guided rubber-tire or rail transit with vehicle capacities of about 50-100 spaces, which can be operated individually or as up to 6-car trains. Right-of-way Category A is required for these systems, as well as automation, which can drive up the costs of construction of AGT systems. This mode has a mid-level capacity of about 3,000-10,000 passengers per hour. A key benefit of AGT is the lack of drivers, which can help keep operating costs low, especially when passenger volumes are low (Vuchic, 2002).

Regional rail and commuter rail are used in many large and medium metropolitan areas, primarily to serve long-distance and within-region commuters. These systems use larger rail vehicles than metros or light rail, with around 120-150 seats, and are mostly powered by electricity or diesel fuel. While commuter rail generally provides service between the city center and suburbs, regional rail may provide service between two or more suburban areas. Using 8-10 car trains, regional rail is said to offer between 15,000-40,000 spaces per hour on a single line (Vuchic, 2002).

Special technology transit systems include ferryboats, cog railways, and funiculars (or inclined plane transit) (Vuchic, 2002). Several other "special" transit technologies were not included in this list.

Vuchic also provided guidance on transit planning and mode selection. He indicated that the first step should be to "define the desired form and character of the city and its metropolitan area". He claims that "to achieve the desired balance between transit and auto travel, transit must be ensured conditions for fast and reliable operation". The next step he outlined was to project future demand for transit travel. If the projected demand is greater than the existing transit system capacity, then this signals the need to improve and expand the system. Larger cities may consider a variety of transit modes and strategies for meeting the needs of various communities within their metropolitan region, while smaller towns and cities typically only use buses to meet their transit needs. Vuchic outlined two decisions related to implementing high-performance transit modes: the alignment of the service and the selection of the mode to be used. Street transit may then be organized around the high-performance system (Vuchic, 2002).

The choice of a high-performance transit mode was said to be between light rail transit and metro (or heavy rail transit) in most cases. While light rail offers lower costs, shorter construction periods, and greater flexibility in right-of-way, metro was said to be the only option for serving very high passenger volumes. Other options might include busways or automated guided transit, with busways generally being more affordable to build but more costly to operate and AGT being more expensive to build but more affordable to operate. The alignment of each of these modes may vary, as would their operating characteristics, depending on the context and design of the system (Vuchic, 2002).

Vuchic followed up his 2002 paper with two textbooks on urban transit. These resources contained even more detailed information on a wide variety of transit modes, from systems and technology to operations, planning, and economics. In addition to public transit modes, Vuchic discussed for-hire modes such as car sharing, taxis, dial-a-ride, and jitneys, as well as rental cars and charter buses. Individual semi-private modes, such as carpools and vanpools, and entirely private modes, such as walking, bicycles, motorcycles, and automobiles, were also mentioned. Street transit modes were identified as shuttle bus, bus, express bus, trolleybus, and streetcar rail (or tramways). Semirapid transit was said to include bus rapid transit, light rail, and AGT shuttles. Rapid transit included automated guided transit, light rail rapid transit, rubber-tired rapid transit, monorails, rail rapid transit (or metro), and regional rail. Specialized transit gained a few new modes, as it included cable car, cog railway, funicular, aerial tramway, ferryboat, and hydrofoil (Vuchic, 2007).

Four categories of transit system characteristics were identified in *Urban Transit Systems and Technology*, including system performance, level of service, impacts, and costs. Key system performance measures were said to include operating speed, reliability, safety, line capacity, productive capacity, productivity, and utilization. Level of service was described as including performance elements that affect users, service quality, and price. Impacts included changes in street congestion, changes in emissions, noise, aesthetics, changing land values, economic activity, physical form, and the social environment. Costs were generally said to be either capital costs or operating costs. Data on these characteristics were provided for several modes of transit, as well as private automobiles as a point of comparison (Vuchic, 2007).

Regarding public transport mode selection, Luke and MacDonald conducted a review of international practice in 2006. These researchers focused on a variety of bus-based and light rapid transit technologies, shown in Figure 1.10, including some lesser-known technologies such as guided light transit (GLT), which combines rail guidance with rubber-tire support systems. Through several case studies of transit planning processes, they identified characteristics and processes that are often used for transit mode selection (Luke & MacDonald, 2006).

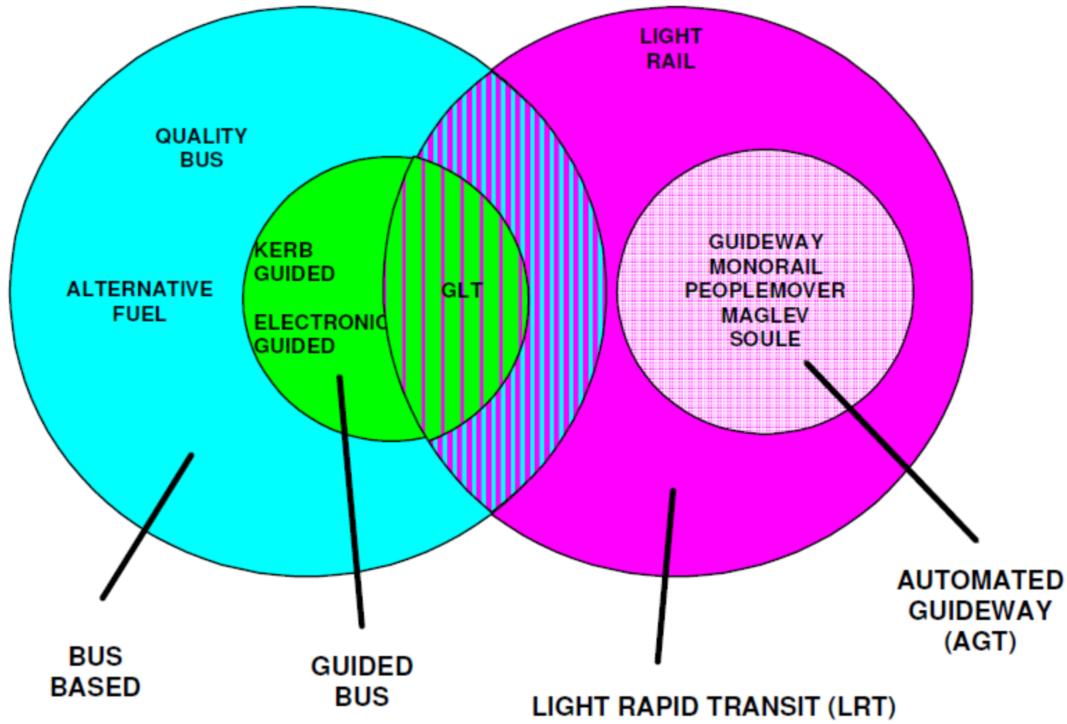


Figure 1.10 – Mode Options Example (Luke & MacDonald, 2006)

An example from Transport for London used capacity, capital cost, operating cost, average speed, reliability, road space allocation, and land use integration to compare bus, maximum bus priority, busway, tram, light rail, and heavy rail. [DEFINE GLT] Another case study from Ottawa, where bus rapid transit was selected over light rail, used capital and operating costs, level of service, staging flexibility, and environmental impact as criteria. Overall the researchers found socio-economic criteria to be the main factors driving public transport mode choice. Pointing to context-sensitive solutions, they said that mode selection is “governed by local circumstances requiring comprehensive examination of alternatives on an objective basis” (Luke & MacDonald, 2006).

A group of Canadian researchers investigated mode selection and succession strategies in their 2009 article entitled, *Mode Succession in a Public Transit Corridor*. They stated in that work that mode selection has “a significant impact on the level of service, capital and operating costs, energy use, environmental impacts and transit market development”. They go on to explain that certain modes are easier to transition to and from than others. For example, they explain that it is preferable to change directly from on-street bus rapid transit to light rail than it is from busways to light rail, since light rail construction would disrupt service on the busways. The two primary criteria to consider regarding mode transitions were said to be system capacity and travel time. The team compared regular bus, express bus, bus rapid transit, busways, light rail, and metro in terms of speed, line capacity, and supply versus demand (Hubbel, et al., 2009).

More recently, a Chinese research team published an article on urban transit mode selection, which proposed a framework for comparing “normal” transit, rapid transit, light rail transit, and mass rapid transit (heavy rail). They used the following characteristics for the mode comparison: 1) operation distance, 2) operation speed, 3) per capita area, 4) passenger capacity, 5) investment cost, 6) accessibility, 7) conformability, 8) safety, 9) sustainability evaluation, 10) circular economy’s evaluation, 11) site selection and layout influence of new area, 12) land use influence of new area, 13) function and development of new area, and 14) scale influence of new area (Hu & Guo, 2013).

The references included in this literature summary are used repeatedly throughout this thesis report, along with mode-specific references and those that are focused on particular aspects of the transit mode selection process.

1.4.3 Mode Definitions

The following transit mode definitions were adapted from the U.S. National Transit Database (NTD) and *Urban Transit Systems and Technology* by Vuchic. Modes marked with an asterisk (*) are not defined in the NTD Glossary.

Aerial Tramway (TR) – An electric system of aerial cables with suspended powerless passenger vehicles. The vehicles are propelled by separate cables attached to the vehicle suspension system and powered by engines or motors at a central location not onboard the vehicle. This mode is also called “Aerial Tram” or “Cable Car”.

Bus (MB) – Rubber-tired passenger vehicles operating on fixed routes and schedules over roadways. This mode is also called “Shuttlebus” or “Motorbus”.

Bus Rapid Transit (BRT or RB) – Fixed-route bus mode in which the majority of each line operates in a separated right-of-way dedicated for public transportation use at least during peak periods, including features that emulate the services provided by rail (fixed-guideway) public transportation systems. This mode is also called “Bus Semirapid Transit”, “Rapid Bus”, or “Enhanced Bus”.

Cable Car (CC) – An electric railway with individually controlled transit vehicles attached to a moving cable located below the street surface and powered by engines or motors at a central location, not onboard the vehicle. The term “Cable Car” is sometimes used to refer to other modes of cable-propelled transit, such as aerial tramways

Commuter Bus (CB) – Fixed-route bus systems that are primarily connecting outlying areas with a central city through bus service that operates with at least five miles of continuous closed-door service. This service may operate motorcoaches and feature peak scheduling, multiple-trip tickets, and limited stops in the central city. This mode is also called “Express Bus” or “Regional Rail”.

Commuter Rail (CR) – An electric or diesel propelled railway for urban passenger train service consisting of local short distance travel operating between a central city and adjacent suburbs. Service must be operated on a regular basis by or under contract with a transit operator for the purpose of transporting passengers within urbanized areas, or between urbanized areas and outlying areas. This mode is also called “Suburban Rail”.

Demand Response (DR) – Passenger cars, vans or small buses operating in response to calls from passengers or their agents to the transit operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations. This mode is also called “Demand Responsive Transport”, “Dial-a-Ride Transit”, or “Flexible Transport Services”.

Ferryboat (FB) – Vessels (generally steam or diesel powered) that carry passengers and / or vehicles over a body of water, typically between two points. This mode is also called “Ferry”.

Funitel* (FT) – Aerial transit mode using cars that detach from the two steel cables that propel them, so that they may be slowed or stopped in stations for boarding and alighting purposes.

Gondola* (GD) – Aerial transit mode using cars that detach from the single steel cable that propels them, so that they may be slowed or stopped for boarding and alighting purposes. Unlike aerial tramways, gondolas are continuously moving and available for on-demand service. This mode is also called “Gondola Lift”.

Heavy Rail (HR) – An electric railway with the capacity for a heavy volume of passengers. It is characterized by high-speed and rapid-acceleration passenger rail cars operating singly or in multi-car trains on fixed rails, separate rights-of-way from which all other vehicular and foot traffic are excluded, sophisticated signaling, and high platform loading. This mode is also called “Metro”, “Rapid Transit”, “Rail Rapid Transit”, “Subway”, or “Underground”.

Hybrid Rail (YR) – Rail system primarily operating routes on the National system of railroads, but not operating with the characteristics of commuter rail. This service typically operates light rail-type vehicles as diesel multiple-unit trains. These trains do not meet Federal Railroad Administration standards, and so must operate with temporal separation from freight rail traffic. This mode is also called “Light Rail Rapid Transit”.

Inclined Plane (IP) – A railway operating over exclusive right-of-way on steep grades (slopes) with powerless vehicles propelled by moving cables attached to the vehicles and powered by engines or motors at a central location not onboard the vehicle. The special tramway types of vehicles have passenger seats that remain horizontal while the undercarriage (truck) is angled parallel to the slope. This mode is also called “Funicular” or “Cliff Railway”.

Jitney (JT) – Passenger cars or vans operating on fixed routes (sometimes with minor deviations) as demand warrants without fixed schedules or fixed stops. This mode is also called a “Share Taxi” or “Jitney Cab”.

Light Rail (LR) – Typically an electric railway with a light-volume traffic capacity compared to heavy rail. It is characterized by: passenger rail cars operating singly (or in short, usually two-car, trains) on fixed rails in shared or exclusive right-of-way; low or high platform loading; and vehicle power drawn from an overhead electric line via a trolley or a pantograph. This mode is also called “Light Rail Transit”.

Maglev Rail* (MV) – A rail transit mode that uses magnetic levitation to eliminate contact between train cars and rails when the system is in operation.

Monorail / Automated Guideway (AGT or MG) – Transit modes on exclusive guideway without using steel wheels on rails. This mode is also called “Automated Guideway Transit” or “Automated Guided Transit”.

Publico (PB) – Passenger vans or small buses operating with fixed routes but no fixed schedules. Publicos are privately owned and operated public transit services which are market-oriented and unsubsidized, but regulated through a public service commission, state, or local government. This mode is also called “Share Taxi”.

Streetcar Rail (SR) – Rail transit systems operating entire routes predominantly on streets in mixed traffic. This service typically operates with single-car trains powered by overhead catenaries and with frequent stops. This mode is also called “Tram”, “Tramcar”, “Trolley”, “Trolleycar”, “Electric Street Railway”; “Interurban”, or “Light Rail”.

Taxi (DT) – A special form of the demand response mode operated through taxicab providers. This mode is also called “Cab”, “Taxicab”, or “Demand Response Taxi”.

Trolleybus (TB) – Electric rubber-tired passenger vehicles, manually steered and operating singly on city streets. Vehicles are propelled by a motor drawing current through overhead wires via trolleys, from a central power source not onboard the vehicle. This mode is also called “Trackless Trolley”, “Trolley”, or “Trolley Coach”.

Vanpool (VP) – Vans, small buses and other vehicles operating as a ridesharing arrangement, providing transportation to a group of individuals traveling directly between their homes and a regular destination within the same geographical area.

Water Bus* (WB) – A waterborne transit mode that operates like a bus, on a schedule with more than two stops in a given service area. This mode is also called “Ferry”, “Sightseeing Boat”, or “Water Taxi”.

Water Taxi* (WT) – A waterborne transit mode that operates like a taxi, on-demand and typically with one origin and one destination per trip. This mode is also called a “Water Bus” or “Sightseeing Boat”.

1.5 Methodology

1.5.1 Approach

The approach taken by the researcher under the guidance of her advisors was as follows. In addition to conducting a preliminary literature review and data collection process, a survey of transit agencies and metropolitan planning organizations (MPOs) was conducted to gain insights into the processes and priorities guiding mode selection decision making. Building on the results of the survey, more literature and data were compiled and analyzed. Factors highlighted in the data collection and analysis portion of this investigation include performance characteristics, as well as environmental, social, and economic aspects of each mode of urban mass transit. The circumstances under which each mode is most suitable are also explored and discussed. Lastly, tools and guidelines are provided to help decision makers through their complex and often context-sensitive transit mode selection processes. Then, the lessons learned and recommendations from the research process, as well as several opportunities for future research, are summarized in the conclusion of this report. While this thesis may serve as a high-level guide to the currently viable modes of urban public transit, many opportunities exist to add new modes and extend this line of research even further.

1.5.2 Measuring Success

A successful result of this research process will be an objective comparative analysis of all currently viable transit modes for moving people within predominantly urban environments. Further, a transparent and streamlined process for context-sensitive evaluation of urban transit modes is proposed. Supporting tools and guidelines will be usable by a wide range of people, from transportation professionals to community organizers and policy makers, to help inform transportation infrastructure development decisions based on economic, social, and environmental factors, thereby promoting long-term system sustainability.

1.6 Organization

The thesis is presented in three parts. Part I focuses on a Transit Mode Selection Survey that was administered directly to transit agency and metropolitan planning organization leaders to gain insights about their processes and priorities for choosing transit technologies to use for system expansion and enhancement. This first part of the report includes Chapter 2 (Survey Development and Distribution) and Chapter 3 (Survey

Results and Analysis). Part II, Urban Transit Mode Data Collection, includes Chapter 4 (Data Collection and Analysis) and Chapter 5 (Urban Transit Case Studies), which focus on the collection and analysis of data on urban transit modes from national data sources and international case studies, respectively. Part III includes Chapter 6 (Transit Mode Selection Process), which provides tools and guidance to aid transit agencies and planning organizations in their transit mode selection processes. Chapter 7 (Conclusion) includes a summary of recommendations from the thesis overall, as well as future research opportunities.

Part 1 – Transit Mode Selection Survey

CHAPTER 2

SURVEY DEVELOPMENT AND DISTRIBUTION

To develop useful tools for transit agencies and planning organizations to use in their mode selection processes, it was important to first gain a thorough understanding of the nature of these processes and the priorities of the entities involved. A survey was developed specifically for this purpose, as explained in the following sections.

2.1 Survey Purpose

There is no single transit mode selection process that is universally used, and it is unlikely that there ever will be. This survey was designed to inform development of tools to help transit planning organizations select the best transit mode or modes for their projects and service areas. Goals of this survey included learning more about transit mode decision making processes from transit planning organizations, such as evaluation criteria used and staff familiarity with available transit modes.

2.2 Survey Development

The *Transit Mode Selection Survey* was developed by the researcher, under the guidance of her advisors and Dr. Pat Mokhtarian, in the summer of 2015. The survey was designed with target audiences in mind, including staff from transit agencies and planning organizations across the United States. The survey was organized into several sections: an introduction, which included questions on mode familiarity; questions regarding the current agency operations with mode definitions; a question on classifying undefined modes (gondola, funitel, maglev, water bus, and/or water taxi) for reporting to the National Transit Database (NTD); questions on transit expansion and enhancement; a few questions on transit mode succession; and several questions on their transit mode selection processes and priorities. Respondents were required to provide the name of their agency, and could optionally provide contact information for possible follow-up.

Modes included in the survey were divided into aerial, rail, rubber-tire, and water modes, with the full list adapted from the modes defined in the NTD Glossary. Aerial modes included aerial tramway, funitel, and gondola. Rail modes included cable car, commuter rail, heavy rail, hybrid rail, inclined plane, light rail, maglev, monorail / automated guideway, and streetcar rail. Rubber-tire modes included bus, bus rapid transit, commuter bus, demand response, jitney, publico, taxi, trolleybus, and vanpool. Lastly, water modes included ferryboat, water bus, and water taxi. “Other” was also provided as an alternative for any respondents who were operating or had considered modes other than those listed.

In accordance with the informed consent policies of the Institutional Review Board of Georgia Institute of Technology, a consent document was written and provided to all study participants to inform them of the survey purpose, participant exclusion and inclusion criteria, study procedures, risks, potential benefits, costs (none other than time), lack of compensation, confidentiality procedures, participant rights, and contact information for the researchers, as well as the Georgia Tech Office of Research Integrity Assurance.

The online survey platform *SurveyGizmo* was used to conduct the research study. This allowed for the efficient use of time, since participants were automatically moved ahead in the survey based on their responses, skipping over questions that were not relevant to them. This tool also facilitated data cleaning and analysis by allowing the researcher to filter, sort, and interpret responses based on a variety of criteria. The full survey can be viewed in Appendix C.

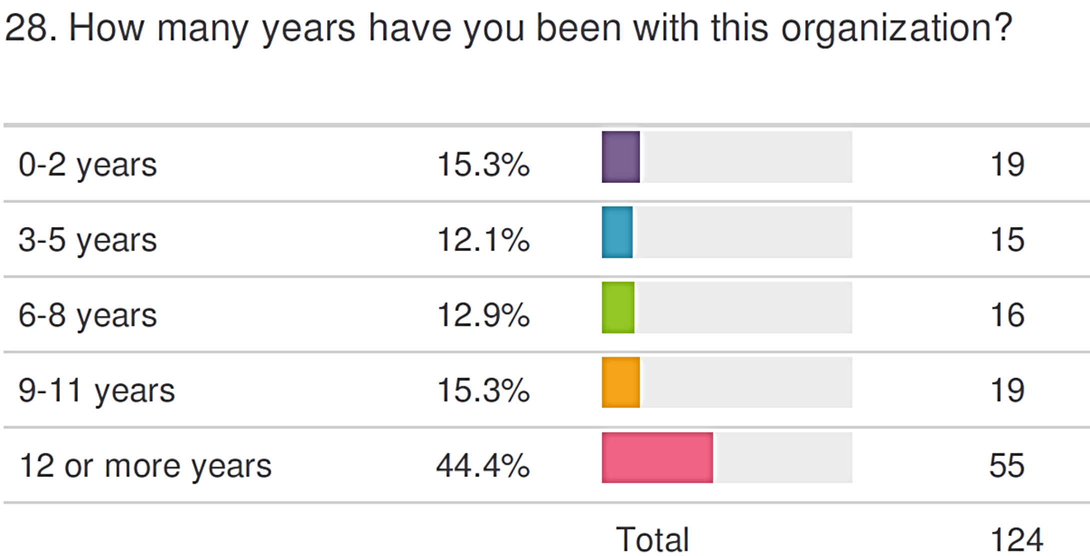
2.3 Outreach and Distribution

Top level leaders and planning officials in transit agencies and metropolitan planning organizations were specifically targeted for participation in the *Transit Mode Selection Survey*. Contact information was compiled from the National Transit Database website, the Transportation Planning Capacity Building Program website, and transit agency and MPO websites, among other sources. In all, 113 transit agencies, including the top 50 by unlinked passenger trips, and 140 metropolitan planning organizations in the U.S. and Puerto Rico were contacted via email with a formal request for their participation in the survey. Participants could follow a link in the email to provide a confidential response on behalf of their agency. Since targeted participants were primarily high-ranking officials within their organization, they were asked to either complete the survey themselves or to delegate this task to another knowledgeable member of their staff.

2.4 Response

A total of 51 (45.1%) of the 113 transit agencies and 69 (49.3%) of the 140 metropolitan planning organizations contacted provided a complete response to the survey. Seven respondents did not provide the name of their organization, but otherwise completed the survey, for a grand total of 127 complete responses. The average completion time for the survey was 8 minutes and 58 seconds.

Since many of the survey questions focused on processes and decisions made within the past decade, it was encouraged that participants would have worked with their organization for ten years or more. Near the end of the survey, Question 28 asked about the amount of time the respondent had been working with their current organization. As shown in Figure 2.1, out of 124 responses to this question, 55 (44.4%) had been with their organization for 12 or more years. The remaining respondents were fairly evenly divided between 0-2 years (15.3%), 3-5 years (12.1%), 6-8 years (12.9%), and 9-11 years (15.3%).


28. How many years have you been with this organization?

0-2 years	15.3%	19
3-5 years	12.1%	15
6-8 years	12.9%	16
9-11 years	15.3%	19
12 or more years	44.4%	55
	Total	124

Figure 2.1 – Respondent Years with Organization

Forty metropolitan planning organization (MPO) respondents provided their job title, with the most common being Executive Director with 15.0% (6 respondents), followed by Senior Planner, Senior Transportation Planner, and Transportation Planning Manager each with 7.5% (3 respondents each), and then Deputy Director and Principal Planner with 5.0% (2 respondents) each. The full list of MPO responses to this question are shown in Table 2.1.

Table 2.1 – Metropolitan Planning Organization Respondent Job Titles

MPO Job Title	**Count**	**Percent**
Executive Director	6	15.0%
Senior Planner	3	7.5%
Senior Transportation Planner	3	7.5%
Transportation Planning Manager	3	7.5%
Deputy Director	2	5.0%
Principal Planner	2	5.0%
Administrator of Public Involvement and Title VI	1	2.5%
Assistant Transportation Planning Director	1	2.5%
Director	1	2.5%
Director for Transportation Planning	1	2.5%
Director of Public Transportation	1	2.5%
Director of Strategic Long Range Planning	1	2.5%
Director of Transportation and Environment	1	2.5%
Federal Coordination Office Director	1	2.5%
Manager, Office of Transit, Bicycle, and Pedestrian Planning	1	2.5%
Manager, Transit/Rail	1	2.5%
Planning and Development Manager	1	2.5%
Principal Transportation Planner	1	2.5%
Program Director	1	2.5%
Senior Transit Planner	1	2.5%
Technical Service Planner	1	2.5%
Transit Planner	1	2.5%
Transit Program Manager	1	2.5%
Transit Services Manager	1	2.5%
Transportation Modeler	1	2.5%
Transportation Planner	1	2.5%
Transportation Project Manager	1	2.5%

Forty-four transit agency respondents provided their job title, with the most common being Chief Executive Officer with 13.6% (6 respondents), followed by General Manager with 11.4% (5 respondents), President with 6.8% (3 respondents), and then Planning and Development Manager and Planning Manager with 4.5% (2 respondents) each. The full list of transit agency responses to this question is shown in Table 2.2.

Table 2.2 – Transit Agency Respondent Job Titles

Transit Agency Job Title	**Count**	**Percent**
Chief Executive Officer	6	13.6%
General Manager	5	11.4%
President	3	6.8%
Planning and Development Manager	2	4.5%
Planning Manager	2	4.5%
Assistant to the General Manager	1	2.3%
Capital Grants Administrator	1	2.3%
Chief Operations Planning Officer	1	2.3%
Chief Planning Officer	1	2.3%
Chief, Division of Transit Services	1	2.3%
Department Head, Long Range Planning	1	2.3%
Deputy GM, Planning and Customer Services	1	2.3%
Director	1	2.3%
Director of Marketing & Planning	1	2.3%
Director of Operations, Planning & Programming	1	2.3%
Director of Planning & Policy	1	2.3%
Director of Public Transit	1	2.3%
Director of Service Development	1	2.3%
Executive Director	1	2.3%
External Resources Officer	1	2.3%
Federal Programs Coordinator	1	2.3%
Founder / Chairman of the Board	1	2.3%
Manager of Service Planning	1	2.3%
Section Manager, Transit & Non-Motorized Planning	1	2.3%
Senior Director Transit System Planning	1	2.3%
Senior Director, Engineering & Technology	1	2.3%
Senior Vice President	1	2.3%
Service and Capital Development Director	1	2.3%
Shoreside Operations Manager	1	2.3%
Transit Administrator	1	2.3%
Transit Planning	1	2.3%
Transportation Planner	1	2.3%
Transportation Planning Manager	1	2.3%
Transportation Specialist	1	2.3%
Vice President, Capital Planning	1	2.3%
Vice President, Strategic Planning & Development	1	2.3%

The responses to the rest of the survey are detailed in Chapter 3, *Survey Results and Analysis*.

CHAPTER 3

SURVEY RESULTS AND ANALYSIS

This chapter includes a discussion and analysis of the responses to the *Transit Mode Selection Survey* described in Chapter 2. The survey results discussed in this section are grouped according to their subject matter, and presented in the order that they appeared in the actual survey. Topic areas covered include mode familiarity, existing modes, considered modes, mode selection process leaders, transit enhancement and expansion, mode selection process, selected modes, mode succession, and factors considered regarding mode selection.

3.1 Mode Familiarity

To avoid overwhelming respondents, the 24 modes included in this survey were grouped into four classifications: aerial modes, rail modes, rubber-tire modes, and water modes. A total of 127 responses were provided to each of these questions. Overall, aerial modes were the least familiar to respondents, with an average familiarity rating of 2.0, compared to 2.9 for water modes, 3.2 for rail modes, and 3.8 for rubber-tire modes. Of the aerial modes, funitels were the least familiar to respondents, which is not surprising given that these are the newest and least-common of the three modes. With a familiarity rating of 1.3 on average, funitel was the least familiar of all modes, as shown in Table 3.1. Aerial tramways and gondolas were somewhat more familiar, with average ratings of 2.5 and 2.3, respectively. Only publico and inclined plane were less familiar than gondola, while hybrid rail and water bus came in just below aerial tramways.

Table 3.1 – Familiarity with Aerial Transit Modes

1. Please indicate your level of familiarity with each aerial transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar).

	1	2	3	4	5	Average	Responses
Aerial Tramway	44 34.6%	25 19.7%	23 18.1%	21 16.5%	14 11.0%	2.5	127
Funitel	102 80.3%	14 11.0%	7 5.5%	4 3.1%	0 0.0%	1.3	127
Gondola	49 38.6%	27 21.3%	21 16.5%	18 14.2%	12 9.4%	2.3	127
Average %	51.2%	17.3%	13.4%	11.3%	6.8%	2.0	381

Familiarity with rail transit modes, shown in Table 3.2, was second highest among the classes. The least familiar rail modes were inclined plane with an average familiarity score of 2.0, with hybrid rail (2.4) and maglev rail (2.7) reported as slightly more familiar. Moderately familiar rail modes included cable car (3.0) and monorail / automated guideway (3.1). The most familiar modes were commuter rail and light rail, with an average familiarity score of 4.0, followed by heavy rail and streetcar rail, with an average score of 3.7.

Table 3.2 – Familiarity with Rail Transit Modes

2. Please indicate your level of familiarity with each rail transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar).

	1	2	3	4	5	Average	Responses
Cable Car	**28** 22.0%	**20** 15.7%	**32** 25.2%	**22** 17.3%	**25** 19.7%	3.0	127
Commuter Rail	**7** 5.5%	**10** 7.9%	**19** 15.0%	**28** 22.0%	**63** 49.6%	4.0	127
Heavy Rail	**11** 8.7%	**15** 11.8%	**21** 16.5%	**30** 23.6%	**50** 39.4%	3.7	127
Hybrid Rail	**44** 34.6%	**22** 17.3%	**37** 29.1%	**15** 11.8%	**9** 7.1%	2.4	127
Inclined Plane	**61** 48.0%	**23** 18.1%	**28** 22.0%	**8** 6.3%	**7** 5.5%	2.0	127
Light Rail	**8** 6.3%	**8** 6.3%	**19** 15.0%	**30** 23.6%	**62** 48.8%	4.0	127
Maglev	**38** 29.9%	**21** 16.5%	**30** 23.6%	**22** 17.3%	**16** 12.6%	2.7	127
Monorail / Automated Guideway	**21** 16.5%	**18** 14.2%	**36** 28.3%	**26** 20.5%	**26** 20.5%	3.1	127
Streetcar Rail	**15** 11.8%	**8** 6.3%	**24** 18.9%	**30** 23.6%	**50** 39.4%	3.7	127
Average %	20.4%	12.7%	21.5%	18.5%	26.9%	3.2	1,143

Rubber-tire modes were the most familiar overall, as shown in Table 3.3. The lowest average familiarity scores in this group went to publico (1.7) and jitney (2.8). The other rubber-tire modes all received an average score of 3.8 or higher. The mid-range average scores among these modes went to trolleybus (3.8), taxi (4.0), and vanpool (4.2). The most familiar of these modes was bus (4.9), followed by bus rapid transit, commuter bus, and demand response, each with an average familiarity score of 4.4.

Table 3.3 – Familiarity with Rubber-Tire Transit Modes

3. Please indicate your level of familiarity with each rubber-tire transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar).

	1	2	3	4	5	Average	Responses
Bus	**0** 0.0%	**1** 0.8%	**3** 2.4%	**10** 7.9%	**113** 89.0%	4.9	127
Bus Rapid Transit	**3** 2.4%	**3** 2.4%	**12** 9.4%	**27** 21.3%	**82** 64.6%	4.4	127
Commuter Bus	**3** 2.4%	**2** 1.6%	**13** 10.2%	**27** 21.3%	**82** 64.6%	4.4	127
Demand Response	**4** 3.1%	**3** 2.4%	**12** 9.4%	**23** 18.1%	**85** 66.9%	4.4	127
Jitney	**29** 22.8%	**24** 18.9%	**35** 27.6%	**16** 12.6%	**23** 18.1%	2.8	127
Publico	**74** 58.3%	**25** 19.7%	**19** 15.0%	**5** 3.9%	**4** 3.1%	1.7	127
Taxi	**7** 5.5%	**8** 6.3%	**22** 17.3%	**28** 22.0%	**62** 48.8%	4.0	127
Trolleybus	**11** 8.7%	**10** 7.9%	**31** 24.4%	**21** 16.5%	**54** 42.5%	3.8	127
Vanpool	**5** 3.9%	**6** 4.7%	**19** 15.0%	**31** 24.4%	**66** 52.0%	4.2	127
Average %	11.9%	7.2%	14.5%	16.4%	50.0%	3.8	1,143

Respondents were less familiar on average with water (or aquatic) modes than surface modes, but better than aerial modes, as shown in Table 3.4. Water bus was the least familiar of these modes, with an average familiarity score of 2.4. Water taxi had the same average familiarity as the water group overall, with a score of 2.9. Ferryboat was the most familiar mode, with an average score of 3.3, including 40 respondents who said they were very familiar with this mode.

Table 3.4 – Familiarity with Water Transit Modes

4. Please indicate your level of familiarity with each water transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar).

	1	2	3	4	5	**Average**	**Responses**
Ferryboat	**27** 21.3%	**16** 12.6%	**21** 16.5%	**23** 18.1%	**40** 31.5%	3.3	127
Water Bus	**46** 36.2%	**28** 22.0%	**24** 18.9%	**13** 10.2%	**16** 12.6%	2.4	127
Water Taxi	**32** 25.2%	**24** 18.9%	**26** 20.5%	**16** 12.6%	**29** 22.8%	2.9	127
Average %	27.6%	17.8%	18.6%	13.6%	22.3%	2.9	381

The average familiarity score for each mode was also calculated separately for each segment of respondents (transit agencies and MPOs), as shown in Figure 3.1.

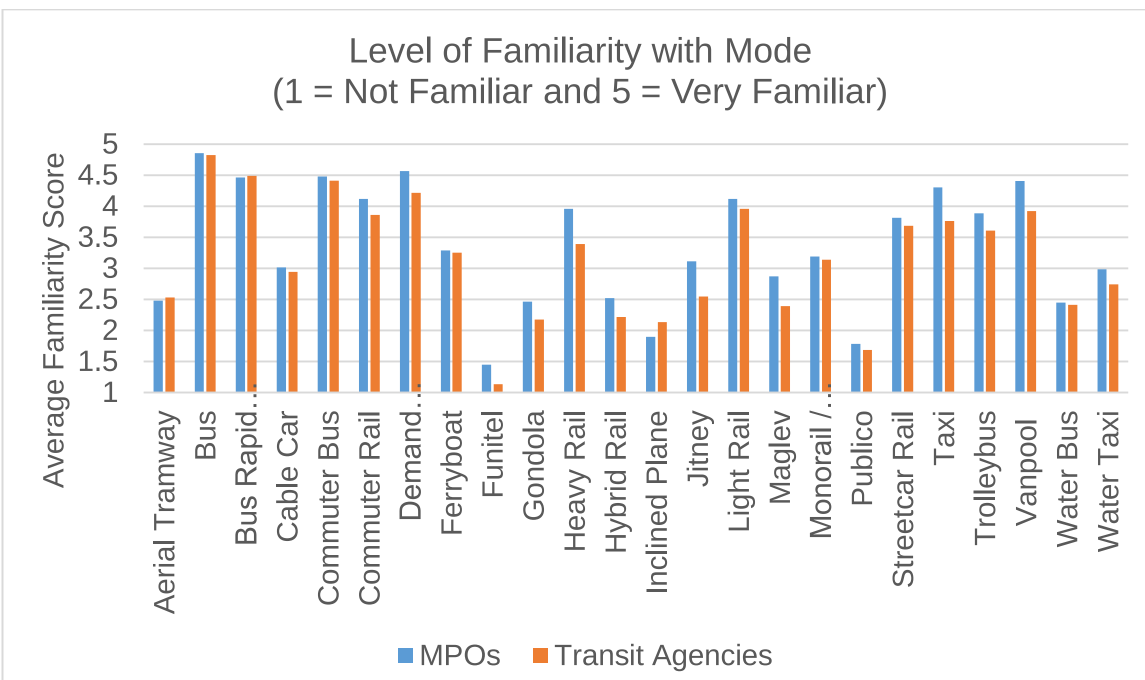


Figure 3.1 – Mode Familiarity for MPO and Transit Agency Segments

3.2 Existing Modes

Respondents were asked about which modes they are currently operating. A total of 117 responses were received, indicating that bus (77.8%) was the most common mode in operation among respondents, followed by demand response (65.8%). The third and fourth highest ranked existing modes were commuter bus (44.4%) and vanpool (42.7%). Bus rapid transit and commuter rail tied for fifth place, both with 27.4% of respondents. Taxi (21.4%) was the next most common existing mode, followed by light rail (19.7%), ferryboat (17.1%), and streetcar rail (17.1%). Fifteen trolleybus systems (12.8%), thirteen heavy rail systems (11.1%), and seven monorail / automated guideway systems (6.0%) were also reported. Three (2.6%) water bus systems and three water taxi services were reported, along with two (1.7%) aerial tramways, hybrid rail systems, and inclined plane railways. One (0.9%) example of cable car, publico, and jitney were reported (0.9%). No respondents reported using funitel, gondola, or maglev. Other responses included paratransit and “flex” routes, carpooling, volunteer assisted transportation, and intercity rail (Amtrak). The responses are shown in Figure 3.2.

The percentage of survey respondents indicating that their organization offers each transit mode was compared to the percent of agencies reporting on these modes to the NTD (out of the 529 agencies reporting to the NTD in 2014). The comparison revealed that bus and demand response modes were more represented in the NTD (88.7% and 85.1%, respectively) than among survey responses, while all other modes were more prevalent in the survey results than in the NTD. There are a few likely reasons for this. Outreach for the survey was targeted toward larger urban transit organizations offering multiple modes, especially rare modes, since comprehensive mode comparison is not common among single-mode operators. The inclusion of MPOs may also increase some of the values seen in Figure 3.2, such as vanpool at 42.7% of respondents versus 13.6% in the NTD.

5. What transit modes are currently offered by your organization? Check all that apply. (See below for a definition of each mode.)

Aerial Tramway	1.7%	2
Bus	77.8%	91
Bus Rapid Transit	27.4%	32
Cable Car	0.9%	1
Commuter Bus	44.4%	52
Commuter Rail	27.4%	32
Demand Response	65.8%	77
Ferryboat	17.1%	20
Funitel	0.0%	0
Gondola	0.0%	0
Heavy Rail	11.1%	13
Hybrid Rail	1.7%	2
Inclined Plane	1.7%	2
Jitney	0.9%	1
Light Rail	19.7%	23
Maglev	0.0%	0
Monorail / Automated Guideway	6.0%	7
Publico	0.9%	1
Streetcar Rail	17.1%	20
Taxi	21.4%	25
Trolleybus	12.8%	15
Vanpool	42.7%	50
Water Bus	2.6%	3
Water Taxi	2.6%	3
Other	17.1%	20

Statistics	
Total Responses	117

Figure 3.2 – Existing Transit Modes

Responses on currently offered modes were also divided into two segments (transit agencies and MPOs), as shown in Figure 3.3 as a percent of total responses in each segment. As previously stated, there were 69 completed responses from MPOs and 51 from transit agencies. More MPO respondents than transit agency respondents stated that their organization offered jitney, publico, taxi, trolleybus, vanpool, water bus, and water taxi services, while a greater proportion of transit agency respondents indicated that they currently offer aerial tramway, bus, bus rapid transit, cable car, commuter bus, commuter rail, demand response, ferryboat, heavy rail, hybrid rail, inclined plane, light rail, monorail / automated guideway, and streetcar rail. This is not surprising, since some MPOs do not operate transit systems at all and transit agencies offer at least one mode, by definition.

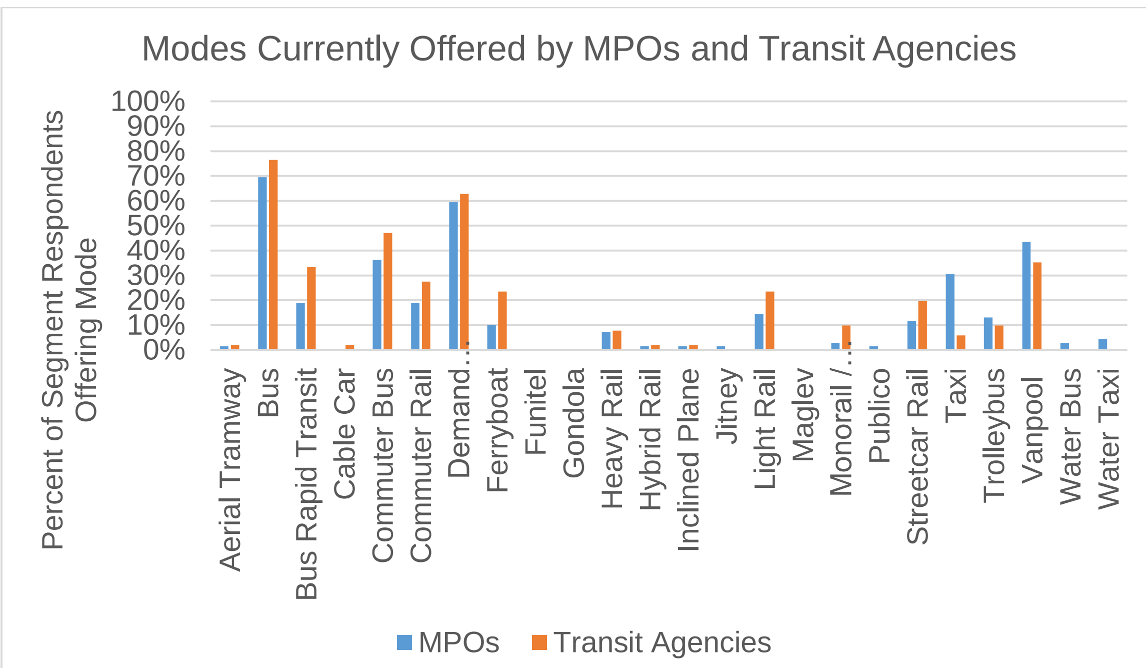


Figure 3.3 – Existing Transit Modes for MPO and Transit Agency Segments

3.3 Considered Modes

Question 7 asked, “In the last 10 years, has your organization considered expanding or enhancing transit services?” The 112 respondents (88.2%) who answered “yes”, were asked which modes they had considered in the last decade. Bus rapid transit (73.2%) was the most considered mode, closely followed by bus (72.3%). Commuter rail (50.0%) was the third most popular mode, followed by commuter bus and light rail (45.5% each), streetcar rail (44.6%), and demand response (42.9%). Vanpool was considered by 35 respondent organizations (31.3%). Heavy rail was considered by 17 organizations (15.2%), trolleybus by 16 (14.3%), ferryboat by 12 (10.7%), monorail / automated guideway by 11 (9.8%), and Taxi and Water Taxi by 10 organizations (8.9%) each. Less popular still were hybrid rail (7.1%), maglev (5.4%), and aerial tramway, gondola, and water bus (each with 3.6%). The least considered modes were jitney with 1.8% of respondents considering it, publico and funitel with one organization (0.9%) each, and cable car and inclined plane, which were not considered at all. Other modes considered were intercity rail (Amtrak), compressed natural gas buses (although fuel type was not specified for buses in the survey), diesel light rail, and ride-sourcing services, such as Uber and Lyft. The results are shown in Figure 3.4.

8. What transit modes has your organization considered for transit expansion and/or enhancement in the last 10 years? Check all that apply.

Aerial Tramway	3.6%	4
Bus	72.3%	81
Bus Rapid Transit	73.2%	82
Cable Car	0.0%	0
Commuter Bus	45.5%	51
Commuter Rail	50.0%	56
Demand Response	42.9%	48
Ferryboat	10.7%	12
Funitel	0.9%	1
Gondola	3.6%	4
Heavy Rail	15.2%	17
Hybrid Rail	7.1%	8
Inclined Plane	0.0%	0
Jitney	1.8%	2
Light Rail	45.5%	51
Maglev	5.4%	6
Monorail / Automated Guideway	9.8%	11
Publico	0.9%	1
Streetcar Rail	44.6%	50
Taxi	8.9%	10
Trolleybus	14.3%	16
Vanpool	31.3%	35
Water Bus	3.6%	4
Water Taxi	8.9%	10
Other	4.5%	5

Statistics

Total Responses	112

Figure 3.4 – Considered Transit Modes

To visualize the relationship between mode familiarity and consideration, the average familiarity score was calculated for each transit mode (including those that were not considered by any respondent), and this was plotted against the number of agencies considering that mode. A very clear positive correlation was noted between familiarity score and the number of agencies considering a mode, with bus at the upper end of both measures and funitel at the lower end. A simple linear fit model was developed in *Excel*, to estimate the number of agencies considering a mode (y) based on respondent familiarity with the mode (x), as shown in Figure 3.5.

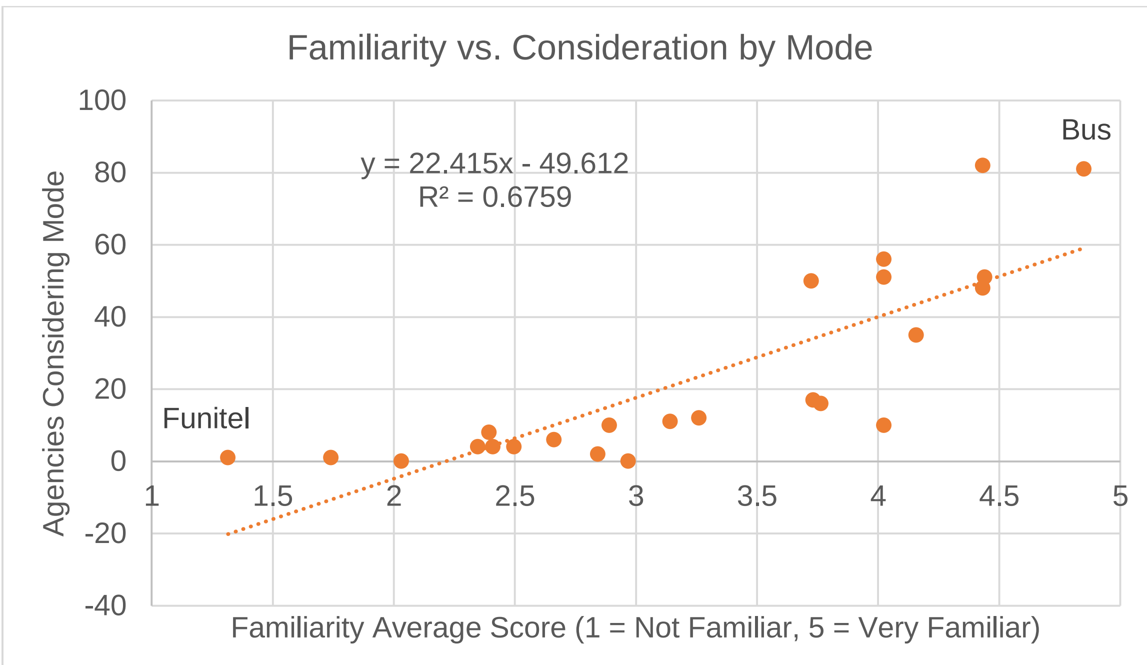


Figure 3.5 – Familiarity vs. Number of Respondents Considering each Transit Mode

Further, a ratio of the number of respondents with organizations that had considered a mode to the number of respondents with organizations that currently operate that mode was calculated, as shown in Figure 3.6.

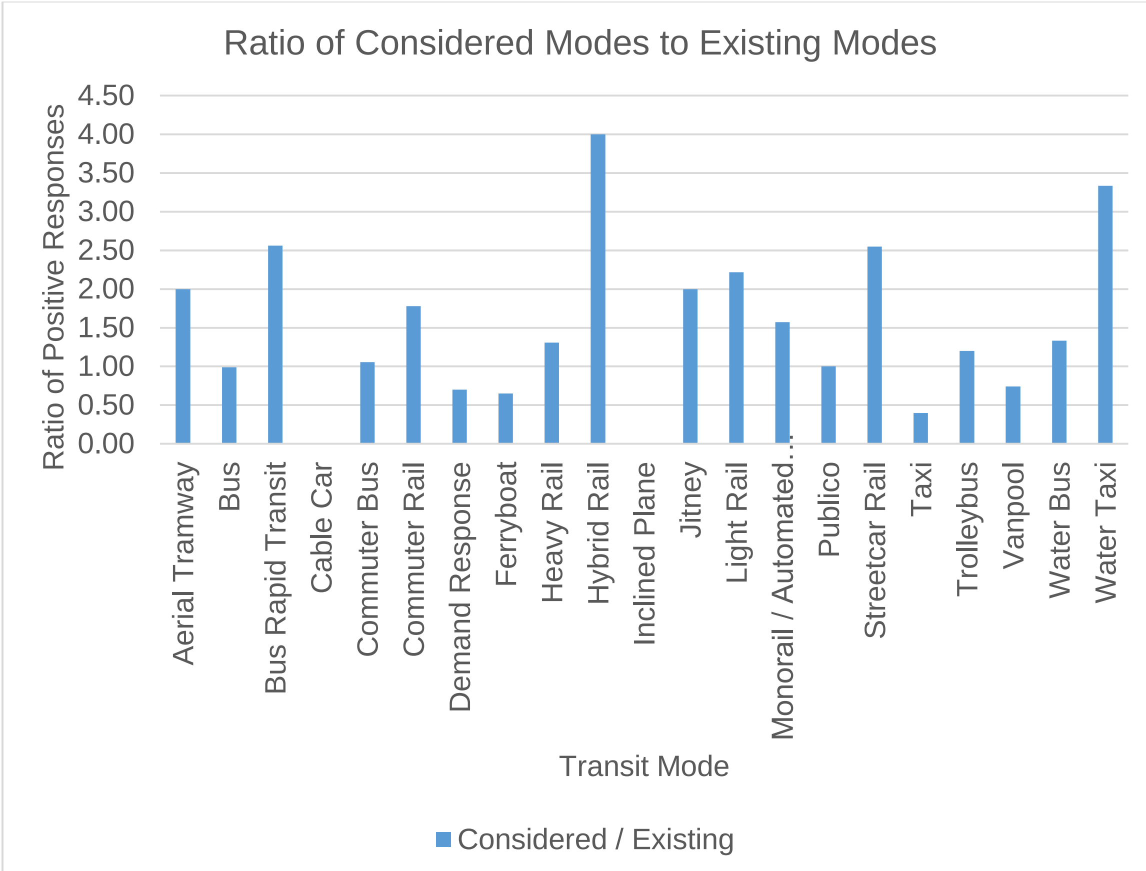


Figure 3.6 – Ratio of Respondents Considering vs. Operating Each Mode

As shown in Figure 3.6, hybrid rail (4.0), water taxi (3.3), bus rapid transit (2.6), streetcar rail (2.6), light rail (2.2), aerial tramway (2.0), and jitney (2.0) services were reportedly considered at least twice as often as they were already offered in this survey. Commuter rail (1.8), monorail / automated guideway (1.6), water bus (1.3), heavy rail (1.3), trolleybus (1.2), and commuter bus (1.1) were considered more than they were reported as already existing, but not more than twice as often. The modes of bus (1.0), vanpool (0.7), demand response (0.7), ferryboat (0.7), and taxi (0.4) were reportedly considered less than they were reported as being already in existence by survey participants. Since no respondents reported that their organization had considered cable car or inclined plane in the last decade, these modes were assigned ratios of 0. Ratios were not calculated for funitel, gondola, or maglev, since these modes were not reported as being currently offered (in existence) by any respondents.

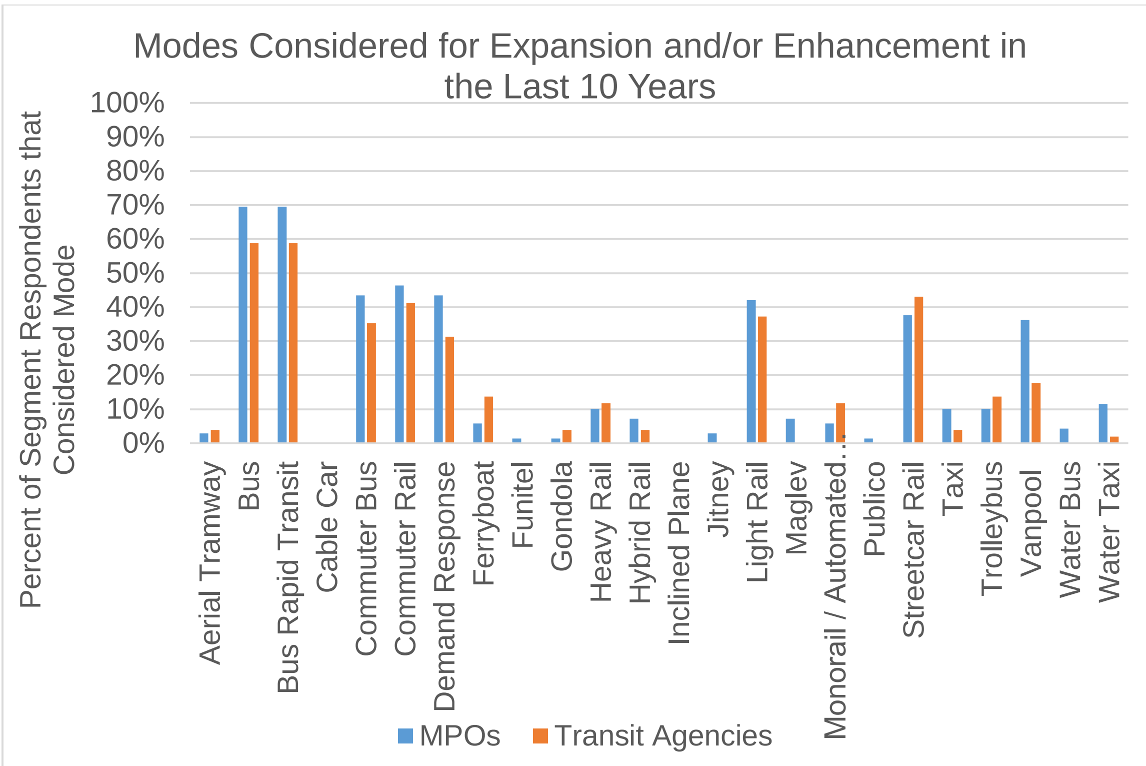


Figure 3.7 – Considered Transit Modes for MPO and Transit Agency Segments

To compare the responses of transit agency representatives with those of MPO representatives, responses were again segmented into transit agency responses and MPO responses, as shown in Figure 3.7 as a percentage of total responses in each segment. A greater proportion of MPOs than transit agencies had considered bus, bus rapid transit, commuter bus, commuter rail, demand response, funitel, hybrid rail, jitneys, light rail, maglev, publico, taxi, vanpool, water bus, and water taxi in the last ten years.

However, more transit agency respondents than MPO respondents said they had considered aerial tramway, ferryboat, gondola, heavy rail, monorail / automated guideway, and trolleybus in the last decade.

3.4 Mode Selection Process Leaders

As a follow-up to the question about which modes their organization had considered in the last 10 years, participants were asked if their transit mode selection studies were all conducted in-house (by their staff alone), or if some or all of their studies were conducted by other organizations, specifically contractors. Only 6 of 112 respondents (5.4%) had performed all of their studies in-house. Eighty respondents (71.4%) reported some of their studies being performed by contractors, while 26 (23.2%) stated that all of their transit mode selection studies had been performed by contractors.

Survey participants were also asked about who decides which modes to include in transit expansion or enhancement studies. The most common answers were transit agencies, MPOs and planners, boards of directors, local governments, in-house staff, and consultants, with input from the public in addition to data analysis results. While some responses indicated that one body or individual, such as City Council or the Executive Director, is deciding which modes to include, many pointed to collaboration between more than one of the aforementioned stakeholders. Collaboration between agency staff and consultants based on input from community leaders and the general public was commonly mentioned. For example, one respondent stated that, "Typically we have a study advisory board consisting of transit planners, transit operators, and government officials that help shape the parameters of the study, including what modes will be considered. The different modes are often selected based on national data that looks at service characteristics. All of our studies have a public involvement component and all recommendations are vetted through public outreach activities." The complete responses to this question are provided in Table D.1 in Appendix D.

3.5 Transit Enhancement and Expansion

Survey participants were asked if their organization had actually expanded or enhanced transit services in the last 10 years (rather than merely considering expansion or enhancement). Overall, 90 (80.4%) of the 112 respondents stated that their organization had expanded transit services in the last decade, with 74 (66.1%) stating that their organization had enhanced transit services during this period. Only seven respondents (6.3%) stated that their organization had neither expanded nor enhanced transit services in the last 10 years. Among transit agency respondents, two-thirds (66.7%) reported that their organization had expanded transit services in the last decade, while 72.6% reported that their organization had enhanced transit services. A larger proportion of MPO representatives (72.5%) than transit agency representatives reported transit expansion activities, while fewer MPO respondents (47.8%) than transit agency respondents reported transit enhancement activities during the last 10 years. A much lower, but almost equal percentage of respondents, 5.8% for MPOs versus 5.9% for transit agencies, reported that their organization had not expanded or enhanced transit services in the last decade.

3.6 Mode Selection Process

Probing into the mode selection process itself, the survey asked participants to describe their organization's process for selecting transit modes to include in an alternatives analysis for transit system expansion or enhancement. The 105 responses to this question varied widely, as shown in Table D.2 in the appendix.

Descriptions of organizational mode selection processes ranged from statements that all modes are considered to various explanations of why only one mode is ever considered. For example, one respondent stated that, "All modes are reviewed through the environmental process for feasibility purposes." Another respondent indicated that, "The modes that enter an alternatives analysis would be all reasonable modes that could hypothetically address the goals and needs of the corridor and project." Yet many respondents stated that their organizations do not consider the full range of options. Some entities "looked only at existing modes of service", for example, while others were constrained by the modes that were included in previous plans. One respondent stated that, "It depends on the corridor, but typically we would examine bus, enhanced bus, and streetcar, or light rail options." This approach could be thought of as including only conventional transit modes. Some organizations are limited to one or a small number of modes based on their organizational mission or funding constraints. One respondent explained that, "It is left to the operator and its consultant to determine alternatives, which are limited due to lack of dedicated local matching funds."

Furthermore, while some processes have modes defined at the outset, others consider a wide array of modes and narrow these down through various processes. One respondent indicated that, "We work with our planning department, MPO, transit service providers, community advisory groups, and the FTA early in the alternatives analysis process to select modes for consideration." Another approach was described as, "We develop the criteria that will be used in the selection process based on the goals for the project. We start with the universe of alternative modes and, through a screening process that might involve several iterations, transit modes to advance through the alternatives analysis process are identified." A simpler approach often adopted by smaller agencies is "We have only one local transit option, so that one is the focus."

While some processes described were simple or even non-existent, others were described as a complex series of multiple studies with increasing levels of detail. At one extreme are the organizations for which "there is no fixed process in place" for mode selection. At the other end of the spectrum were long-drawn out processes where the transit mode may not be selected until several plans have been completed. One respondent simplified their process as developing a "network plan followed by environmental review and engineering of individual projects.” An example of a more complex process description was, “There are usually several visioning type of studies that are done to initially establish transit corridors. Then a project gets included in the MPO's long range plan. We typically perform several studies after a project has been included in the long-range plan. These studies include land-use plans, transit feasibility studies, corridor studies, etc. in order to establish the locally preferred alternative (LPA). Typically, the LPA is adopted by the local municipality, the transit agency, and the MPO.” These processes may in fact be fairly similar, though they are described using different levels of detail. Generally it was stated that most mode selection processes involve multiple stakeholders and steps, but that these will vary from project to project. A selection of the responses to this question are shared in Table 3.5.

Table 3.5 – Selected Responses to Question 12

Question 12: Please describe your organization's process for selecting transit modes to include in an alternatives analysis for transit system expansion / enhancement.
A master plan is developed (we have one now for BRT) and mode selection is generally determined by that process.
Agency planners, engineers, executive offices and other support staff consult with internal experts and outside consultants to discuss transit mode options.
An extensive public outreach and technical analysis explores all reasonable alternatives once a corridor and purpose and need have been established. A steering committee of stakeholders guides the selection of transit modes.
As an older region with a mature and robust transit network, most alternatives analyses in our region involve either extensions of existing rail lines or new services that would directly interface with existing lines. In both cases, some modal elements are predefined by this context, and vary only in their details.
As part of our planning process we consider population and land use with regard to density and common destination. We look for corridors that are commonly traveled and then establish through standard alternatives analysis the type and mode that best fits the need.
Broad-based process to examine modes that are appropriate for the situation. Also, previous planning has already, in some cases, decided the mode to move forward.
Determine demand based on land use densities and destinations, analyze service thresholds for different modes and evaluate feasibility of corridors for expanded / enhanced service.

Table 3.5 (continued)

Larger projects follow a federally approved process of alternatives analysis, (in our case usually headed by one or more county). Corridors selected for these analyses must have been included in the regional policy plan. The preferred alignment and mode is then forwarded to the MPO for adoption and implementation.
No build alternative usually includes enhanced bus, and build alternatives include BRT and some kind of rail, whether light rail or commuter rail.
Public process lead by outside consultants in coordination with MPO. The process looks at cost, demand, and feasibility.
Standard bus is the only option considered for expanding our fixed route system.
Study needs analysis followed by alternatives analysis to decide the proper mode. This includes a detailed ridership, capital cost and operating cost analysis.
Taken from modes previously identified for consideration in regional planning documents by the Metropolitan Planning Organization and transit agency.
Taking in consideration the study area, and the context of the area, modes are selected, based on what works best and what could work in the area.
The Metropolitan Planning Organization (MPO) uses the priorities outlined in its current adopted Long Range Transportation Plan as a guide to making decisions regarding transit projects. The MPO also works closely with local transportation/transit agencies and municipalities, including public participation and input, to determine transit goals and modes to include in transit system expansion/ enhancement studies.
The modes are refined by examining various national data sets which show average capital costs, average operating costs, ridership thresholds, density of areas served, and results of computer modeling.

Table 3.5 (continued)

The modes are typically identified during the alternatives analysis process in response to the purpose, need, and stakeholder input. There are often numerous modal options considered in response to suggestions from the public, property and business owners, real estate developers, local government staff, economic development departments, elected officials, MPO staff, and transit operations and planning staff.
The process includes input from affected stakeholders, local communities, and the public. Financial and engineering viability are also factors.
The transit modes selected for analysis were primarily based on existing modes already in service. Some emerged from studies.
Transit mode studies follow a process outlined by regional boards (bus and rail) and include considerations for residential growth, population estimates, commercial/employee centers, funding availability, and service needs.
Transit modes are generally based off proven and reasonable modes that are existing in the region (i.e. support systems already in place) or identified for expansion in the long-range plan. New technologies are occasionally considered but only if unique challenges exist.
Transit modes that are included in the Transit Development Plan are selected for expansion/enhancement.
We have used a combination of technical input from staff and contractors, review of TCRP and other documents for best practices and peer comparisons, and gathered public input for this purpose.
We selected a few modes to analyze based on several modes' operating characteristics.

Table 3.5 (continued)

We started with a broad range of options, and then gradually narrowed the options through a couple of screening steps.
We typically include most transit modes that may be applicable to the study area, i.e. modes that would be serve high density areas.
We use our knowledge and that of our consultants to eliminate unrealistic modes from consideration.
We use service guidelines to determine how much service an area warrants, research into market potential, and public outreach to determine the appropriate type of service for an area. We attempt to provide all-day bus service to areas with market potential, but recognize that transit-dependent populations in certain, less-dense areas may not be well-served by traditional bus service. In these cases and in conjunction with the community in question, we attempt to develop alternative solutions, which are sometimes novel.
We usually start with the universe of alternatives at the beginning of the analysis, in which the technical staff and stakeholders determine all reasonable alternatives.
We would look at the need and feasibility. This has led us to focus on bus, commuter rail, and streetcar based on the passenger loads and available rights-of-way.
When conducting planning studies or alternatives analysis, identification of transit modes is typically based on study purpose and need, stakeholder and public input, consideration of existing system and any previous plans or studies.
When the regional planning process is done, the lead agency (typically the metropolitan planning organization) will consider/analyze several modes. Since we are a commuter rail-only service, we do not consider other modes when we look to expand or enhance service.

Survey participants were also asked to describe their process for selecting modes to include in their final recommendations. While at least five respondents indicated no significant difference between their process for selecting modes to include in alternatives analyses and their process for selecting final modes for implementation, some additional insights were gained from the responses (105 total) to this question. The full set of responses to Question 13 are shown in Table D.3 in the appendix.

In most cases it appears that mode selection is decided through an alternatives analysis or similar evaluation process involving multiple stakeholders. Transit agencies and metropolitan planning organizations may take different approaches to mode selection, but these entities often work collaboratively to come to a decision. As one respondent stated, “That decision is typically made by the transit authority, with input from the MPO.” Many other stakeholders may be involved in mode selection decisions, whether it be through public input processes or as formal authorities with voting privileges. One respondent stated that, “Based on public input and a range of quantitative and qualitative analyses, the steering committee defined for a corridor recommends final transit modes. Then each involved agency / jurisdiction, including cities, counties, state department of transportation, regional planning entity, and transit agency, formally adopt the preferred mode.” Although most processes are collaborative efforts, in some cases the final mode is selected or approved by a single entity, such as a board of directors or local government officials.

As with deciding which modes to include in a study, final mode selection decisions may be handled differently depending on the nature and context of the project. These processes can be lengthy and involved, or as simple as going with the only mode that an agency is already using. A fairly involved but representative response was that, “Our selection process involves a combination of technical analysis, public engagement, and formal policy decision making… The modal selection (usually in the form of a

Locally Preferred Alternative) is finalized through the combination of a city council decision, a decision by our board, and (assuming the presence of federal funding) the MPO." A common approach among small transit agencies and MPOs was to expand service of their existing mode, which was often bus, but sometimes ferryboat or another less common mode.

Many different factors may be considered, based on the need and purpose of a project, as well as based on the organizations involved in mode selection decisions. Cost-benefit analysis and funding limitations were commonly mentioned as critical factors driving mode decisions, but other factors are also considered in many cases. As one respondent stated, "Generally, the final transit modes selected for transit system expansion / enhancement are those that best address the purpose and need statements developed for individual planning studies. Typical factors that we consider in our region to evaluate transit modes are impacts to existing services, potential impacts to new ridership, potential economic development impacts, environmental impacts, financial feasibility, and social and environmental justice impacts."

Large projects seeking FTA funding are vetted through federal alternatives analysis processes, while small projects may face less rigorous requirements. As one respondent explained, the approach "depends on the scale of the study. In the case of FTA major capital investment grants (New Starts, etc.), we follow the established process. In the case of other concept-development or feasibility studies, we typically develop a range of possibilities and screen down to recommended options based on an analysis that amounts to cost versus benefit as understood during the course of the study." Federal grants are mode-specific in many cases, which may also play a role in the transit mode selection process. More selected responses are shown in Table 3.6.

Table 3.6 – Selected Responses to Question 13

Question 13: Please describe your organization's process for selecting final transit modes to use for transit system expansion / enhancement.
After the corridor studies and an LPA is determined, we decide whether to pursue additional local and/or federal money. If there is momentum and funding, then we perform additional environmental and engineering studies. This solidifies mode and precise alignment.
All modes that are ultimately chosen for implementation must come from an adopted plan that is fiscally constrained and has been reviewed by the public.
As mentioned we initially perform a feasibility study looking for fatal flaws then roll that effort into an alternatives analysis that considers various weighting factors and provides opportunity for public input while weighing impacts and cost. Then when we feel that the effort has been robust enough we work to come to a decision or selection.
Based on services offered by transit operator. Evaluated based on anticipated ridership and cost of service.
Based on the outcome of the study or alternatives analysis, the preferred mode is selected.
Bus is the only option considered.
Final selection is determined by local government officials.
Final selection occurs after a study's analysis has determined the best option in terms of performance and level of financial investment.
From the planning document with general outlines a corridor is selected. A structured public involvement process ensues accompanied by detailed technical analyses that leads into a formal FTA alternatives analysis if federal funding is desired.

Table 3.6 (continued)

Generally a detailed study, including an operating plan and financial analysis are part of the decision making process. Ridership projections and public opinion are also considered.
It's based on an evaluation of alternatives, selecting the option that provides the most cost-effective ridership and development potential.
Modal options generally are constrained to current operating modes for rubber-tired transit. Recent years have focused on development of service planning guidelines for expansion and enhancement; and on development / expansion of alternatives to fixed route bus services more appropriate to and cost effective in low density communities and / or as a complement to the fixed route bus system.
Modes are usually cross-compared based on a variety of services and/or performance characteristics that can be ranked against each other. Assuming the final mode meets with public acceptance, the selection then would typically be based on the mode that would carry the most passengers in the most frequent service time, but could be provided within a budget acceptable to that service area's governmental entity.
MPO provides regional forum for transit expansion deliberations and covers some of the costs but ultimately city councils have to approve transit service changes in their jurisdictions.
Once a project has been identified, it is evaluated based on the most recent long range transportation plan goals, objectives and project selection criteria.
Other modes prove to be too costly.
Our studies have different scenarios to choose from and the final selection is made by elected officials.

Table 3.6 (continued)

Selection criteria are developed at the beginning of the process, and the alternatives are analyzed against each other based on the selection criteria. The project steering committee then examines the results of this analysis to determine the appropriate mode and alignment.
Selection occurs through a comprehensive alternatives analysis.
Team consensus
Technical Advisory Committee (TAC) reviews alternatives and costs against available resources and provides recommendations to the Policy Committee. TAC is made up of primarily professional engineers. The PC is made up of engineers, managers and appointees.
The final screening was based on mode and alignment and performance in a wide variety of characteristics.
The local transit operator works with the MPO and other agencies to study transit system enhancements and expansions, with implementation subject to resource availability.
The process involves detailed study of the transportation and economic impacts of different alignments and modes. This process also includes extensive public involvement.
There is no fixed process in place. Guidance is provided by the Board of Directors for Chatham Area Transit
This is completed through the Master Plan process and community involvement as well as facility planning studies.
This varies in different situations.

Table 3.6 (continued)

Transit mode expansions / enhancements are selected from phased implementation plans included in the Transit Development Plan.
Transit mode selections are made based on funding availability (local, regional, and federal participation), as well as service / public needs and land availability.
We define the goals and objectives for the project and then screen the modes to identify which alternatives are the ones that best respond to the purpose of the project.
We only operate one type of service.
We use an alternatives analysis process that includes several criteria. Most important would be cost effectiveness and community support.
When conducting planning studies or alternatives analysis, alternatives are evaluated and screened in a multi-step process that incorporates purpose and need, performance measures, stakeholder and public input, and comparative evaluation of alternatives.

3.7 Selected Modes

Survey participants were asked which modes their organization had actually selected in the last 10 years. A total of 105 responses were received to this question, as summarized in Figure 3.8.

14. What transit modes has your organization selected for transit expansion and/or enhancement in the last 10 years? Check all that apply. (Be sure to include modes that have been selected, even if they have not yet been built.)

Aerial Tramway	1.0%	1
Bus	71.4%	75
Bus Rapid Transit	52.4%	55
Cable Car	0.0%	0
Commuter Bus	27.6%	29
Commuter Rail	37.1%	39
Demand Response	26.7%	28
Ferryboat	6.7%	7
Funitel	0.0%	0
Gondola	0.0%	0
Heavy Rail	8.6%	9
Hybrid Rail	3.8%	4
Inclined Plane	0.0%	0
Jitney	1.9%	2
Light Rail	27.6%	29
Maglev	0.0%	0
Monorail / Automated Guideway	1.9%	2
Publico	1.0%	1
Streetcar Rail	21.0%	22
Taxi	3.8%	4
Trolleybus	7.6%	8
Vanpool	14.3%	15
Water Bus	1.9%	2
Water Taxi	4.8%	5
Other	5.7%	6

Statistics

Total Responses	105

Figure 3.8 – Selected Transit Modes

As shown in Figure 3.8, the most popular modes selected in the last 10 years among participating organizations was bus (71.4%) followed by bus rapid transit (52.4%) and commuter rail (37.1%). The next most frequently selected modes were commuter bus and light rail, each with 27.6%, then demand response (26.7%) and streetcar rail (21.0%). Fifteen organizations (14.3%) had selected vanpool, while nine (8.6%) selected heavy rail, eight (7.6%) selected trolleybus, and seven (6.7%) selected ferryboat. Less popular but still selected modes included water taxi (4.8%), taxi (3.8%), and hybrid rail (3.8%). Jitney, monorail / automated guideway, and water bus were each selected twice among responding organizations (1.9% of respondents). Aerial tramway and publico were each selected once (1.0% of respondents). Cable car, funitel, gondola, inclined plane, and maglev were not selected by any of the responding organizations. Other modes selected (as reported under the “other” option from the list) were employer commuter services, intercity rail, and on-demand “flex” bus services.

A comparison was made between the average familiarity score for each mode and the number of respondents reporting that their agency had selected that mode in the last 10 years. This comparison, shown in Figure 3.9, indicates a positive relationship between familiarity and the number of agencies selecting each mode, though this relationship is not as strong as it was between the familiarity score and the frequency of consideration for each mode among survey respondents (as indicated by the difference in the estimated slope coefficients of the linear models).

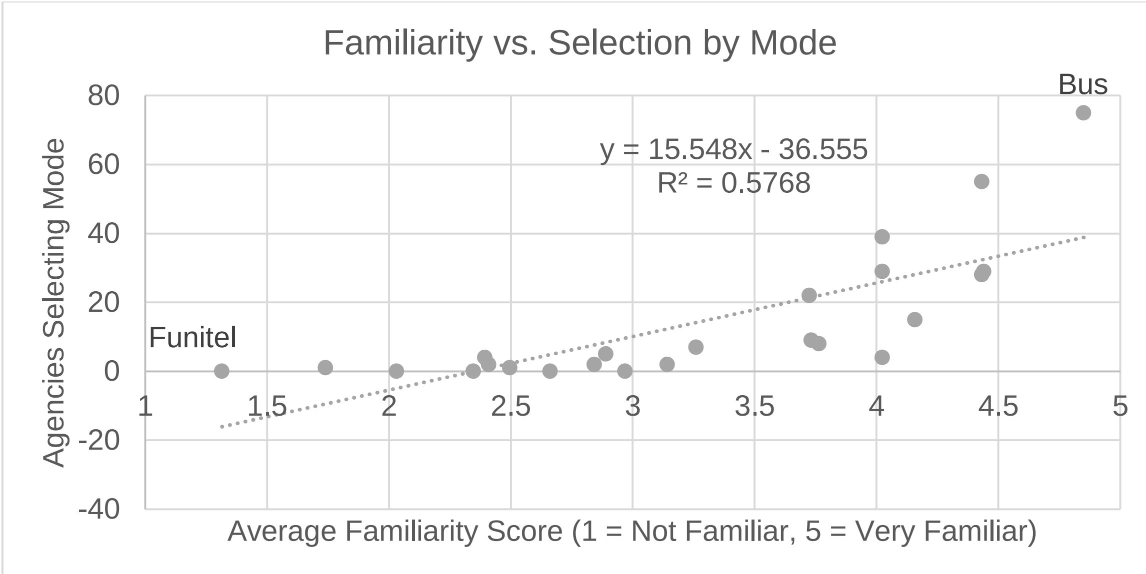


Figure 3.9 – Familiarity vs. Number of Respondents Selecting each Transit Mode

A ratio of the number of participating organizations selecting each mode to the number considering each mode was calculated, as shown in Figure 3.10. Interestingly, jitney and publico had the highest ratio of 1, indicating that they were selected in every instance that they were considered (though they were rarely considered). Bus had the next highest ratio of 0.83, followed by commuter rail (0.68) and bus rapid transit (0.67). Other modes with ratios above 0.5 were light rail (0.57), ferryboat (0.54), commuter bus (0.53), heavy rail (0.53), and demand response (0.52). Right at the 0.50 mark were water bus and water taxi modes. Just below this were the modes of trolleybus (0.44), streetcar rail (0.43), vanpool (0.41), and taxi (0.40). On the lower end of the scale were aerial tramway (0.25) and monorail / automated guideway (0.18). Although they were considered in a few cases, the modes of funitel, gondola, and maglev were not selected by any organizations participating in the survey. Cable car and inclined plane modes were not considered by any respondent organizations.

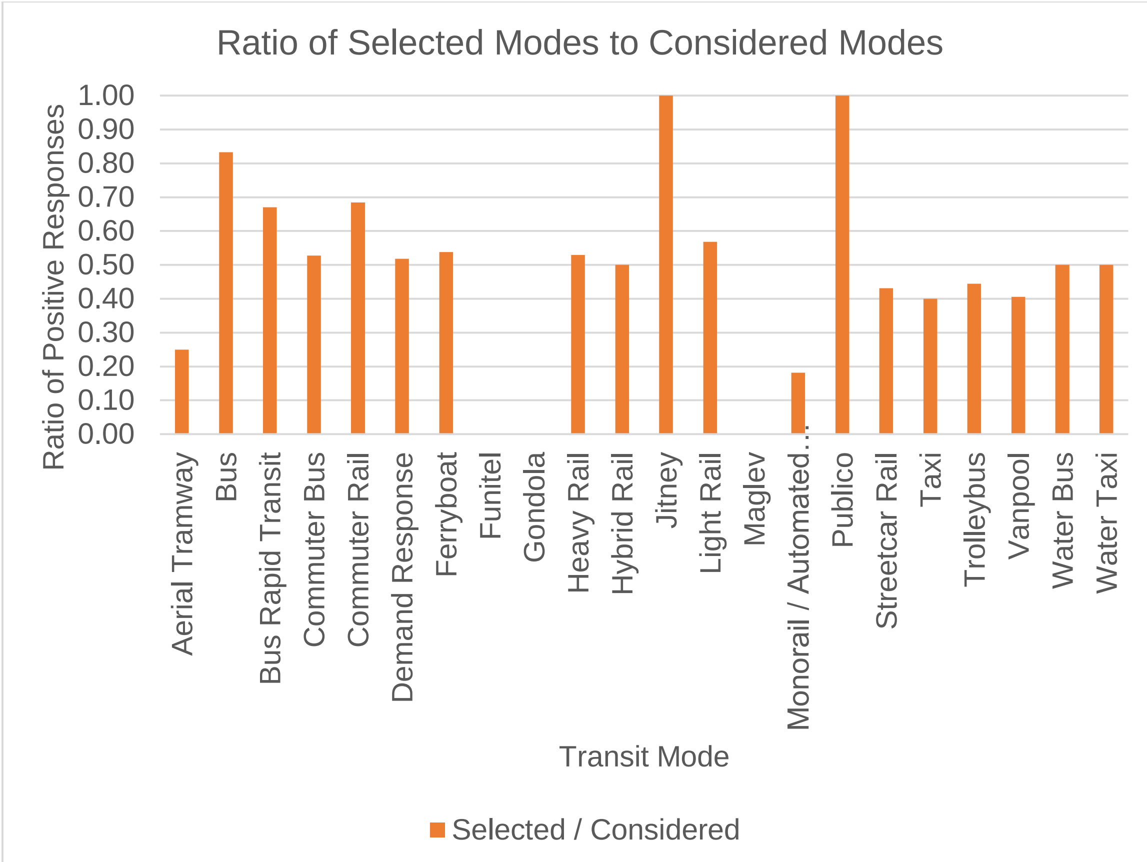


Figure 3.10 – Ratio of Respondents Selecting vs. Considering Each Mode

The ratios between the number of agencies selecting a mode and the number of agencies with the mode already existing in their system were calculated, as shown in Figure 3.11. Hybrid rail and jitney were selected twice as often as they were reported to exist. Bus rapid transit had the third highest ratio (1.72), followed by water taxi (1.67). Slightly below these were the modes of light rail (1.26), commuter rail (1.22), streetcar rail (1.10), and publico (1.00). Modes with ratios below 1 included bus (0.82), heavy rail (0.69), water bus (0.67), commuter bus (0.56), trolleybus (0.53), aerial tramway (0.50), demand response (0.36), ferryboat (0.35), vanpool (0.30), monorail / automated guideway (0.29), and taxi (0.16). No agency selected cable car or inclined plane.

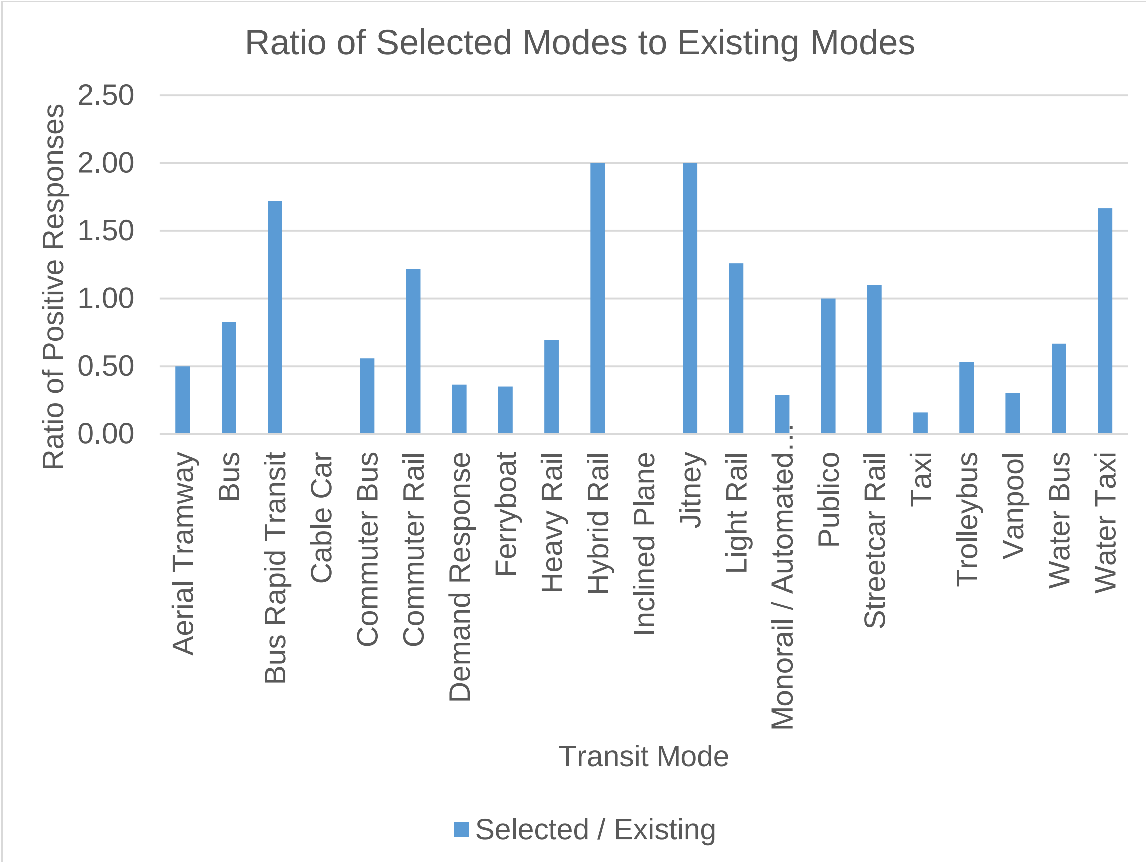


Figure 3.11 – Ratio of Respondents Selecting vs. Operating Each Mode

To compare the mode selections of transit agencies versus metropolitan planning organizations over the last 10 years, the data was broken into two segments as shown in Figure 3.12. Although the differences between these two segments were often small, the MPO respondents had a higher proportion reporting selection of bus, commuter bus, jitney, publico, streetcar rail, taxi, trolleybus, vanpool, water bus, and water taxi modes. A larger percentage of transit agency respondents than MPO respondents indicated that their organization had selected aerial tramway, bus rapid transit, commuter rail, demand response, ferryboat, heavy rail, light rail, and monorail / automated guideway.

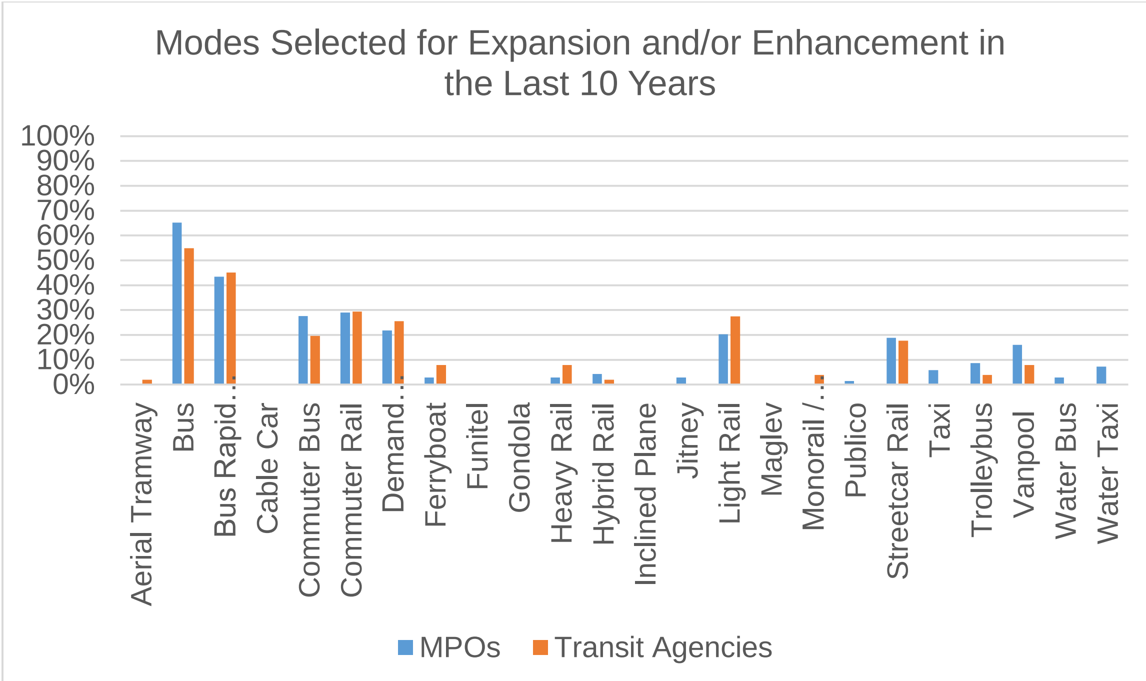


Figure 3.12 – Selected Transit Modes for MPO and Transit Agency Segments

The numbers of participating organizations that had operated, considered, and selected each mode were also put into tabular format for further analysis. As shown in Table 3.7, these values were proportionally shaded, with the highest value in each column colored bright green and lighter shades of green applied to lower values. This formatting shows very clearly that bus is the most common mode operated, considered, and selected by participating organizations. It is also apparent that less common modes are considered and selected far less often than conventional modes. For example, although aerial modes (aerial tramway, funitel, and gondola) were considered in several instances, only aerial tramway (the lowest capacity mode of the three) was selected, and only in one case. Further, modes such as bus rapid transit, commuter rail, light rail, and streetcar rail seem to have gained popularity in the last decade, while demand response, ferryboat, taxi, and vanpool seem to have declined in popularity over the same period.

Table 3.7 – Number of Agencies Operating, Considering, and Selecting each Mode

Mode	Existing	Considered	Selected
Aerial Tramway	2	4	1
Bus	91	90	75
Bus Rapid Transit	32	82	55
Cable Car	1	0	0
Commuter Bus	52	55	29
Commuter Rail	32	57	39
Demand Response	77	54	28
Ferryboat	20	13	7
Funitel	0	1	0
Gondola	0	4	0
Heavy Rail	13	17	9
Hybrid Rail	2	8	4
Inclined Plane	2	0	0
Jitney	1	2	2
Light Rail	23	51	29
Maglev	0	6	0
Monorail / Automated Guideway	7	11	2
Publico	1	1	1
Streetcar Rail	20	51	22
Taxi	25	10	4
Trolleybus	15	18	8
Vanpool	50	37	15
Water Bus	3	4	2
Water Taxi	3	10	5

Respondents were asked why their organization chose the modes they had selected over the last 10 years. Answers to this question varied widely, as shown in Table D.4 in the appendix. Overall the major considerations in mode selection were reported as cost effectiveness or cost / benefit analysis, available funding, and appropriateness of each mode to meet the expected demand for and purpose of the proposed service. Selected responses to this question are provided in Table 3.8.

Table 3.8 – Selected Responses to Question 15

Question 15: Why were these modes selected?
Based on a detailed assessment of trip types, employment and job centers, and community wishes.
Because they fulfilled the study goals and objectives as they relate to improving transit access, mobility and community support.
BRT was selected as a way to develop our streetcar system at a lower cost.
Bus and commuter bus were selected because they were cost effective for new service with relatively low ridership. A hybrid commuter rail-light rail system was selected as the LPA for a project that did not move forward due to the lack of local governance / funding structure. BRT is being pursued now because it is the most cost effective and would best serve the needs of the corridor given the location of the rail line and current freight service on it.
Cost and ridership projections.
Current modes offered or community request.
Decision based upon the analysis and available funding.
Each case is different, but local preference, cost, economic impact, and ridership are always factors.
Each was responsive to the needs in the corridor as defined by technical analysis, public input, and steering committee guidance as well as transit board guidance.
Financial savings and more service for the customer.
Fixed route transit offers the best service and cost effective qualities for our community.

Table 3.8 (continued)

Generally, the final transit modes selected for transit system expansion / enhancement are those that best address the purpose and need statements developed for individual planning studies.
Good fit with market needs.
In most cases study analysis determined them to be the most feasible. In a limited number of cases stakeholder organizations specifically sought to implement them.
It is consistent with what we already operate.
Political reasons for bus rapid system and actual transportation needs for expanding the bus fixed route services.
In some cases, political influence led to a certain mode being selected. In a recent example, a funding partner was only willing to fund LRT and not BRT.
Selection was based on our strategic planning process and availability of funding.
Some were enhancements to existing modes that were unable to meet demand. Expansions to other modes were selected as a result of the planning and technical process described above.
They are mostly expansions of the current system.
There was need and financing available. They were publicly supported and politically endorsed.
These modes were already the predominant mode in the area already and the infrastructure was in place.
These modes were selected based on the outcome of a regional transportation long-range plan.
These modes were selected because they address need and because they are relatively cost effective.

Table 3.8 (continued)

They are the only modes operating in our region.
They best met the purpose and need of the study corridor.
They could be funded by FTA, state and local sources.
They had the highest ridership.
They performed well in our urban environment and were considered desirable by the community to the point where they were willing to fund the operation of these modes.
They satisfy the service requirements for existing or future service.
They were best to serve the markets requiring service and public involvement in the Long Range Transportation Planning process strongly favored these modes.
They were deemed most productive from a ridership or development perspective within the particular service corridors.
They were found to be the most appropriate based on planning studies, alternatives analyses, environmental documents, transit operations plans, and financing.
They were identified as being the most feasible from a cost and need perspective. In addition, the institutional structure for implementing these measures and for operating the service is already in place.
User demand by local municipalities and transit agencies.
Various corridors had attributes that caused the selection of the mode for that corridor. Land use goals and existing infrastructure played a part.
We have a mandate to provide rubber-tire service. BRT was selected to provide high-quality transit on heavily-used corridors. Trolleybus expansion helps reduce fuel costs and CO2 emissions (helps us meet environmental sustainability goals). Employer commute services help meet state environmental goals and manage congestion.

3.8 Mode Succession

Survey participants were asked whether or not their organization has been involved with mode succession activities (replacing one mode with another). Of the 105 total responses, 70 (66.7%) indicated that their organization had not been involved with mode succession, while 28 (26.7%) responded that their agency had been involved with mode succession activities and 7 (6.7%) were unsure. Respondents were also asked which modes were being used originally, and which modes were replacing them. Of the 28 respondents whose organization has engaged in mode succession activities, the vast majority (75.0%) had been using bus originally, followed by commuter bus (25.0%), demand response and vanpool (7.1% each), then streetcar rail and trolleybus (3.6% each). The most commonly noted replacement modes were bus rapid transit and light rail (tied at 39.3%), followed by commuter rail (17.9%). Aerial tramway, bus, commuter bus, hybrid rail, jitney, monorail / automated guideway, and streetcar rail were each cited as replacement modes by one respondent (3.6% each).

Question 19 asked participants why their organization made the modal change they had described in the last few questions. The full set of responses is shown in Table D.5 in the appendix, while selected responses are presented in Table 3.9. Many of the mode succession examples described involved replacement of bus service with higher-capacity modes, such as bus rapid transit and light rail. A key challenge was dealing with customers who were upset that their bus service was being cut, and that they would have to transfer or travel farther to access the station of the higher capacity mode. Other common reasons for mode succession were to avoid congestion and to provide more attractive services to customers. Mode changes were often planned well in advance, but sometimes driven by short-term funding availability, stakeholder desires, or other agencies with a mandate to provide a specific type of service in a nearby corridor.

Table 3.9 – Selected Responses to Question 19

Question 19: Why did you make this modal change and how did the process go? Include any challenges you faced in this process, and how you dealt with them.
BRT is the only mode with good cost effectiveness and can serve bus lines carrying between 8,000 and 20,000 daily trips. Rail is too expensive. Ferries are terrible from a greenhouse gas perspective.
Challenges in integrating bus networks with new rail lines are primarily in changing travel patterns for current riders. These riders maintain significant resistance to change, especially if the benefit of new rail services are directly benefitting other or new riders and not themselves.
Change was anticipated as part of our agency System Planning efforts. First Plan adopted in 1983 and revised in 1989; 1995; and 2006 to reflect changing regional demographics and to fulfill bond and voter obligations. Followed AA process to confirm mode and develop engineering, cost estimates and environmental clearance. The technical aspects of the projects went well. Experienced some difficulties with explosive growth and ROW acquisition. Economic climate created bigger issues relative to escalation of material costs.
Change was made to provide greater capacity.
Commuter bus was originally set-up as a demonstration project for commuter rail. Challenges with commuter rail have been cost and rail delays associated with increased freight demand. Replacing bus with bus rapid transit was a challenge of finding funding for non-rail transit modes expansions in already heavily used corridors. Challenges with replacing bus with light rail were very technical and corridor-specific.

Table 3.9 (continued)

Commuter rail was supported by a large and consistent commuting pattern. The rail option was intended to reduce congestion on a major interstate highway.
Evolution of transit to higher capacity modes within key commute corridors.
Basically, our approach to the implementation of a BRT system has been to have that mode replace the existing bus service on a given corridor. Typically, our regular service in the area of the new BRT corridor is reconfigured to provide connectivity between BRT stations on the corridor and surrounding areas.
We recently upgraded transit service on the Sahara Avenue corridor from regular fixed route bus to BRT. The project was funded through the TIGER program and included the conversion of a 6-lane arterial to one with dedicated curbside bus/bike lanes, less frequent stops, pedestrian facilities, landscaping, more robust passenger shelters, system branding, and some route restructuring. Overall a great success with faster service and increase in boardings from 6,700 per day to over 10,000 per day.
Lots of challenges with patrons who used to have a one-seat ride and then had to transfer. We tried to promote the fact that commuter rail had more trips per day than the old express bus. Difficult issue.
The corridor continued to grow with population and jobs as well as congestion. The mobility benefits and development benefits of light rail were preferred by steering committee and stakeholders as well as involved jurisdictions / agencies over continuing bus service or pursuing another mode like bus rapid transit.
There were a number of vanpools originating and ending at similar places. A commuter service was put in along those routes.

Table 3.9 (continued)

This change occurred because another agency with a mandate to build light rail did so. Our agency removed duplicative service and restructured service to take advantage of the expanded capacity provided by the light rail line. The process (which is ongoing as other light rail segments open) can be contentious, but we seek consensus with the affected communities. Many do not like to see bus service cut, particularly when they have to walk farther to reach light rail. We seek to demonstrate how reinvesting service hours in different ways leads to a better overall system that serves the entire community better. As a result of having to reduce service, we have also replaced fixed-route and demand-response services with alternatives, typically smaller, demand-responsive community shuttles.
We assisted SEPTA with an evaluation of alternative future vehicle technologies for two historic trackless trolley (now bus) routes, including consideration for trackless trolley restoration, bus continuation, and electric bus replacement / piloting. One challenge was the rapidly evolving nature of electric bus technology, and the resulting difficulty in assessing costs / details with certainty. The outcome was that the study's recommendations were a bit more nuanced / conditional than they might otherwise have been. Some other "mode replacement" work has involved development of BRT or "enhanced bus" concepts that would replace or overlay fixed route bus operations.
We took high performing bus lines and replaced them with higher capacity transit modes.

3.9 Factors Considered

One of the primary reasons for conducting the *Transit Mode Selection Survey* was to understand which factors are most important and most often considered in the transit mode selection processes of transit planning organizations in the U.S. and Puerto Rico. Factors were divided into four groups: economic factors, environmental factors, social factors, and performance factors. Most of the expected factors were listed, along with an “other” option that allowed respondents to include factors that were not already on the list. All respondents were asked questions in this section of the survey, so a total of 127 responses were received.

Overall, most respondents reported that their organization considered many, if not all, of the factors mentioned in the provided lists and more. As shown in Table 3.10, the most commonly cited factors were capacity and capital costs with 92.9% of respondents including each of these factors in their mode selection process. Operating costs and reliability were each considered by 91.3% of respondents, followed by availability of funding and safety with 88.2% each. Accessibility (86.6%) was next highest in the rankings, followed by community views, emissions, and speed each with 82.7% of respondents. Economic development and jobs access tied with 100 respondents (78.7%) each, closely followed by maintenance requirements (78.0%) and fuel / power supply (76.4%). Around 70% of respondents said their organizations considered political influences and schedule type (91 respondents each), aesthetics (90 respondents), and resiliency (86 respondents). Factors with between 50-70% of respondents considering them in their processes included: spatial requirements (82 respondents), energy use (79), land requirement (78), noise / vibrations (73), resource impacts (68), job creation (67), and build time (64).

Table 3.10 – Mode Selection Factors Considered by Respondent Organizations

Factor	Count	Percent
Capacity	118	92.9%
Capital costs	118	92.9%
Operating costs	116	91.3%
Reliability	116	91.3%
Availability of funding	112	88.2%
Safety	112	88.2%
Accessibility	110	86.6%
Community views	105	82.7%
Emissions	105	82.7%
Speed	105	82.7%
Economic development	100	78.7%
Jobs access	100	78.7%
Maintenance requirements	99	78.0%
Fuel / power supply	97	76.4%
Political influences	91	71.7%
Schedule type	91	71.7%
Aesthetics	90	70.9%
Resiliency	86	67.7%
Spatial requirements	82	64.6%
Energy use	79	62.2%
Land requirement	78	61.4%
Noise / vibrations	73	57.5%

Factor	Count	Percent
Job creation	67	52.8%
Build time	64	50.4%
Innovation	54	42.5%
Wildlife impacts	54	42.5%
Water impacts	52	40.9%
Equipment origin	44	34.6%
Availability of skilled workers	39	30.7%
Demand	5	3.9%
Equity	3	2.4%
ADA accessibility	2	1.6%
Land use	2	1.6%
Proven technology	2	1.6%
Air quality	1	0.8%
Congestion mitigation	1	0.8%
Corridor condition	1	0.8%
Cost effectiveness	1	0.8%
Demographics	1	0.8%
Environmental Justice	1	0.8%
FRA compliance	1	0.8%
Health	1	0.8%
Livability	1	0.8%
Service requirements	1	0.8%
Vehicle battery range	1	0.8%

The lowest ranking listed factors (considered by 50% to 30% of respondents) were innovation and wildlife impacts (54 respondents each), water impacts (52), equipment origin (44), and availability of skilled workers (39). Other factors listed by respondents (less than 5%) were: demand (5 respondents); equity (3); ADA accessibility, land use, and proven technology (2 respondents each); and air quality, congestion mitigation, corridor condition, cost effectiveness, demographics, environmental justice, FRA compliance, health, livability, service requirements, and vehicle battery range, each with one respondent.

The economic factors considered by survey respondents' organizations are shown in Figure 3.13. The most commonly considered economic factors were capital costs (also tied for highest overall) and operating costs. Availability of funding was close behind, with economic development and jobs access tied for fourth among the economic factors. Twenty three respondents (18.1%) stated that their organization considered all economic factors in their process, while only two (1.6%) considered none of the economic factors. Other factors listed by participants under economic factors were demand, appropriateness of technology, cost effectiveness, FRA compliance, land use allocation, livability and accessibility, proven technology and market, past plans, and proximity to affordable housing.

20. What economic factors are currently considered in your organization's process for selecting transit modes for system expansion / enhancement? Check all that apply.

Capital costs	92.9%	118
Operating costs	91.3%	116
Economic development	78.7%	100
Jobs access	78.7%	100
Job creation	52.8%	67
Availability of skilled workers	30.7%	39
Availability of funding	88.2%	112
Innovation	42.5%	54
Equipment origin	34.7%	44
All of the above	18.1%	23
None of the above	1.6%	2
Other	29.9%	38

Statistics

Total Responses	127

Figure 3.13 – Economic Factors Considered by Respondent Organizations

The environmental factors considered by survey respondents' organizations are shown in Figure 3.14. The most commonly considered environmental factors were emissions and fuel / power supply. Land requirement, noise / vibrations, and resource impacts were all considered by more than 50% of respondent organizations. Thirty nine respondents (30.7%) stated that their organization considered all environmental factors in their process, while eight (6.3%) considered none of the environmental factors. Other factors listed by participants under environmental factors were air quality, visual factors, environmental justice, and land use allocation. Wildlife and water impacts were among the least considered listed factors in the environmental factors group, as well as among listed factors considered overall.

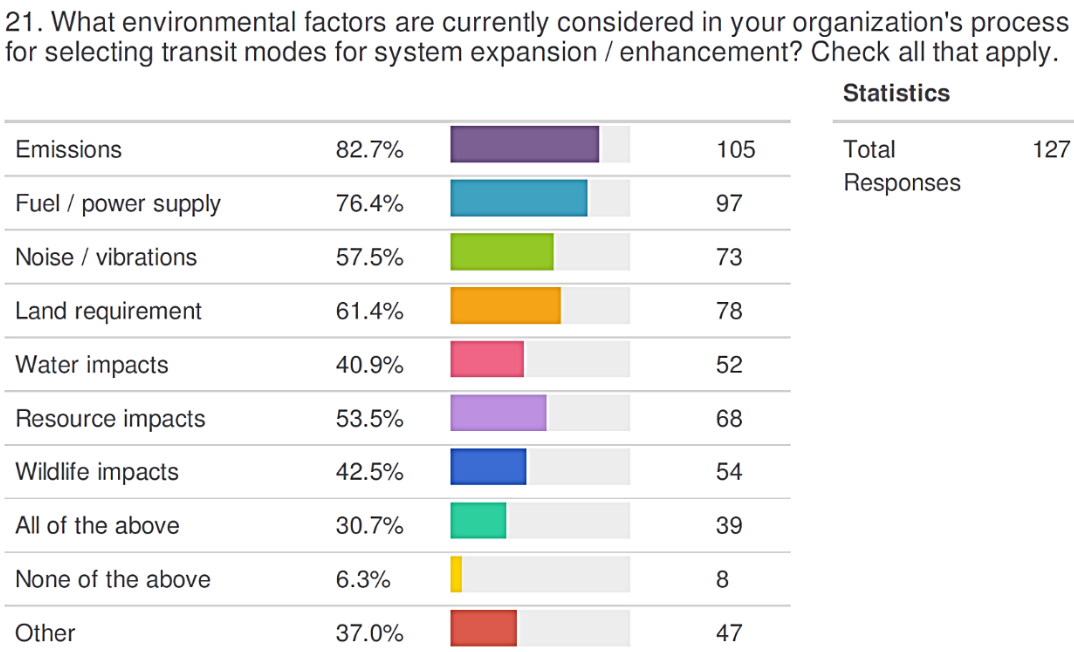


Figure 3.14 – Environmental Factors Considered by Respondent Organizations

The social factors considered by survey respondents' organizations are shown in Figure 3.15. The most commonly considered social factors were reliability, safety, accessibility, and community views. Between 65-75% of respondents stated that their organization considers political influences, aesthetics, and resiliency during the mode selection process. None of the listed social factors was reportedly considered by less than 65% of respondents. Forty nine respondents (38.6%) stated that their organization considered all social factors in their process, while four (3.2%) considered none of the social factors. Other factors listed by participants under social factors were equity, congestion mitigation, demographics, justice, health, and ADA accessibility.

22. What social factors are currently considered in your organization's process for selecting transit modes for system expansion / enhancement? Check all that apply.

Safety	88.2%	112
Reliability	91.3%	116
Resiliency	67.7%	86
Aesthetics	70.1%	89
Community views	82.7%	105
Political influences	71.7%	91
Accessibility	86.6%	110
All of the above	38.6%	49
None of the above	3.2%	4
Other	47.2%	60

Statistics	
Total Responses	127

Figure 3.15 – Social Factors Considered by Respondent Organizations

The performance factors considered by survey respondents' organizations are shown in Figure 3.16. The most commonly considered performance factors were capacity (also highest ranking overall), speed, maintenance requirements, and schedule type. The less considered factors were spatial requirements, energy use, and build time. None of the listed performance factors was reportedly considered by less than 50% of respondents. Forty one respondents (32.3%) stated that their organization considered all performance factors in their process, while three (2.4%) considered none of the performance factors. Other factors listed by participants under performance factors were congestion and pavement condition, estimated ridership, market potential, service requirements, and vehicle battery capacity (for electric vehicles).

23. What performance factors are currently considered in your organization's process for selecting transit modes for system expansion / enhancement? Check all that apply.

Capacity	92.9%	118
Speed	82.7%	105
Schedule type	71.7%	91
Build time	50.4%	64
Energy use	62.2%	79
Maintenance requirements	78.0%	99
Spatial requirements	64.6%	82
All of the above	32.3%	41
None of the above	2.4%	3
Other	40.2%	51

Statistics	
Total Responses	127

Figure 3.16 – Performance Factors Considered by Respondent Organizations

Survey participants were asked to rate the importance of each set of factors on a 1 (not important) to 5 (very important) scale. Responses to this question are shown in Table 3.11. While all factors were rated as being closer to very important than to not important overall, economic factors received the highest average rating of 4.5, followed by performance factors with an average rating of 4.3. Social factors were not far behind with an average score of 4.1, but the average rating for environmental factors (3.8) was four tenths of a point less than that of social factors. Still, the highest percentage of respondents (35.4%) gave environmental factors a rating of 4, which would suggest that environmental factors are viewed as important in the mode selection process.

Table 3.11 – Importance of Each Set of Factors in Mode Selection

24. Rate the importance of each set of factors in your organization's transit mode selection process, using a 1-5 scale (1 = Not Important and 5 = Very Important).

	1	2	3	4	5	Average	Responses
Economic factors	5 3.9%	2 1.6%	3 2.4%	36 28.3%	81 63.8%	4.5	127
Environmental factors	7 5.5%	9 7.1%	28 22.0%	45 35.4%	38 29.9%	3.8	127
Social factors	5 3.9%	5 3.9%	12 9.4%	59 46.5%	46 36.2%	4.1	127
Performance factors	4 3.1%	4 3.1%	13 10.2%	41 32.3%	65 51.2%	4.3	127
Average %	4.1%	3.9%	11.0%	35.6%	45.3%	4.2	508

Survey respondents were also asked an open-ended question, “What are the most important factors in your organization's transit mode selection process?” Word counts were performed for several key words within the full set of responses, as shown in Table 3.12. The responses (Table D.6) overwhelmingly referred to cost, economic, and funding factors over all others. Factors related to performance, capital, need, and riders were considered to be among the most important considerations by about 10% of respondents. The words “access”, “demand”, and “social” were each used by only nine respondents (7.1%), while “development”, “effective”, “environment”, and “support” were each mentioned in eight responses. References to safety and reliability were far less common, despite these being among the top national transportation priorities. Many other important factors appear to be widely viewed as less important than cost.

Table 3.12 – Key Word Frequency in Responses to Question 25

Keyword	**Count**	**Percent**
Cost	41	32.3%
Economic	29	22.8%
Funding	16	12.6%
Performance	14	11.0%
Capital	12	9.4%
Need	12	9.4%
Riders	12	9.4%
Access	9	7.1%
Demand	9	7.1%
Social	9	7.1%
Development	8	6.3%
Effective	8	6.3%
Environment	8	6.3%
Support	8	6.3%
Community	7	5.5%
Public	7	5.5%
Capacity	6	4.7%
Jobs	6	4.7%
Benefit	5	3.9%
Political	5	3.9%
Safe	5	3.9%
Sustainability	5	3.9%
Land	3	2.4%
Reliability	3	2.4%

It is interesting, but not unexpected, to find that economic factors, especially costs, are viewed as the most important factors in transit mode selection overall. Many important decisions are still being based solely or primarily on the fiscal bottom line, despite several decades of thought leaders and sustainability experts making the case for greater emphasis on environmental and social factors. Since the economy is only one of several social systems, all of which depend on supporting environments for their existence, it seems more logical to the author for economics to be considered secondary to larger environmental and social concerns, as well as transit performance factors.

Part 2 – Urban Transit Mode Data Collection

CHAPTER 4

DATA COLLECTION AND ANALYSIS

The focus of Chapter 4 is to summarize the findings of a data collection and analysis process that included national data sets from the United States (including Puerto Rico). A brief description of the data sources is provided, followed by data on the prevalence and usage of public transit, as well as performance, environmental, social, and economic factors of each transit mode.

4.1 Data Sources

The three primary sources of national transit data used in this thesis were the National Transit Database (NTD), Bureau of National Transportation Statistics (NTS), and the American Public Transportation Association (APTA). Additional data sources were used, including *Urban Transit* by Vuchic, and others as cited in the text.

4.2 Prevalence and Usage

To understand the comparisons between each mode, it is important to gain perspective on the prevalence and usage of each mode in the United States. This was accomplished through analysis of data from the NTD, summarized below. While data from before 2011 is available, changes to the mode classification system used by the NTD in 2011 led to discontinuities in the data. Therefore, although the data from before 2011 was also analyzed, the charts showing changes over time generally only include data from 2011-2014, for the sake of clarity and readability.

Data on average unlinked passenger trips by mode is displayed in Figure 4.1. As shown, bus (MB) and heavy rail (HR) consistently had the highest values by far, with bus hovering around 5 billion trips annually and heavy rail just under 4 billion. The mode with the third highest number of trips was commuter rail (CR), closely followed by light rail (LR), both with just under 500 million trips per year. Demand response (DR), commuter bus (CB), and trolleybus (TB) had roughly 100 million annual trips over the last few years (commuter bus trips more than tripled from 2011 to 2013). Ferryboat (FB) was the next highest with around 65 million annual trips, followed by streetcar rail (SR) with about 50 million trips per year. Bus rapid transit (RB) has seen massive gains, going from around 6 million trips in 2011 to more than 50 million trips in 2014. Vanpool (VP) has remained steady at around 35 million annual trips, while publico (PB) dropped from almost 40 million trips in 2011 to less than 30 million since 2013. Monorail / automated guideway (MG) has experienced an increase in trips, from about 14 million in 2011 to more than 22 million in recent years. In the “low” category are the modes of cable car (CC) and taxi (DT) with around 7 million annual trips each, and hybrid rail (YR) with about 5 million. Inclined plane (IP) dropped to just over 1 million trips, while aerial tramway (TR) rose to almost 2 million trips annually since 2013 (Federal Transit Administration, 2016).

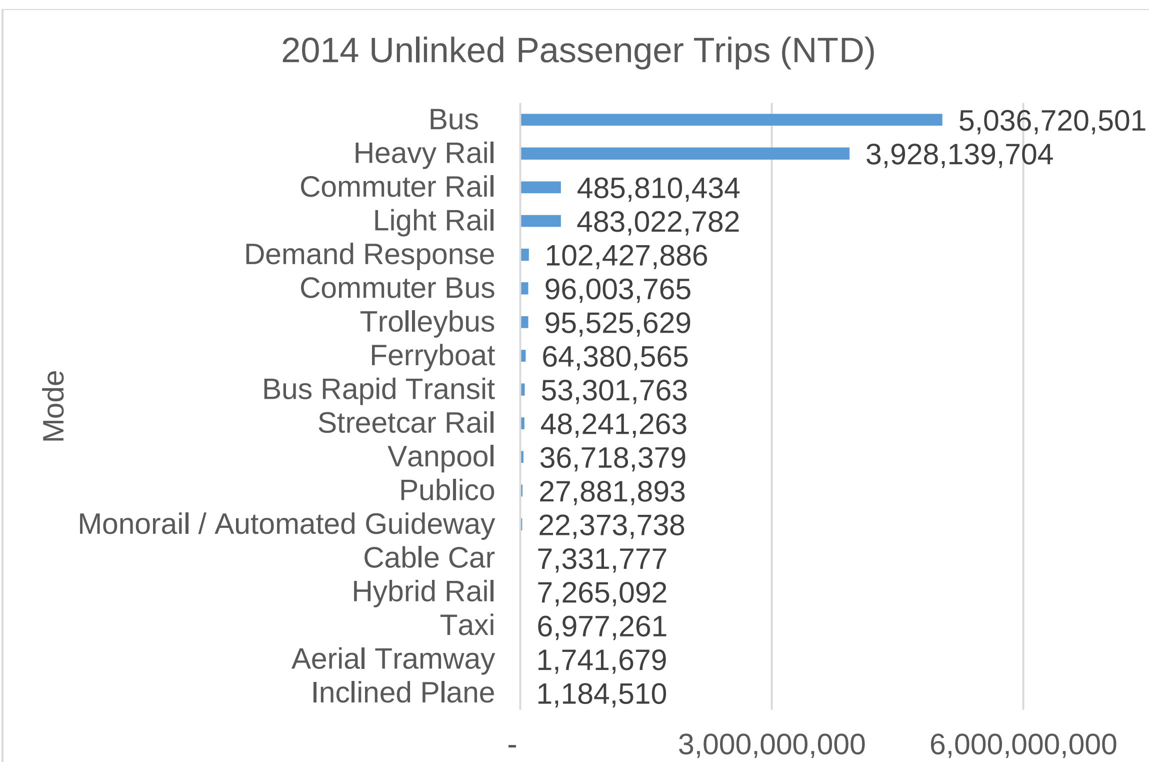


Figure 4.1 – All Modes Unlinked Passenger Trips (Federal Transit Administration, 2016)

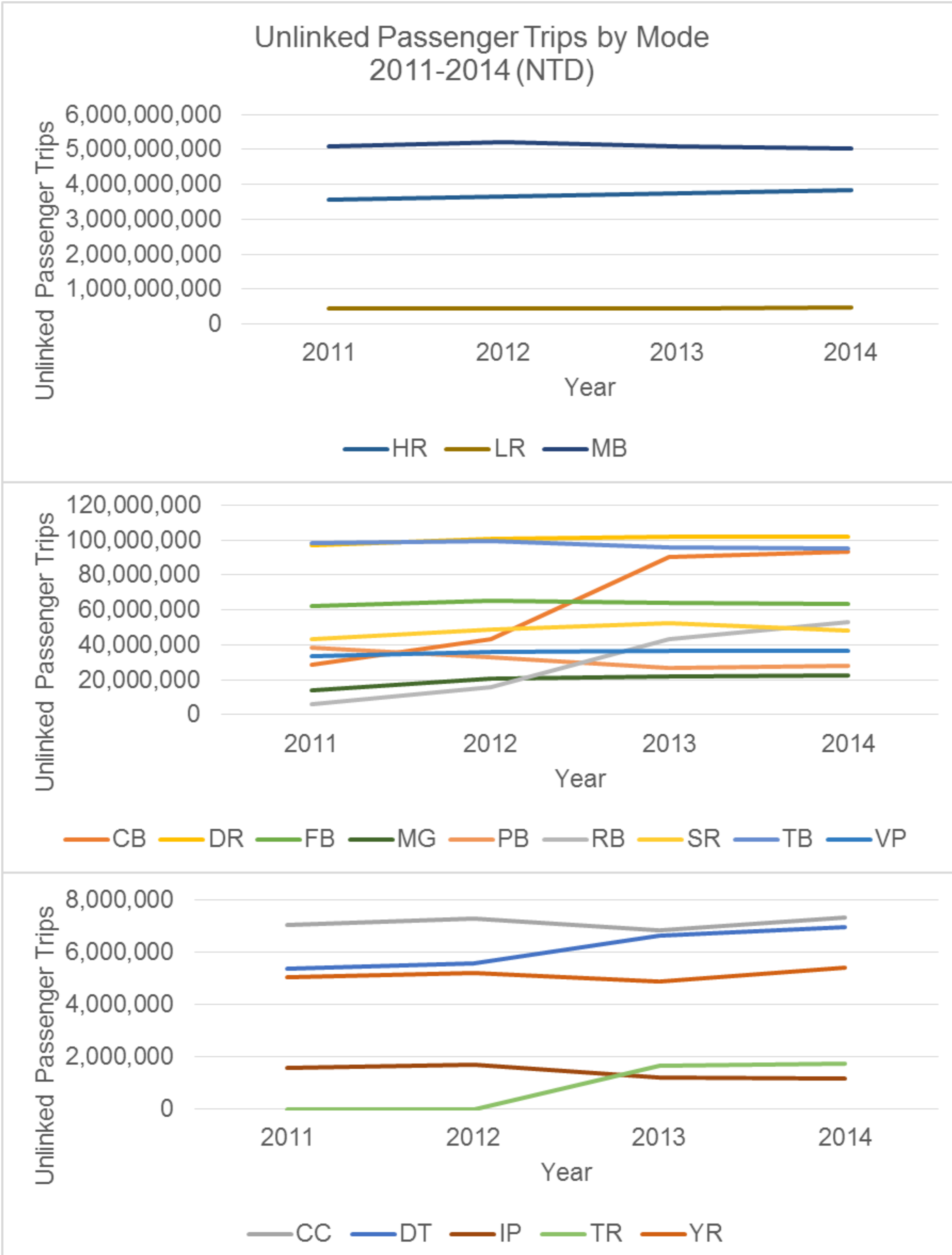


Figure 4.2 – Grouped Modes by Unlinked Passenger Trips (Federal Transit Administration, 2016)

A similar procedure was followed for comparing the passenger miles traveled per year for each mode from 2011-2014. As shown in Figure 4.3, bus (MB) was moving people the farthest of all modes, but a drop from over 20 billion passenger miles in 2012 to less than 19 billion in 2013 brought the passenger miles traveled by bus closer to the total passenger miles traveled by heavy rail (HR), which has seen an increase from roughly 17 billion passenger miles in 2011 to more than 18 billion in 2014. Commuter rail (CR) was again ranked third with 12 billion passenger miles, followed by light rail (LR) and commuter bus (CB), each with about 2.5 billion passenger miles in 2014. Commuter bus (CB) increased from being ranked 7th in 2011 with 653 million passenger miles to 5th in 2013 with just under 2.5 billion passenger miles traveled. This increase in commuter bus travel is especially interesting when viewed in contrast with regular bus, which declined during this period (Federal Transit Administration, 2016).

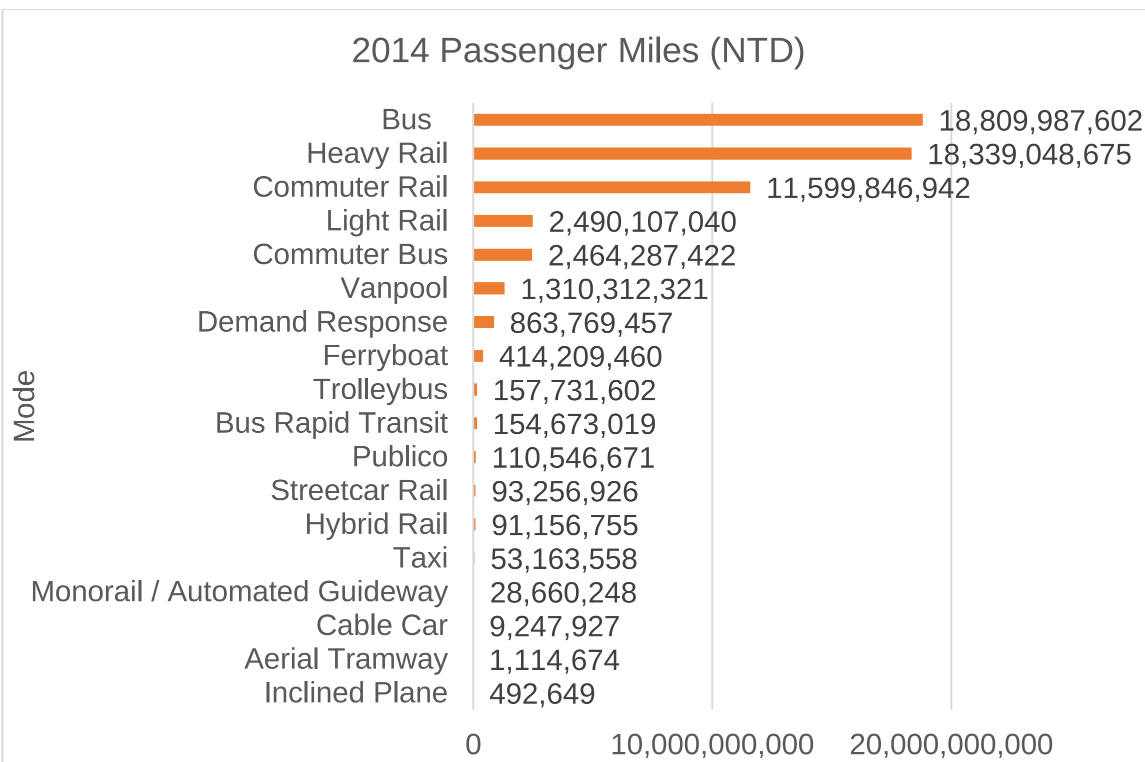


Figure 4.3 – All Modes Passenger Miles Traveled (Federal Transit Administration, 2016)

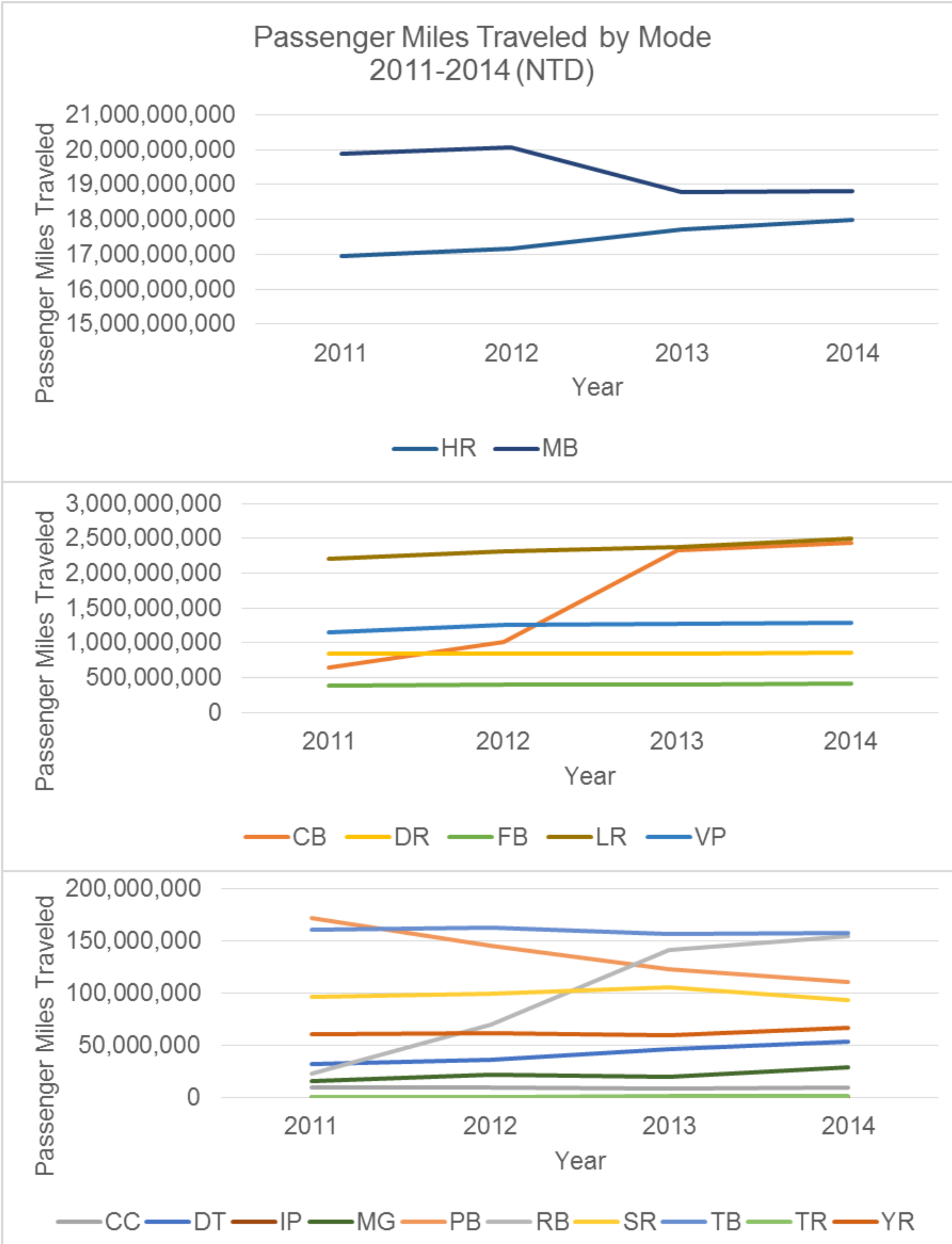


Figure 4.4 – Grouped Modes by Passenger Miles Traveled (Federal Transit Administration, 2016)

The modes were again grouped as high-, medium-, and low-use, as shown in Figure 4.4. Vanpool (VP) held steady at around 1.3 billion, with demand response (DR) around 860 million, and ferryboat (FB) just under 500 million. No other mode has exceeded 200 million passenger miles during this period. Trolleybus (TB) and bus rapid transit (RB) were close to 150 million passenger miles in 2014, with bus rapid transit travel increasing dramatically from about 25 million passenger miles to over 150 million in just three years. Meanwhile publico (PB) fell from 170 million to just above 100 million passenger miles annually. Streetcar rail (SR) held steady at around 93 million passenger miles, followed by hybrid rail (YR) at around 67 million, and taxi (DT) at 53 million, up from about 40 million in 2011. Monorail / automated guideway is third to last among reported modes, with about 29 million passenger miles, followed by cable car (CC) at just under 10 million and aerial tramway in last place with about 1 million annual passenger miles traveled (Federal Transit Administration, 2016). It is important to note that passenger miles traveled are more indicative of mode prevalence than mode popularity. For example, cable car data comes from a single system with multiple lines, while aerial tramway data represents a single line.

Average trip length was also calculated for each reported mode, by dividing the annual passenger miles by the annual unlinked passenger trips. The results for all modes are shown in Figure 4.5. Vanpool (VP) had the longest trips overall, at around 35 miles, followed by commuter bus (CB) at about 25 miles and hybrid rail (YR) at 12 miles. Although it is not shown in Figure 4.5, commuter rail had an average trip length of about 24 miles in 2014. No other mode exceeded 10 miles for any year. Medium-distance modes included demand response (DR), which averaged between 8-9 miles, then taxi (DT), which has risen from 6 miles to almost 8 miles in recent years. Ferryboat (FB) trip lengths have averaged between 6-7 miles, while light rail (LR) and heavy rail (HR) have consistently averaged around 5 miles (Federal Transit Administration, 2016).

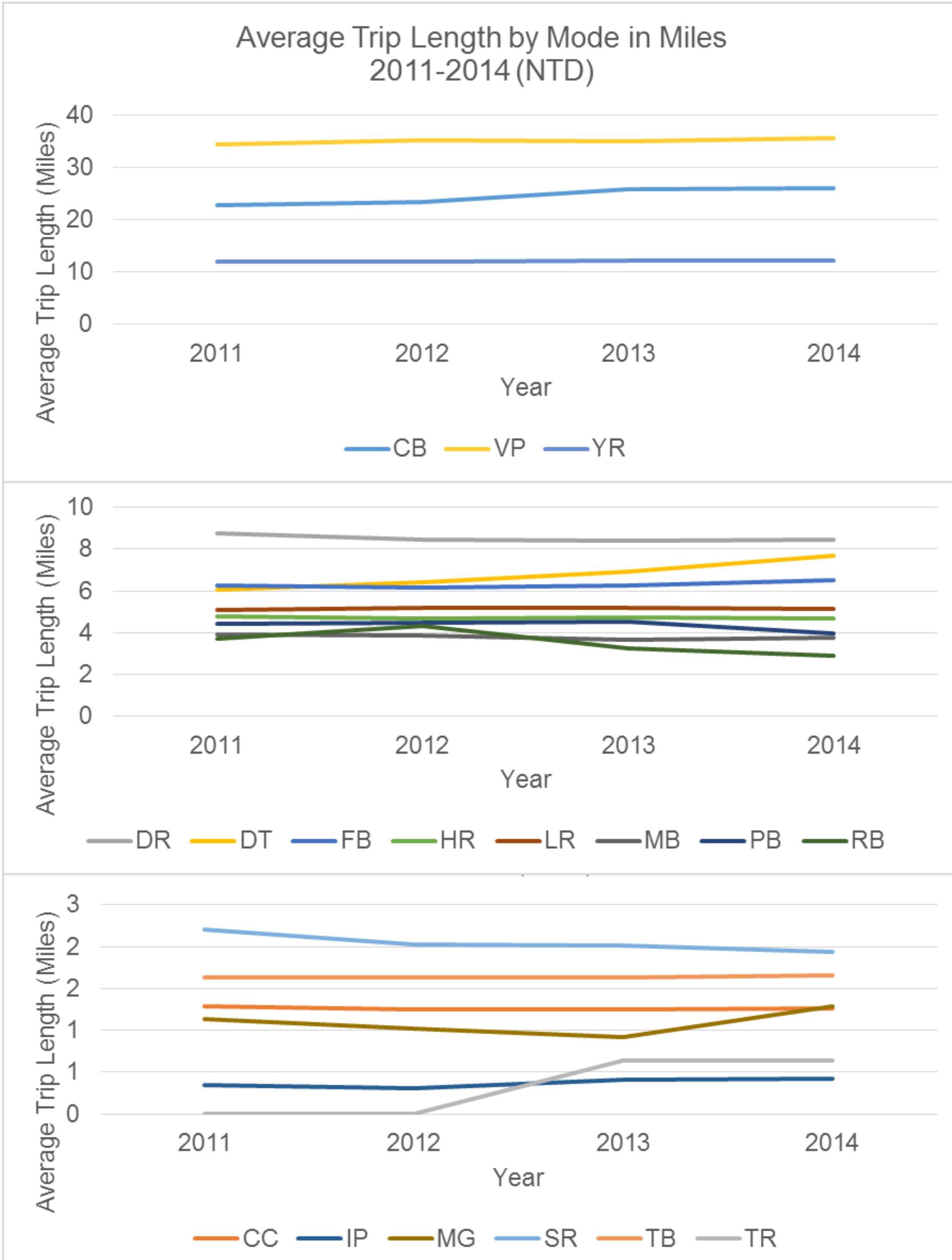


Figure 4.5 – Transit Mode Average Trip Length (Federal Transit Administration, 2016)

On the lower end of the medium-distance modes are publico (PB) at between 4-5 miles, bus (MB) at just under 4 miles, and bus rapid transit (RB), which peaked at 4.3 miles in 2012 but has since dropped to just below 3 miles. Short-distance modes did not exceed 2.5 miles for their average trip length. Streetcar rail (SR) averaged about 2 miles per trip, dropping from 2.5 miles in 2011 to less than 2 miles in 2014, followed by trolleybus (TB) at 1.6 miles, then cable car (CC) and monorail / automated guideway (MG) at about 1.3 miles each (MG trip length has increased since 2013). Modes with the shortest average trip length were aerial tramway (TR) at around 0.6 miles (the increase shown in the chart is due to a lack of data for 2011 and 2012, and it should be noted that the single aerial tramway included in this data has a fixed trip length that cannot vary due to service being offered only between two fixed stations) and inclined plane (IP) at roughly 0.4 miles (Federal Transit Administration, 2016).

Another measure of the extent of transit infrastructure in the U.S. is the total miles of existing transitways by mode. Commuter rail was included in this dataset, although modes operating without dedicated infrastructure (such as taxi and vanpool) are not included. The results of this analysis, performed using 2014 data from the NTD, are shown in Figure 4.6. As shown, the commuter rail network in the U.S. is the most extensive, with over 7,700 miles of commuter rail line. Bus infrastructure came in second at 2,600 miles, followed closely by heavy rail with about 2,300 miles. Light rail (1,500 miles) and commuter bus (1,400 miles) were not far behind. Much less extensive, but still notable, were transitways for trolleybus (400 miles), streetcar rail (300 miles), hybrid rail (200 miles), and bus rapid transit (170 miles). Roughly 36 miles of transitways are provided for monorail / automated guideway, followed by almost 9 miles for cable car and 1.5 miles for inclined plane (Federal Transit Administration, 2016).

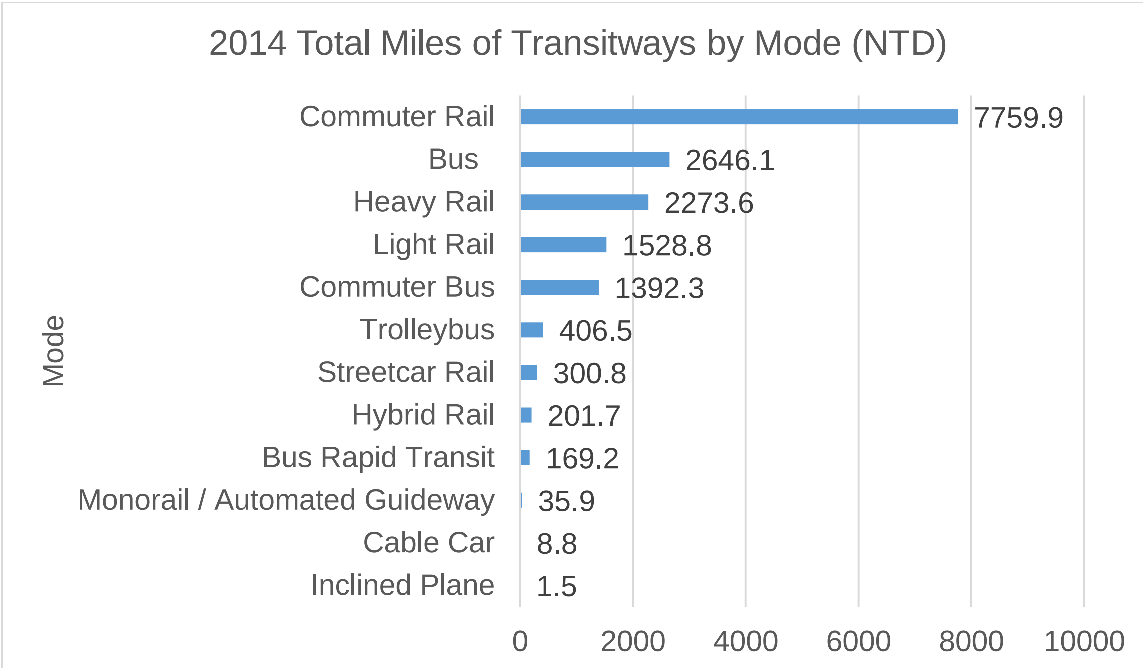


Figure 4.6 – 2014 Total Miles of Transitways by Mode (Federal Transit Administration, 2016)

As shown in Figure 4.7, not all transitways are the same for any given mode. While trolleybus transitways are all exclusive fixed guideways, cable car transitways are all at-grade with mixed and cross traffic, and inclined plane transitways are all at-grade exclusive, the other modes included in the NTD used a variety of transitways.

In 2014 commuter rail transitways included over 4,250 miles of at-grade rails in mixed traffic, more than 2,800 miles of at-grade exclusive rail lines, and over 450 elevated-on-fill miles, among other transitway types. Hybrid rail operated on more than 160 miles of at-grade rails in mixed traffic, 27 miles of at-grade exclusive rail lines, and a few other types. Heavy rail operated on over 800 miles of subway lines, nearly 750 at-grade exclusive rail lines, and about 500 elevated-on-structure rail miles. Light rail transitways were mostly at-grade with mixed traffic (more than 750 miles), followed by more than 320 miles of at-grade exclusive rail lines. Just over 150 miles of light rail lines were elevated-on-structure, while 83 miles were subway lines, 82 miles were elevated on-fill miles, and a couple other transitway types were used. Streetcar rail operated on more than 240 miles of at-grade rail lines with mixed and cross traffic, 47 miles of at-grade rail with mixed traffic, and a few other transitway types. Monorail / automated guideway modes operated mostly on elevated-on-structure transitways (more than 30 miles), with about four miles of at-grade exclusive right-of-way (Federal Transit Administration, 2016).

Bus and commuter bus transitways included mostly controlled access high-intensity lanes, followed by exclusive high-intensity lanes, and exclusive fixed guideway miles. Bus rapid transit, however, operated mostly on exclusive fixed guideway miles (more than 150 miles total) and secondarily on controlled access high-intensity bus lanes (16.5 miles) (Federal Transit Administration, 2016).

Aerial modes, which always operate on exclusive fixed guideways, were not included in this dataset, but the two urban aerial tramways operating in the U.S. each measure about 0.6 miles, for a combined 1.2 total miles of aerial transitways (Creative Urban Projects, 2013). Water modes, on the other hand, rarely have exclusive guideways, but may in rare cases where they are allowed to operate on waterways that do not accommodate any other vessels.

While the characteristics of these modes and their transitways may vary widely, including the fact that some modes only operate on a combination of shared and exclusive guideways, the prevalence and diversity of transitways for each mode help to provide a sense of the infrastructure requirements and array of options for accommodating various types of transit vehicles and services.

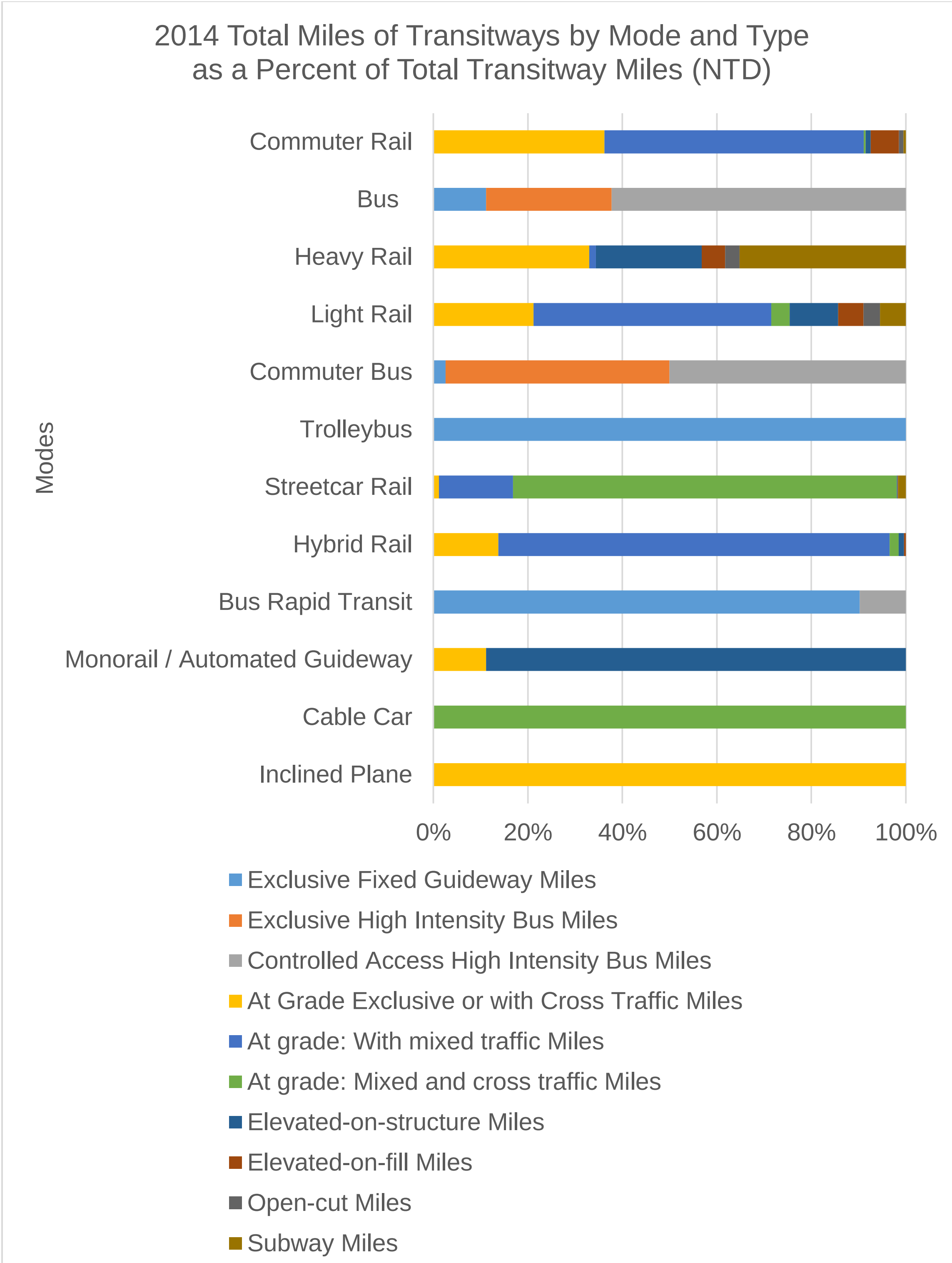


Figure 4.7 – 2014 Miles of Transitways by Mode and Type (Federal Transit Administration, 2016)

Lastly, it is important to consider the vehicle fleets of transit agencies nationwide, since vehicles come in a variety of sizes, and some are far more prevalent than others. As of 2014, buses were clearly the most prevalent transit vehicles in the United States (and Puerto Rico), with about 57,598 vehicles available, yet only 47,915 (83%) were operated in maximum service. Demand response vehicles totaled to 28,027 available, with 25,577 (91%) operated in maximum service. Vanpool vehicles were third, with 14,667 available and 13,015 (89%) operated in maximum service.

Heavy rail vehicles were the next most prevalent with 10,551 available and 9,273 (88%) operated in maximum service, followed by commuter rail with 7,177 vehicles available and 6,239 (87%) operated. Next most prevalent was commuter bus with 4,450 available and 3,795 (85%) operated in maximum service. Taxis (reported to the NTD) were about 3,404 vehicles, with more operated than available from the dataset. Since 3,404 was the number of taxis operated in maximum service, it was assumed that this was also the number available. Publico systems had 2,873 vehicles available and 2,096 (73%) operated in maximum service. Light rail was next, with 2,057 vehicles available and 1,495 (73%) operated in maximum service.

Modes with less than 1,000 vehicles included trolleybus with 537 available and 404 (75%) operated, bus rapid transit with 401 available and only 214 (53%) operated, streetcar rail with 337 available and 213 (63%) operated, monorail / automated guideway with 167 available and 127 (76%) operated, and ferryboat with 144 available and 114 (79%) operated in maximum service. Modes with less than 100 vehicles included hybrid rail with 50 available and 39 (78%) operated and cable car with 40 available and 27 (68%) operated in maximum service. Six inclined plane vehicles were available and operated in maximum service. Only two aerial tramway vehicles (both in Portland) were reported to the NTD as being available and operated in 2014 (Federal Transit Administration, 2016). All of this information is shown in Figure 4.8.

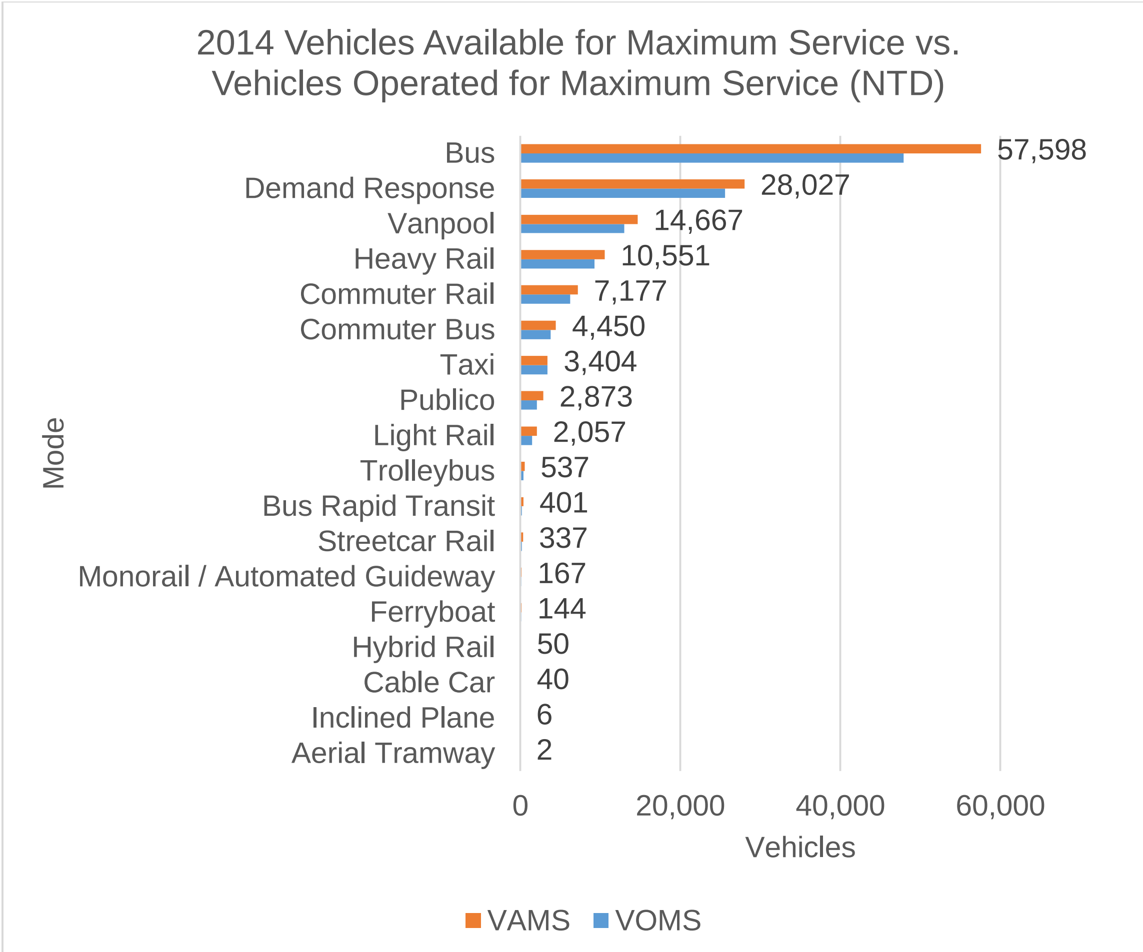


Figure 4.8 – 2014 Vehicles Available and Operated in Maximum Service (Federal Transit Administration, 2016)

4.3 Performance Factors

As shown in Part I of this report, the most commonly-considered performance factors in the mode selection processes of transit agencies and MPOs include capacity, speed, and maintenance requirements, followed by schedule type, spatial requirements, energy use, and build time. While a fair amount of data is available related to system performance, it is often difficult to measure performance characteristics due to the numerous external and internal factors influencing transit systems. Nationally aggregated data and case studies can give an idea of how a system might perform in general, but the specific performance outcomes always depend on the context and application of each transit system. Nonetheless, this is a useful first step toward understanding national performance trends. For most of the performance factors of interest, it was necessary to use multiple metrics to gain a comprehensive understanding of the relationships between the performance aspects of various modes of transit.

4.3.1 Capacity

Capacity is determined through a combination of vehicle capacity and frequency, and in some cases (such as productive capacity) speed. In *Urban Transit Systems and Technology*, Vuchic estimated the line capacity and productive capacity of a variety of conventional modes using a theoretical range. For comparison purposes, an average was calculated from the high and the low end of these ranges for several transit modes, as well as for private automobiles to serve as a reference point.

The average line capacity in spaces per hour per direction (s/h/d) for automobiles, which includes taxis, jitneys, demand response, and other small vehicle modes, was 885 on surface streets and 2,200 on freeways. These numbers were based on an assumed 1.2-1.3 passengers per vehicle. The on-freeway value (2,200) was doubled to give an estimate for vanpool and publico modes (4,400), since vehicles used for these modes hold more passengers than regular cars and operate on both highways and surface streets. The case could be made for a higher estimate of vanpool and publico line capacity, but it did not seem logical to estimate a higher line capacity for vanpool than bus, given the smaller vehicles used. Bus, commuter bus, and trolleybus likely have somewhat different capacities, but these were estimated to be 5,200 s/h/d compared to 6,000 for a single bus rapid transit line and 12,000 for a multi-line BRT system with overtaking. Streetcar rail was estimated to have the lowest line capacity among rail modes at 9,500 s/h/d, while light rail was estimated at 13,000, and monorail /

automated guideway modes at 16,400. Regional rail (commuter rail, hybrid rail, etc.) was estimated at 34,000 s/h/d, while heavy rail topped the list at 40,000 (Vuchic, 2007).

Line capacity for several cable-propelled transit (CPT) modes was gathered from one of the major manufacturers of these technologies, Doppelmayr/Garaventa Group. Aerial tramways were said to have a maximum capacity of 500-2,000 s/h/d, so the average of 1,250 was calculated. Funitel systems have a line capacity of about 4,000 s/h/d. Gondola systems come in a variety of types, with the monocable detachable gondola offering a line capacity of about 3,600 and the larger 3S gondola systems offering a line capacity of about 5,000 s/h/d (4,300 average). The CABLE Liner (similar to a modern cable car) offers up to 5,000 s/h/d, while modern inclined rail systems can move as many as 8,000 s/h/d (Doppelmayr Seilbahnen GmbH, 2016). This data is compiled and shown in Figure 4.9. Line capacity for water modes has a huge range based on differences in docks, boats, and frequencies, among other factors.

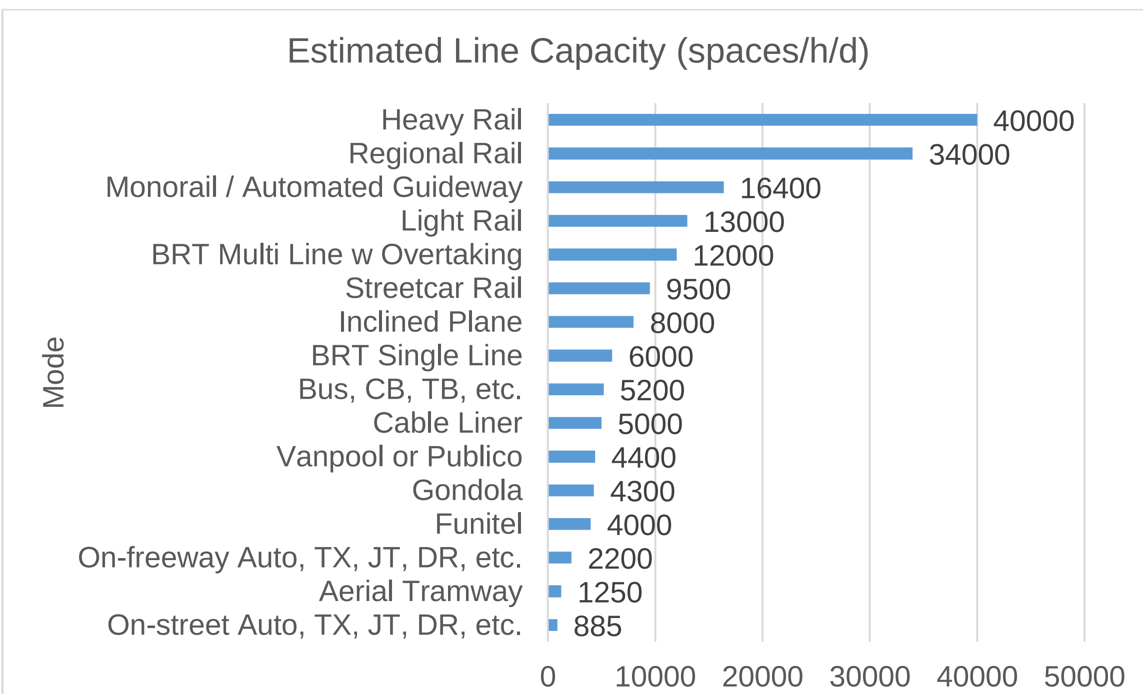


Figure 4.9 – Estimated Line Capacity for Aerial and Surface Modes

Although the capacities shown in Figure 4.9 are theoretically possible, they require investment in enough vehicles, transitways, and station capacity to deliver the stated level of service. Transit systems in the U.S. rarely come close to these stated capacities. For example, although heavy rail can offer more than 40,000 spaces per hour per direction for a single line, even peak 3-minute headways used by some subway lines in the New York City Transit system would require train capacities of 2,000 spaces (generally 12+ vehicle trains) to achieve this level of capacity. Similarly, even New York's Penn Station only offers up to 5 trains per hour to Newark Broad Street (using two different lines), which means that trains would need to have 6,800 spaces each to reach 34,000 spaces per hour per direction, or nearly double that if only a single line is considered (New York City MTA).

The Las Vegas Monorail, one of the highest-capacity monorail / automated guideway systems in the U.S., uses peak headways of 4 minutes. Therefore, to achieve a capacity of 16,400 spaces per hour per direction, trains would need to hold over 1,000 passengers each. The existing system only uses trains with a capacity of 222 including standing spaces, so the peak capacity of this system is 3,330 spaces per hour per direction (Las Vegas Monorail, 2016). The Los Angeles Metro Light Rail system has peak headways of 6 minutes for a single line (Metro, 2016). So for this line to achieve a capacity of 13,000 spaces per hour per direction, trains would have to accommodate 1,300 passengers each. With a maximum of 3-car trains (due to platform size and congestion concerns) and a total train capacity of 432, this system's most frequent line, the Blue Line, only offers a peak capacity of 4,320 spaces per hour per direction (Federal Transit Administration, 2016).

New York City Transit's Select Bus Service is an example of a high-capacity BRT system in the U.S. The First / Second Avenue line uses exclusive lanes with offsets for overtaking, and up to 22 articulated buses per hour (New York City MTA). A maximum vehicle capacity of 106 passengers means that this line offers a peak capacity of 2,332 spaces per hour per direction (Federal Transit Administration, 2016), which is less than one-fifth the average peak capacity taken from Vuchic and shown in Figure 4.9. Streetcar rail is also limited by smaller vehicles, as demonstrated by the Portland Streetcar, which can only accommodate a maximum of 156 passengers per vehicle (Federal Transit Administration, 2016). With no less than 15 minute peak headways, these streetcar lines offer a maximum peak capacity of only 624 spaces per hour per direction, or 1,248 where two lines overlap (Portland Streetcar, Inc., 2016). This capacity is less than one-tenth the stated capacity in Figure 4.9. Many other examples can be found in the U.S. where a transit mode is used in a way that does not come close to the potential capacity of that mode. However, given the right context and sufficient level of investment, these capacities are theoretically possible. How far reality strays from theory depends largely on the individual projects and decisions made by their operators.

Speed is taken into account when estimating productive capacity of a given mode, which is especially useful if one is concerned not merely with how many people can be transported in an hour, but also how far they can be transported in that time. By multiplying the estimated line capacity and average normal speed values from Vuchic and Doppelmayr, average productive capacity was calculated for aerial and surface modes. Based on mode speeds, the ranking of modes based on productive capacity varied slightly from that based on capacity. The results are shown in Figure 4.10.

On-street automobiles, as well as taxis, jitneys, publicos, and demand response vehicles operating on surface streets were estimated to travel at an average of 22 mph, thereby offering about 19,000 s-m/h/d. Bus, trolleybus, and similar modes were estimated to offer productive capacities of 72,800 s-m/h/d, based on an estimated speed of 14 mph. Streetcar rail was estimated to be 95,000 s-m/h/d, using an operating speed of 10 mph. Due to higher travel speeds (estimated 47 mph), on-freeway automobile modes had a higher estimated productive capacity of 103,400 s-m/h/d. Bus rapid transit came next, with estimated speeds of 19 mph and productive capacity of 114,000 s-m/h/d for a single line and 228,000 s-m/h/d for multiple BRT lines with overtaking. Monorail / automated guideway modes (164,000 s-m/h/d) came next, using an estimated speed of 10 mph. Due to much higher speeds than most other transit modes (47 mph), vanpool was estimated to have a productive capacity of 206,800 s-m/h/d. Commuter bus was slightly higher than multi-line BRT in estimated productive capacity (244,400 s-m/h/d), due mostly to estimated speeds of 47 mph. Light rail was estimated to have a productive capacity of 260,000 s-m/h/d, using a speed of 20 mph. Heavy rail was estimated at 26 mph and 1,040,000 s-m/h/d, with regional (commuter and hybrid) rail estimated at 37 mph and 1,258,000 s-m/h/d (Vuchic, 2007).

Using data from Doppelmayr, several more innovative modes were also included in the analysis of productive capacity. The lowest productive capacity of 15,000 space-miles per hour per direction (s-m/h/d) was estimated for aerial tramway due to fairly low capacity and moderate speeds (12 mph typical operating speed used). Funitel system productive capacity was estimated at 48,000 s-m/h/d based on an estimated speed of 12 mph, while gondola had a higher estimate of 51,600 s-m/h/d despite a lower speed of 11 mph. Doppelmayr’s CABLE Liner productive capacity was estimated at 65,000 s-m/h/d, using an estimated operating speed of 13 mph. Inclined plane rail came in at an estimated 10 mph and 80,000 s-m/h/d (Doppelmayr Seilbahnen GmbH, 2016). Most of these estimates of productive capacity also greatly exceed the productive capacity of typical transit systems in the U.S. This is mostly due to lower frequencies and speeds often found in practice than the values used above, which were found to be on the high end of typical operating speeds, including stops, when compared with NTD data.

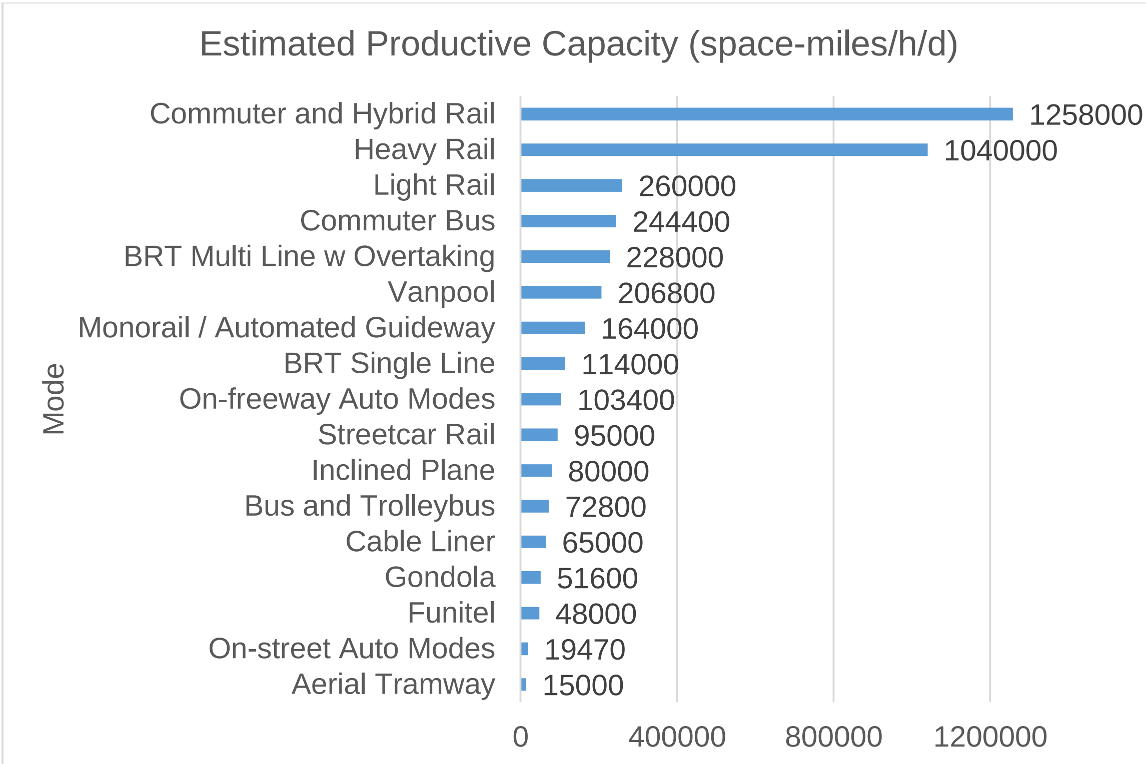


Figure 4.10 – Estimated Productive Capacity for Aerial and Surface Modes

4.3.2 Occupancy

Transit systems do not always operate at full capacity; the offered capacity is determined by the operating entity, including their schedule and level of service. Peak demand is commonly the driving factor for determining needed system capacity, so highly peaked demand patterns may result in empty transit vehicles during off-peak times unless service frequency is reduced outside of peak hours. Occupancy is also closely tied to the efficiency of a transit system, and may be an indicator of how well a system is meeting demand within its service area. Since transit vehicles in the U.S. are rarely filled to capacity, it is important to consider typical passenger loads aboard these vehicles. The weighted average passenger load was calculated for each mode from the NTD data, by dividing the total passenger miles in 2014 by the annual vehicle revenue miles for each mode. The unweighted average passenger load was also calculated by averaging the number of passengers per vehicle across all agencies for all modes, regardless of agency size. Since there are more small agencies than large agencies in the U.S., the unweighted value is more representative of the small agency operating characteristics, while the weighted value is more influenced by large agencies. The results of this analysis are shown in Figure 4.11.

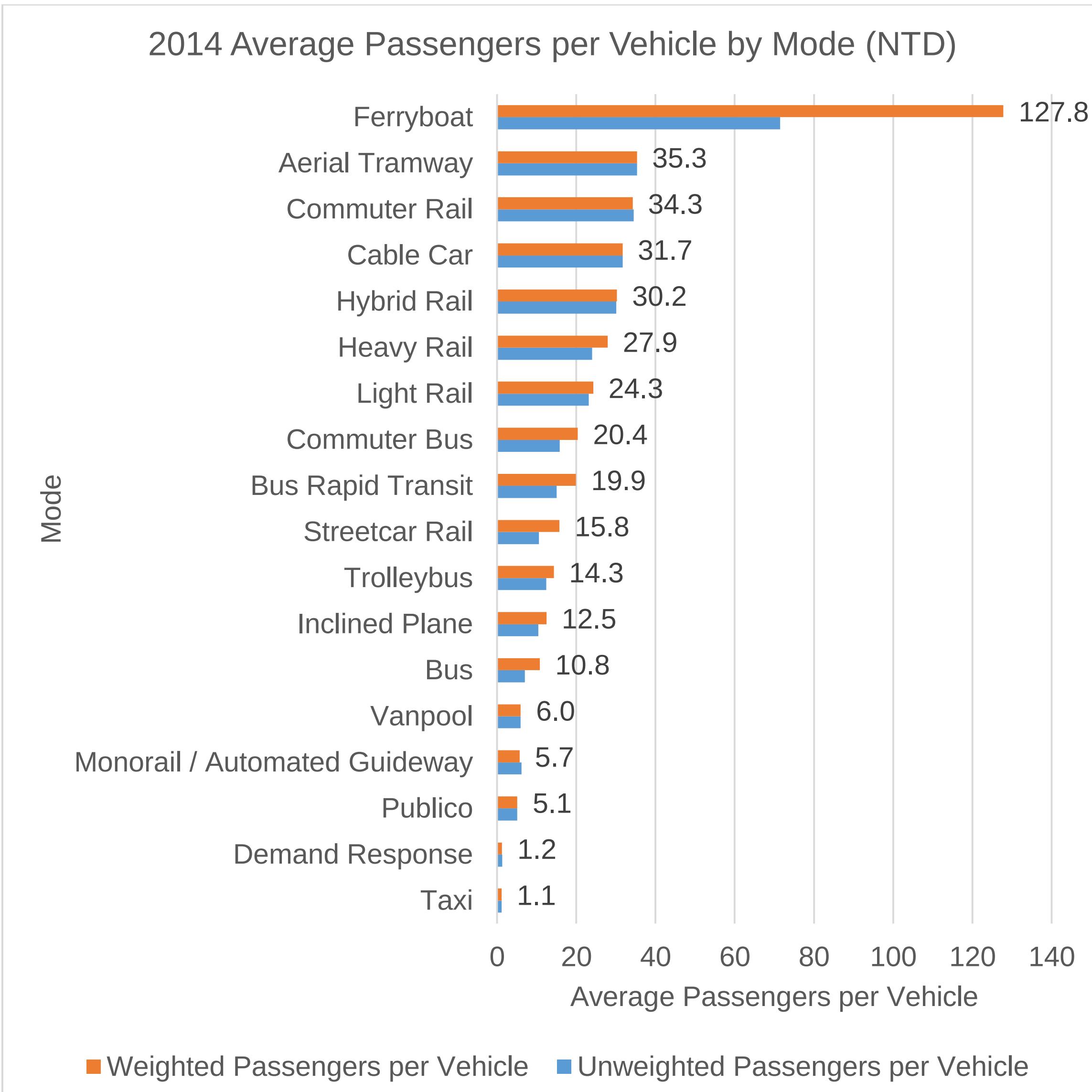


Figure 4.11 – 2014 Average Passenger Load per Vehicle by Mode (Federal Transit Administration, 2016)

This process provided several important insights into transit mode usage. Ferryboat had the highest average passenger load by far, with about 128 passengers per vehicle (p/v) (71 unweighted). The Portland Aerial Tram averaged 35 p/v. Commuter rail was just below aerial tramway with 34 p/v (weighted and unweighted). San Francisco cable cars averaged 32 p/v, which was higher than hybrid rail at 30 p/v (weighted and unweighted), heavy rail at 28 p/v (24 unweighted), and light rail at 24 p/v (23 unweighted). Commuter bus had the next highest average passenger per vehicle, with 20 p/v (16 unweighted), closely followed by bus rapid transit at 20 p/v (15 unweighted). Streetcar rail was next, with 16 p/v (11 unweighted), then trolleybus with 14 p/v (12 unweighted), inclined plane with 12 p/v (10 unweighted), and bus with 11 p/v (7 unweighted). Modes that generally use smaller vehicles also had the lowest average passenger loads (all roughly equal for weighted and unweighted averages), with vanpool and monorail / automated guideway at 6 p/v, publico at 5 p/v, and demand response and taxi each at just over 1 passenger per vehicle (Federal Transit Administration, 2016).

To put the average passenger load per vehicle into perspective, the weighted average vehicle capacity was calculated for each mode, using the NTD vehicle inventory data for 2014, and then these values were compared to the weighted average passenger loads from Figure 4.11 (since both values were ratios of aggregate totals for all the data). The results of this analysis are shown in Figure 4.12. Clearly, much of the transit service provided in the U.S. is going unused. While the average passenger load for a ferryboat in 2014 was 128 (weighted), the average vehicle capacity was actually 664 spaces. Hybrid rail vehicles had the next highest average capacity at 208 spaces, but an average load of only 30 passengers. Light rail vehicles offered an average of 188 spaces for an average load of 24 riders. Commuter rail was close behind in terms of capacity, with an average vehicle capacity of 174 for an average of 34 passengers. Heavy rail vehicle capacity was the fifth highest, with an average of 143 spaces per vehicle to accommodate an average load of 28 passengers (Federal Transit Administration, 2016). Adding density and destinations along existing transit stops could help to improve ridership and occupancy rates, to make more efficient use of our existing infrastructure, which would help fund and support better service and system expansion.

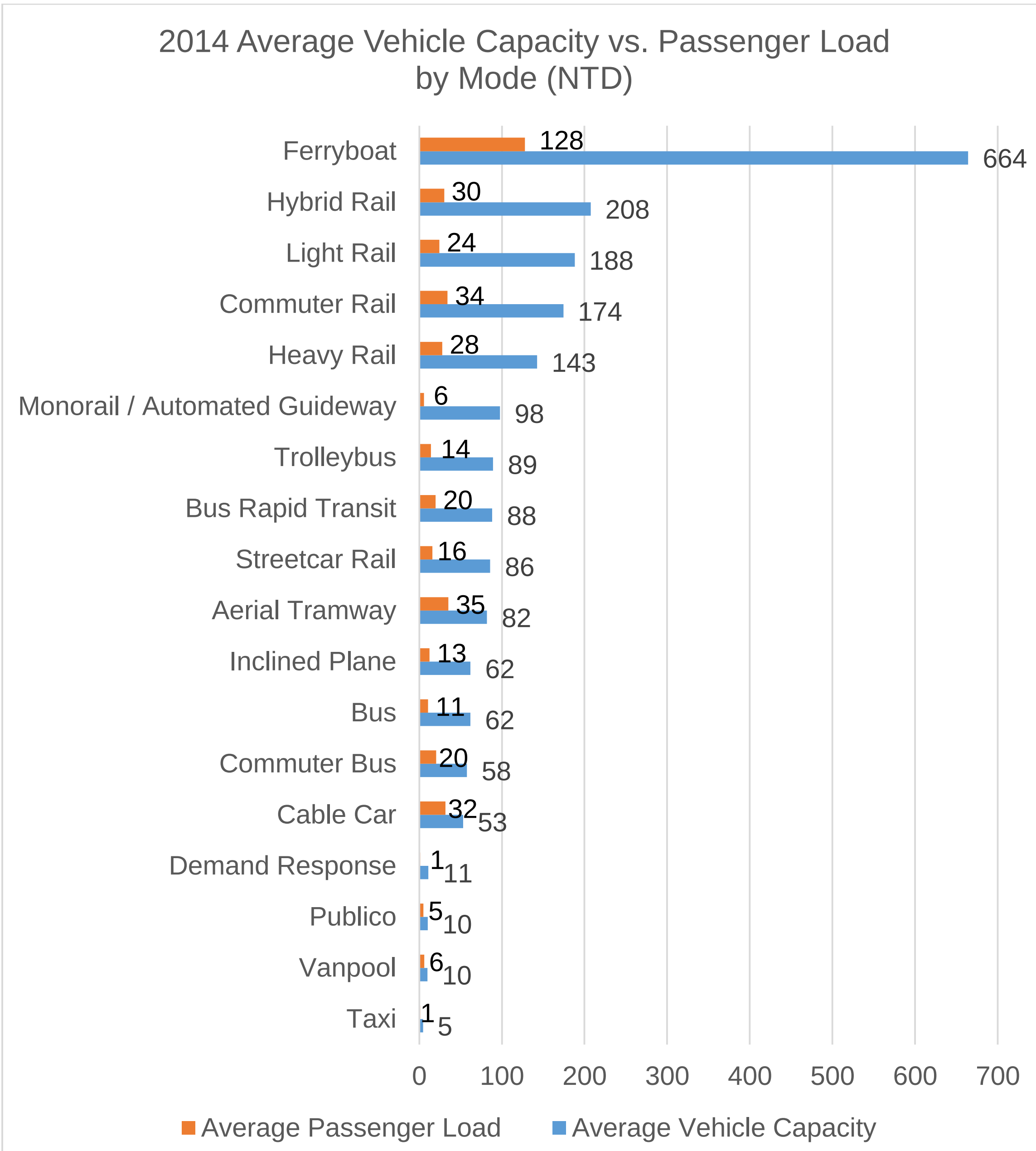


Figure 4.12 – 2014 Vehicle Capacity vs. Passenger Load by Mode (Federal Transit Administration, 2016)

Monorail / automated guideway modes had an average vehicle capacity of 98 spaces, but served only six passengers per vehicle on average. Trolleybus, bus rapid transit, streetcar rail, and aerial tramway all had vehicle capacities between 80-90, but of these the new Portland Aerial Tram had the highest average load of 35 passengers (second overall), followed by BRT with 20, then streetcar with 16, and trolleybus with 14 passengers per vehicle. Inclined plane rail and bus modes each had an average vehicle capacity of 62, but inclined plane had a higher weighted average load (13 passengers) than bus (11 passengers). Commuter bus had a slightly lower vehicle capacity (58), but almost twice the average load (20 passengers) of regular transit buses. The San Francisco cable cars had an average capacity of 53, and the fourth highest average load (32 passengers) (Federal Transit Administration, 2016).

The smallest capacity modes also had the lowest average loads (with the exception of monorail / automated guideway). Demand response vehicles had an average of 11 spaces in 2014, but carried an average of just over one passenger per vehicle. Vanpool and publico both had an average capacity of 10 spaces, with average passenger loads of 6 and 5, respectively. Taxis on average had the lowest capacity of 5 spaces, with only slightly more than 1 passenger per vehicle (Federal Transit Administration, 2016). The ratio of average passengers to vehicle capacity was then calculated as a percent for each mode, as shown in Figure 4.13.

Interestingly, vanpool and cable car tied for the highest average vehicle percent occupancy, at 60%. Publico was next with 49%, followed by aerial tramway with 43% and commuter bus with 35%. No other modes exceeded 25% average vehicle occupancy. Taxi and bus rapid transit had the next highest occupancies of 24% and 23%, respectively. Inclined plane rail, commuter rail, and heavy rail tied at roughly 20%. Then came ferryboat (19%), streetcar rail (18%), bus (17%), trolleybus (16%), and hybrid rail (15%). Light rail (13%), demand response (11%), and monorail / automated guideway (6%) had the lowest percentages of vehicle occupancy of all modes reported.

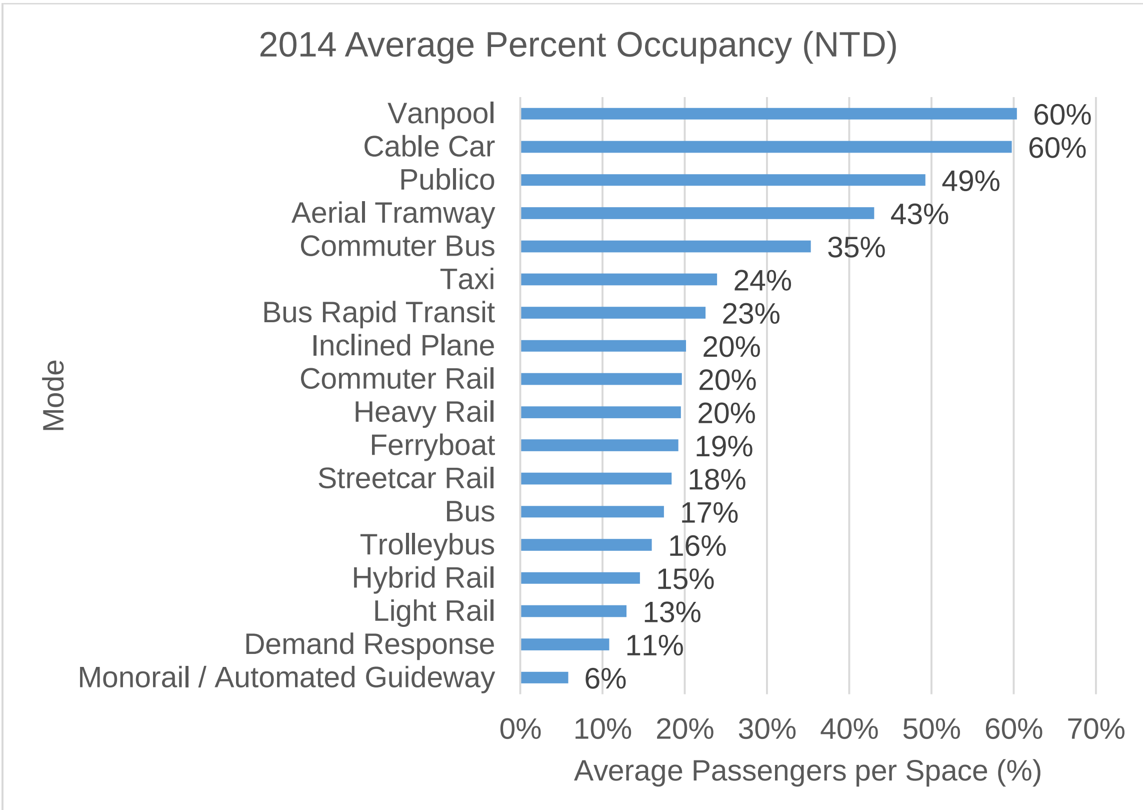


Figure 4.13 – 2014 Average Percent Occupancy (Federal Transit Administration, 2016)

4.3.3 Attraction

Another consideration related to capacity and occupancy is attraction, which can be indirectly measured in terms of vehicle occupancy rates (shown previously), and unlinked passenger trips per vehicle revenue hour (direct measurement would likely involve public input). This metric was calculated for each mode reported in the NTD, from 2011-2014, as shown in Figure 4.14. The most immediate information observed from this chart was the extremely high value calculated for the Portland Aerial Tram (TR), which exceeded 500 trips per vehicle revenue hour in 2014. This could be attributed to many factors, including the novelty of the system, the small number of vehicles (2), and the short distance of trips (less than a mile), but the older Roosevelt Island Tram was attracting about 87 trips per vehicle revenue hour when it was last reported on in 2004, so there does seem to be a high level of attraction to the only two examples of urban aerial transit in U.S. cities (Federal Transit Administration, 2016).

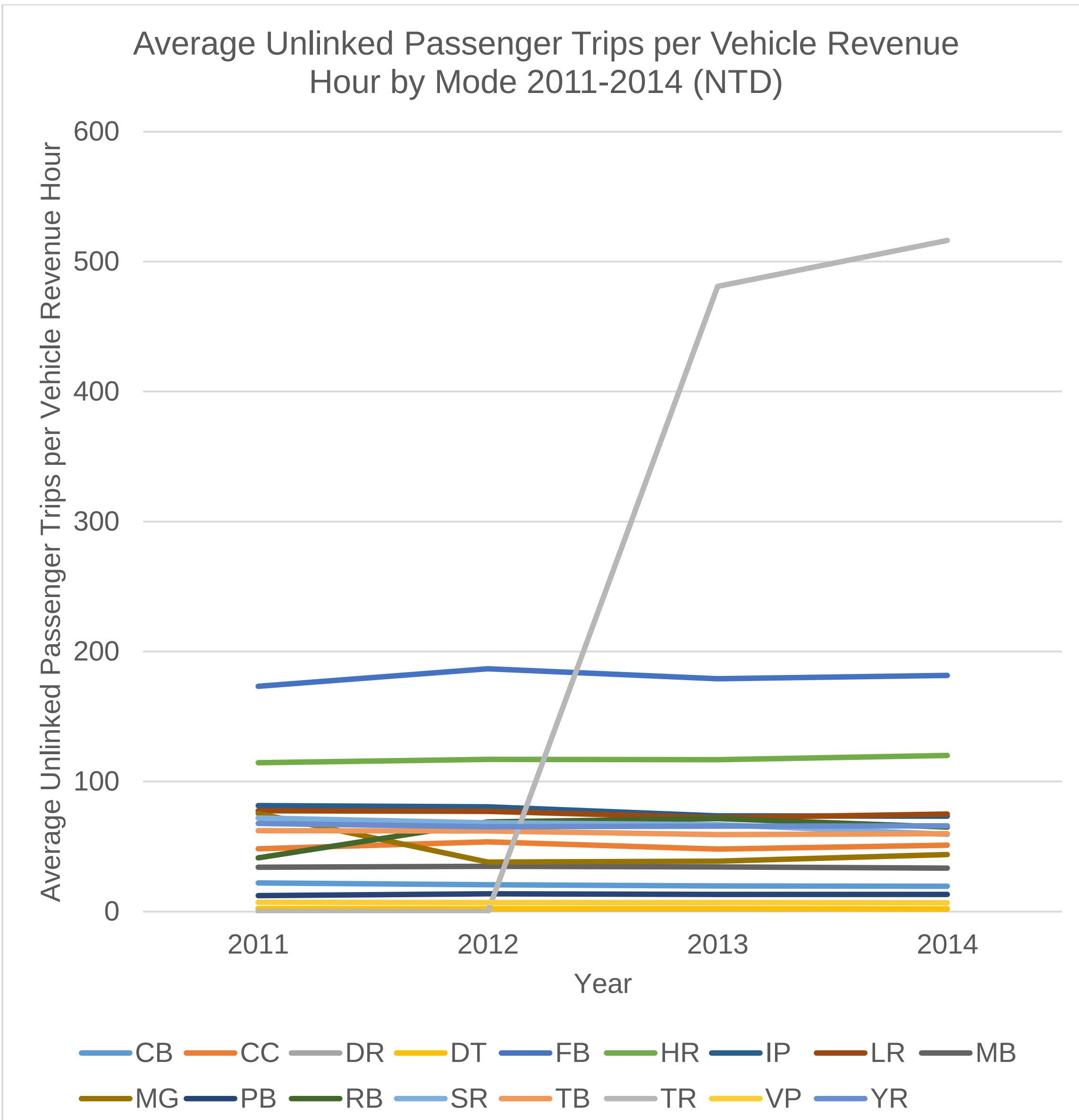


Figure 4.14 – Unlinked Passenger Trips per Vehicle Revenue Hour (Federal Transit Administration, 2016)

Vehicle size plays a role in influencing this metric, as higher vehicle capacity should drive these values up. As shown in Figure 4.15, in 2014 aerial tramway was the national leader in this metric, with 512 passenger trips per vehicle revenue hour, followed by ferryboat (180) and heavy rail (120). Light rail (75) and inclined plane (74) were in the next tier down, followed by bus rapid transit (65). Trolleybus was sixth with 60 trips per vehicle revenue hour, closely followed by streetcar rail (59) and hybrid rail (58). Cable car (51), commuter rail (46), and monorail / automated guideway (44) were the next highest, followed by bus (33) and commuter bus (20). Small vehicle modes, including public (13), vanpool (7), taxi (2), and demand response (2), had the lowest values, likely due in large part to small vehicles and little or no added infrastructure.

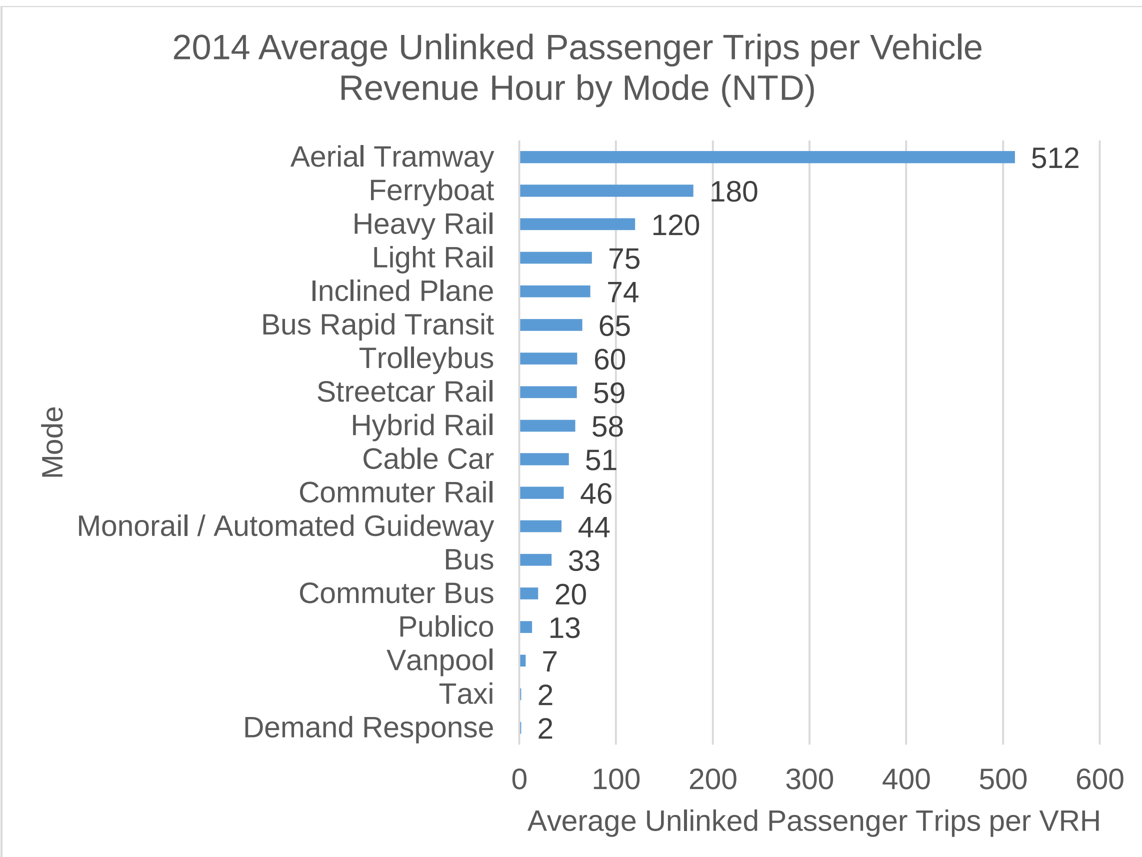


Figure 4.15 – 2014 Unlinked Passenger Trips per Vehicle Revenue Hour (Federal Transit Administration, 2016)

4.3.4 Productivity

Transit vehicle productivity, which can be measured as the average passenger miles per vehicle revenue hour, is also a useful measure of transit mode performance. Vehicles have different characteristics and capital costs, but the cost of operating each vehicle is based largely on the cost of personnel, as well as energy and maintenance costs. More productive vehicles can lead to lower vehicle operator costs per passenger mile (a large vehicle that can be operated by a single person or small crew is better than a small vehicle operated by a single person in this respect), but larger vehicles may have higher fuel and upkeep costs. Figure 4.16 shows the 2014 average passenger miles traveled per vehicle revenue hour for each mode (Federal Transit Administration, 2016).

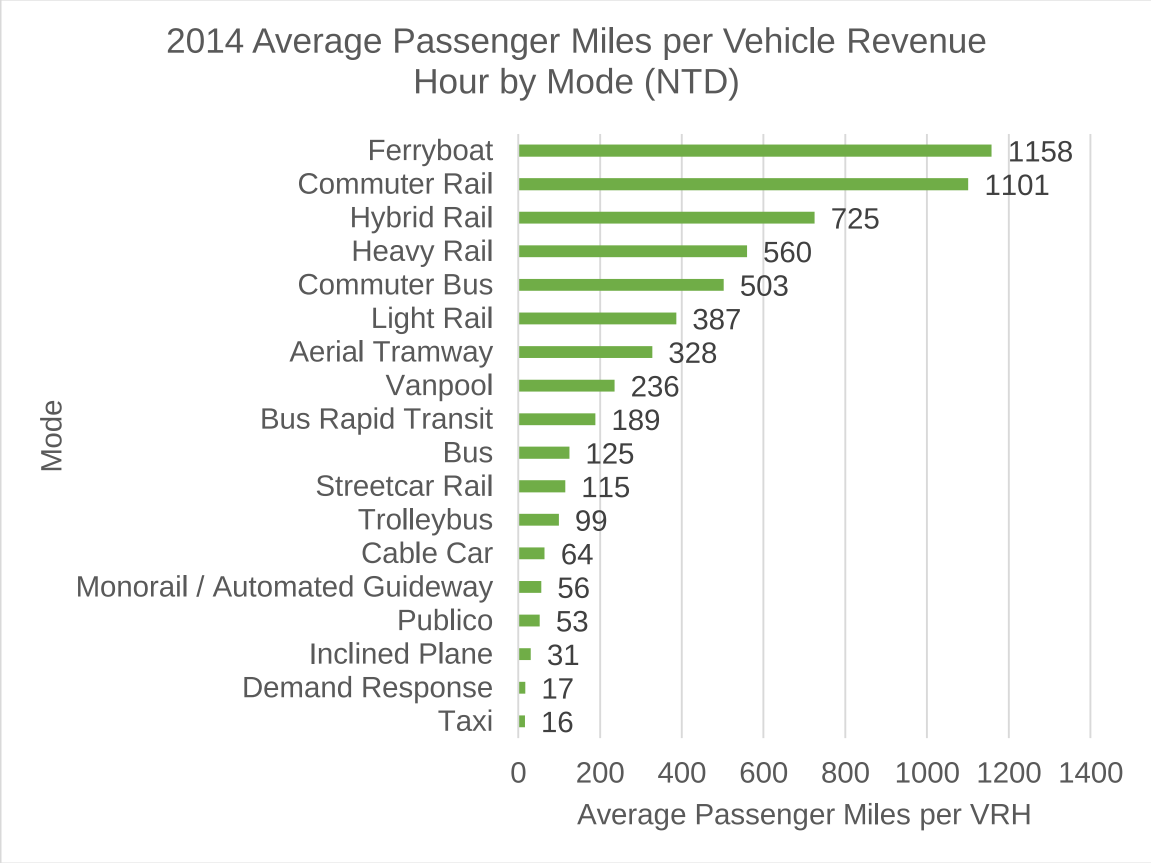


Figure 4.16 – 2014 Average Passenger Miles per Vehicle Revenue Hour (Federal Transit Administration, 2016)

4.3.5 Speed

Using speed to distinguish between transit modes is very common, but metrics that focus on maximum vehicle speeds as opposed to typical operating speeds can be misleading. As shown in Figure 4.17, maximum technical speeds are often much higher than operating speeds for most modes, due to traffic and stopping to serve customers. While maximum travel speeds are important for understanding safety and community impacts of a service, operating speeds are more closely related to customer travel times. Estimates of maximum and operating speeds were mostly based on Vuchic (Vuchic, 2007) using the average of his provided range, but modes marked with an asterisk (*) were based on data from Doppelmayr (Doppelmayr Seilbahnen GmbH, 2016).

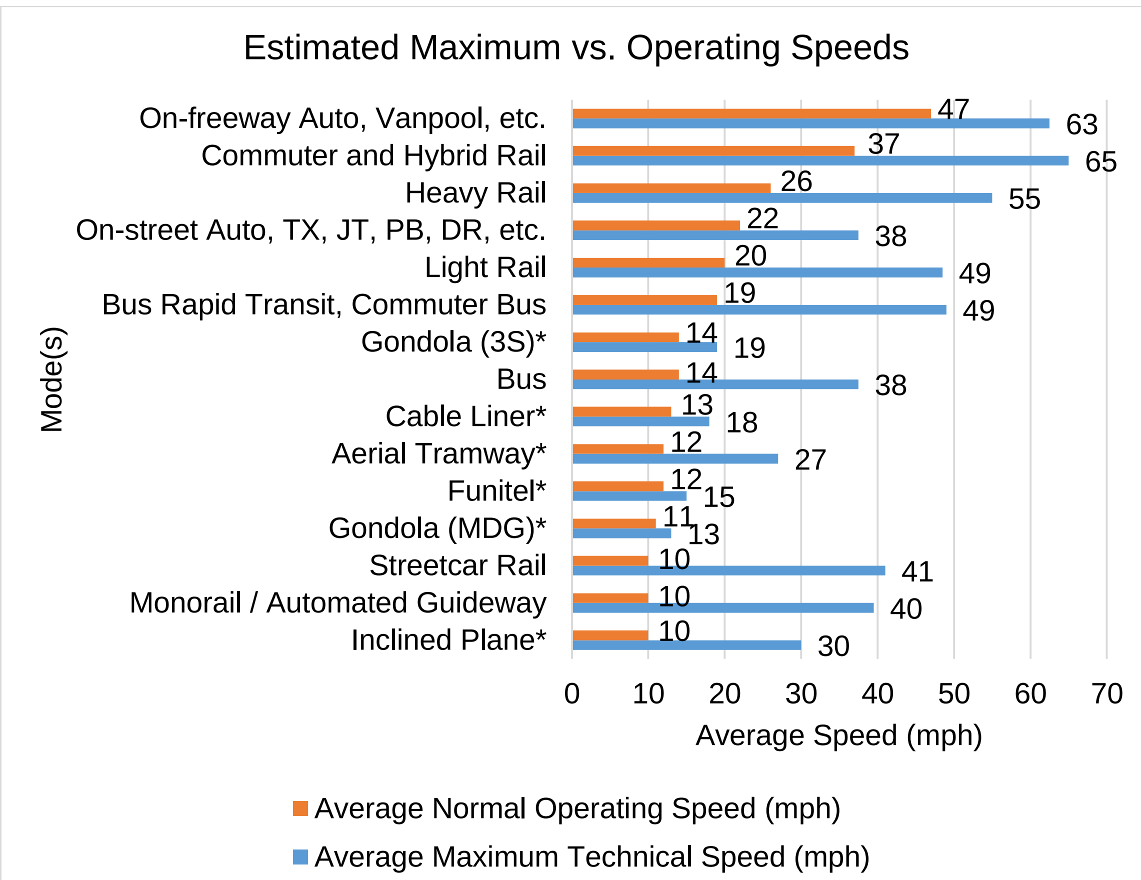


Figure 4.17 – Estimated Maximum Speeds vs. Operating Speeds by Mode

Estimated average speeds were also calculated from the NTD data by dividing the total vehicle revenue miles by the total vehicle revenue hours for each mode. This method includes dwell time, so the calculated values may be lower than what a passenger experiences riding transit without sitting through any lengthy stops. As shown in Figure 4.18, this data verifies and expands upon the information shown in Figure 4.17. Groupings used for the previous estimates are broken apart, revealing that commuter bus tends to operate at higher speeds than bus rapid transit (which here appears to be slower than regular bus). Taxi and demand response were shown to be faster on average than publico, as well as buses (Federal Transit Administration, 2016).

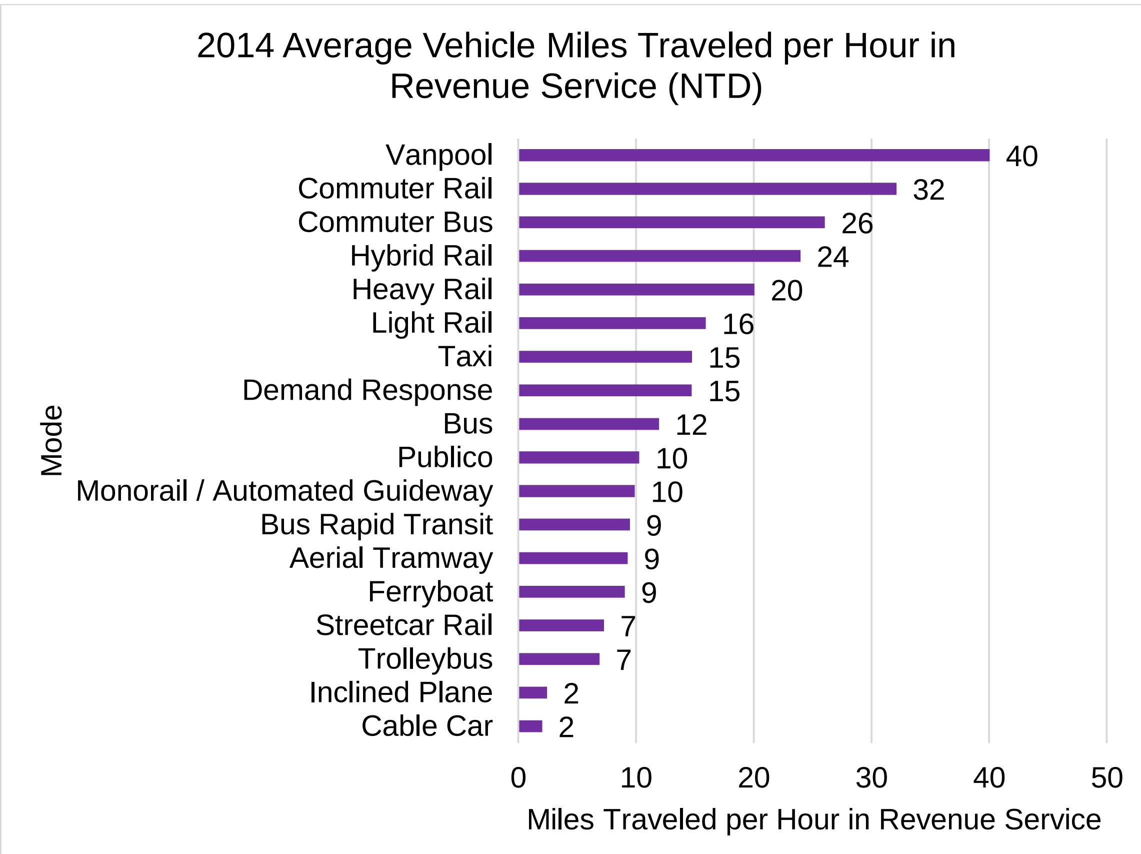


Figure 4.18 – 2014 Average Vehicle Miles Traveled per Revenue Hour (Federal Transit Administration, 2016)

4.3.6 Energy Usage

Lower vehicle occupancy rates often contribute to reduced energy efficiency among transit modes, which can impact revenue and costs, increase pollution and global conflicts over oil, and negatively impact public health. Therefore, energy usage and fuel or power supply should be given serious consideration during the mode selection process. A balance should be sought between performance and energy efficiency, depending on the purpose and context of each project. Planners and engineers should aim to design and use systems that are the right size for the job, while allowing for future growth as needed. For 2014, Figure 4.19 shows the average energy consumed per passenger mile among transit modes reported to the NTD.

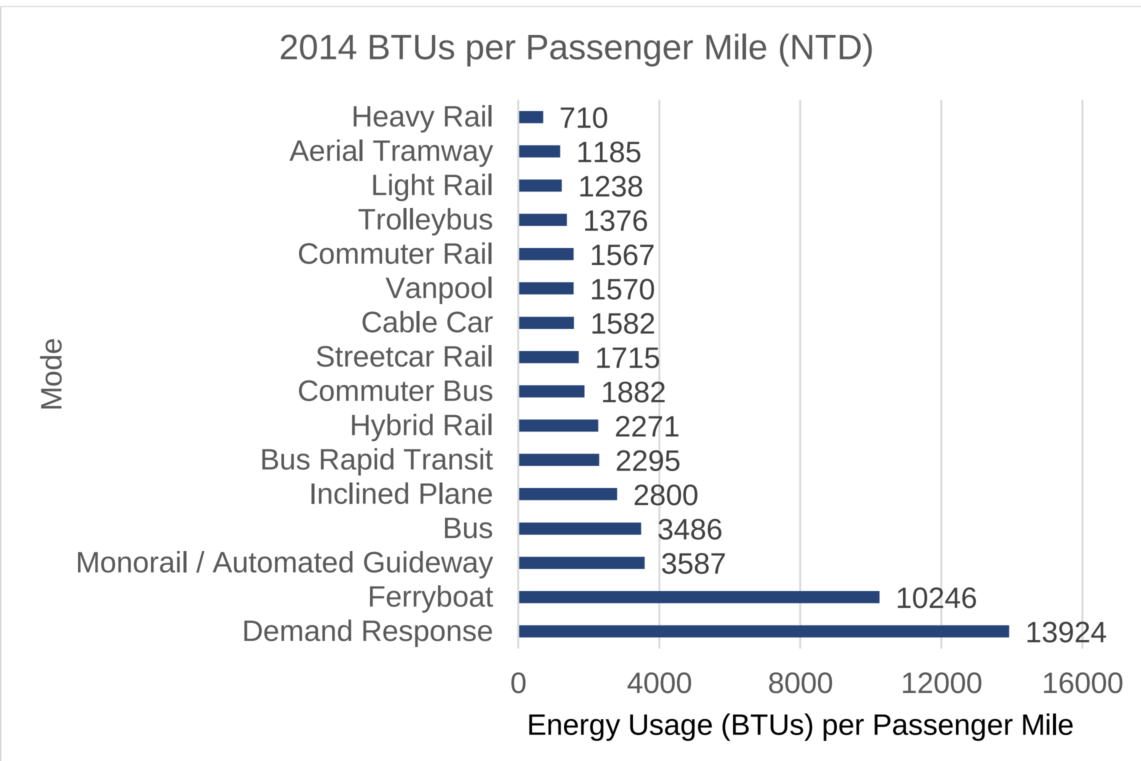


Figure 4.19 – 2014 Average Energy Usage per Passenger Mile by Mode (Federal Transit Administration, 2016)

As shown, heavy rail was the most energy efficient mode reported in the NTD, followed by aerial tramway, light rail, and trolleybus. Commuter rail, vanpool, and cable car were all fairly close with just over 1,550 BTUs per passenger mile. Commuter bus, hybrid rail, and inclined plane all performed better than regular buses, the workhorse of most American transit systems. Demand response and ferryboat were the least energy efficient, followed by monorail / automated guideway and bus (Federal Transit Administration, 2016). Low vehicle occupancy was clearly a determining factor for all these modes, but ferryboat may have been impacted by the fact that many ferry services allow vehicles aboard the ship, rather than just people and their belongings. While boats may use wind energy, currents, and other means to improve their efficiencies, many urban water transit services rely on diesel fuel and may travel against water currents.

Aerial modes not yet used in major U.S. cities appear to be the most energy efficient of all, with the continuously-moving cable used for propelling gondolas and funitels offering advantages over stop-and-go aerial tramways. Of the three aerial modes included in this report, gondolas seem to be the most efficient, with at least one example of a high-capacity (3,800 s/h/d) 3S gondola system using as little as 212 BTUs per passenger mile, according to the manufacturer (Doppelmayr Seilbahnen GmbH, 2016). Also this figure is not exactly comparable to the data from the NTD, it points to a great opportunity for cities in the U.S. and around the globe to improve the energy efficiency of their transit systems. Efficiency is the first step toward a clean energy economy.

4.3.7 Maintenance

Maintenance is another important factor that should be accounted for in the mode selection process. The NTD provides data on the number of major mechanical failures (MMF) and other mechanical failures (OTF), which were scaled using the vehicles operated in maximum service (VOMS) for each surface mode and ferryboat. The results are shown in Figure 4.20.

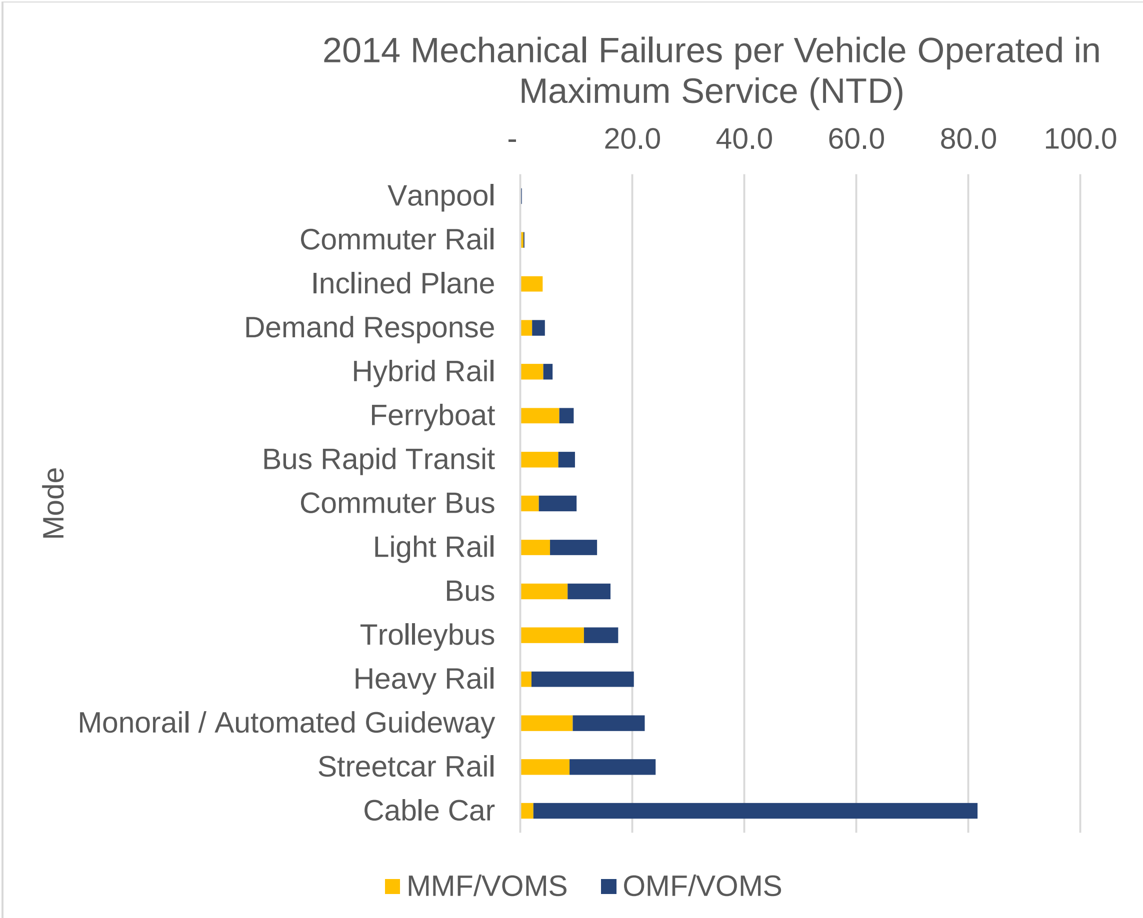


Figure 4.20 – 2014 Mechanical Failures per Vehicle Operated in Maximum Service (Federal Transit Administration, 2016)

In 2014, Vanpool had the lowest rate of mechanical failures per vehicle operated in maximum service with only 0.3 total revenue service mechanical failures per vehicle operated in maximum service (TRSMF/VOMS) (31% major failures), followed by commuter rail with 0.7 TRSMF/VOMS (69% major failures). Inclined plane had the third lowest rate (4.0 TRSMF/VOMS), but all of the reported failures were major failures. Demand response was a close fourth with 4.4 TRSMF/VOMS (46% major failures). Hybrid rail was next with 5.8 TRSMF/VOMS (72% major failures), followed by ferryboat with 9.5 TRSMF/VOMS (69% major failures), bus rapid transit with 9.8 TRSMF/VOMS (60% major failures), and commuter bus with 10.1 TRSMF/VOMS (29% majors failures).

Light rail (13.7, 39%), bus (16.1, 52%), and trolleybus (17.5, 65%) were next, followed by heavy rail (20.3, 18%), monorail / automated guideway (22.2, 41%), and streetcar rail (24.1, 22%). The historic San Francisco Cable Car system had the highest failure rate of 81.6 TRSMF/VOMS, which is not surprising given that the system was originally installed in the late 1800s. Interestingly, cable car had the lowest rate of major failures by far, at only 3%, followed by heavy rail (18%) and streetcar rail (22%) (Federal Transit Administration, 2016). Based on the data shown and common sense, it can be argued that water modes and modes that use shared public right-of-way have an inherent advantage with regard to maintenance, since their infrastructure maintenance burdens are comparatively lower than modes that require maintenance of exclusive right-of-way. In such cases, vehicle maintenance is the dominating system maintenance concern.

Unfortunately comparable values for aerial modes could not be calculated due to a lack of data, but several insights were gleaned from *Cable Car Confidential*. Routine preventative maintenance is needed with aerial modes, as with other transit modes, to minimize the risk of failure. Short-term maintenance needs can be performed during off-hours, while a system shutdown and thorough inspection should take place annually and as needed. Aerial tramway, unlike funitel or gondola, can keep one line operational while the other is closed for major repairs (since there are usually at least two independently operated lines). Funitels are the newest and most complex of the three aerial technologies included in this report, and “possess the highest operations and maintenance costs of any aerial cable system, largely due to increased energy and maintenance costs”. It is also reported that most components of aerial transit systems are designed to last 20 to 30 years, while towers and stations can last for up to 50 years. The longevity of aerial transit is comparable to rail and better than buses. However, heavy use can lead to major part replacements throughout the life of the system. Some steel cables may need to be replaced every 7-14 years (Creative Urban Projects, 2013).

4.3.8 Schedule Type

Schedule type is discussed here as being either on-demand or fixed, though "fixed" represents schedule and headway type service and not all "on-demand" services are immediately available. Demand response services, for example, often require reservations hours or even days in advance, making them less available, convenient, and flexible than other on-demand services. Funitel and gondola cars are continuously circulating, so patrons walk up, pay their fares, and get on, unless there happens to be a (usually short) line. Some modes can be used for "either" on-demand or fixed service. Fixed schedule service often involves some amount of waiting and uncertainty, but frequent services (typically headway-based) can reduce waiting times enough to be competitive with wait times for taxis and various other on-demand services. Table 4.1 shows transit modes divided into on-demand, either, and fixed categories. These categories should not be thought of rigidly, as bus vehicles can certainly provide on-demand services (as with some shuttles and flex services) and so forth, but the general definitions and uses of these modes place them roughly into these categories.

Table 4.1 – Transit Modes by Schedule Type

On-Demand	**Either**	**Fixed**
Demand Response	Aerial Tramway	Bus
Funitel	Automated Guideway	Bus Rapid Transit
Gondola	Ferryboat	Cable Car
Jitney	Inclined Plane	Commuter Bus
Publico	Maglev Rail	Commuter Rail
Taxi	Monorail	Heavy Rail
Water Taxi	Vanpool	Hybrid Rail
		Light Rail
		Streetcar Rail
		Trolleybus
		Water Bus

4.3.9 Spatial Requirements

Spatial characteristics of transit modes include acceptable operating environments (aerial, terrestrial, or aquatic), stop or station spacing, the right-of-way needed to accommodate a given mode, and gradient and turning capabilities of transit vehicles. The operating environment is fairly straightforward, in that aerial modes can go over almost anything, surface modes travel over land, and water modes travel in the water. However, some surface modes can be elevated, at-grade, or underground. Furthermore, amphibious vehicles allow for travel on land and through water bodies.

Stop or station spacing is highly context-sensitive and dependent upon system planning and design. However, spacing typically falls within a range for each mode. Average stop spacing recommendations were developed based on data from *Urban Transit Systems and Technology* (Vuchic, 2007) and *Cable Car Confidential* (Creative Urban Projects, 2013). Quarter-mile stop spacing is common among bus, trolleybus, and streetcar rail modes. Bus rapid transit and light rail tend to have station spacing closer to half a mile (Vuchic, Urban Transit Systems and Technology, 2007), with most aerial modes falling between 0.25 and 0.5 miles (Creative Urban Projects, 2013). Heavy rail stations tend to be roughly 0.75 miles apart, while monorail, low-speed maglev, and automated guideway systems typically have stations about every mile. Commuter, high-speed maglev, hybrid, and regional rail systems have larger stop spacing of every 1-5 miles (Vuchic, 2007).

Vehicle widths impact the lane width needed to safely operate, such that larger vehicles can be more difficult to accommodate in a space-limited right-of-way. Lane width is primarily a consideration for surface modes. Estimated lane widths based on Vuchic are shown in Table 4.2 (Vuchic, 2007).

Table 4.2 – Estimated Minimum, Maximum, and Average Lane Widths (Vuchic, 2007)

Mode	Minimum Lane Width (ft.)	Maximum Lane Width (ft.)	Average Lane Width (ft.)
Monorail / Automated Guideway	6.5	10.5	8.5
Inclined Plane	7.5	11.5	9.5
Streetcar Rail	9	11	10
On-street bus and auto transit modes*	9	12	10.5
Light Rail	11	12	11.5
On-freeway bus and auto transit modes*	12	13	12.5
Maglev Rail	12	13	12.5
Heavy Rail	12	14	13
Commuter Rail, Hybrid Rail	13	16	14.5
**Includes: Bus (MB, BRT, CB, TB) and Auto (DR, JT, PB, TX, VP) transit modes*			

As shown in the table, monorails and small automated guideway systems have a distinct advantage in fitting within the urban environment. The cost of elevating monorail / automated guideway systems is lower, in terms of materials and aesthetic impacts, and, like most electric rail modes, they can be elevated, at-grade, or underground. Inclined plane and modes operating on surface streets, such as streetcar rail, bus, trolleybus, taxi, vanpool, and demand response, can all fit within a typical lane width (11 feet). Light rail corridors tend to need about 11 to 12 feet. Modes that use larger vehicles and operate at higher speeds tend to need wider lane widths of 12 to 15 feet (Vuchic, 2007).

Aerial modes do not require a particular lane width, but rather space for support towers and stations on the ground and space for cars to move without interference at the design height (which can vary along the route). The width of a system is dependent on the design and performance characteristics of that system, but since space is generally more available above ground than on the surface in an urban area, finding space to accommodate aerial modes is often straightforward. Monocable detachable gondolas

(MDG) generally have the smallest tower footprint, with tower diameters ranging from 2-5 feet, but also the shortest distances between towers (2,500 feet as a typical maximum value). Funitel systems have larger support towers, with 6.5-10 foot diameters, but also larger spacing of up to 3,250 feet. Faster 3S gondola systems often use a rectangular lattice tower structure measuring about 15-18 feet on a side, but these towers can be placed up to 10,000 feet apart. Information specific to aerial tramway footprints was not available. Typical aerial mode tower heights range from 50-300 feet (Creative Urban Projects, 2013). Right-of-way needed for water modes ranges widely and depends on the size and weight of the boat at capacity, relative to the available clearances (height, width, depth) along a waterway, including at tidal extremes in coastal areas.

While minimum turning radii for many surface and water modes depends entirely on the vehicle capabilities and design speeds of their operating environment, some modes are more constrained than others. Recommended minimum horizontal curve radii were developed based on Vuchic, as shown in Table 4.3. It is clear that bus and short-train rail modes can navigate turns more easily than larger and longer trains on regular tracks (Vuchic, 2007).

Table 4.3 – Recommended Minimum Horizontal Curve Radii (Vuchic, 2007)

Mode	**Recommended Minimum Horizontal Curve Radius (feet)**
Demand Response, Jitney, Publico, Taxi, Vanpool	15
Bus, Bus Rapid Transit, Commuter Bus	30
Trolleybus	40
Streetcar Rail	60
Light Rail	80
Maglev Rail	200
Monorail / Automated Guideway	230
Heavy Rail	400
Inclined Plane	650
Commuter Rail, Hybrid Rail	725

Turning is not preferred for most aerial modes, as it is typically only possible through the use of turning (angle) stations, which are often more complex and expensive than regular (straight) stations. Dual-direction gondolas, which are more commonly used in the urban environment, can only change direction within turning stations, which may or may not allow passengers to board or alight. However, unidirectional gondola systems can make even sharp turns (>270 degrees) at turning towers. Aerial tramway systems are not able to make turns, so they are the least flexible aerial mode in terms of routing.

Lastly, maximum gradient is a key concern for transit systems, especially for rail modes. Table 4.4 shows the minimum and recommended maximum gradient for each surface and aerial mode as a percent (100% = 1:1 slope). While rail modes may be more stable in inclement weather, they are only capable of ascending or descending grades of 0-6% safely in most cases. Regional rail modes are even more limited at a maximum recommended gradient of only 4% (Vuchic, 2007). Maglev rail is the most capable of the rail modes, with the ability to ascend and descend slopes up to 8% (Rotem, 2004).

Table 4.4 – Minimum and Recommended Maximum Gradients

Mode	**Minimum Gradient (%)**	**Maximum Recommended Gradient (%)**
Commuter Rail, Hybrid Rail	0%	4%
Bus, Bus Rapid Transit, Commuter Bus, Heavy Rail, Light Rail, Streetcar Rail	0%	6%
On-freeway: Demand Response, Jitney, Publico, Taxi, Vanpool	0%	7%
Maglev Rail, Trolleybus	0%	8%
Monorail / Automated Guideway	0%	10%
On-street: Demand Response, Jitney, Publico, Taxi, Vanpool	0%	15%
Aerial Tramway, Funitel, Gondola	0%	100%
Inclined Plane	10%	100%

Rubber-tired modes are capable of ascending and descending much steeper gradients, thanks to higher friction forces. Even buses and trolleybuses have been operated on slopes up to 20% in cities like San Francisco. However, in areas that may experience snow and ice, maximum gradients of 6-8 percent are recommended for bus modes. Trolleybuses are faster and quieter when ascending steep grades, so they are generally preferable to regular buses for use on hilly terrain. Smaller vehicles, such as vans and private automobiles, may be required to ascend or descend steeper gradients, but common practice in North America is to limit freeways to 7% gradients or less and surface streets to 15% or less. Of course there are exceptions to the road design guidelines as well.

Some monorail and automated guideway systems designed in recent years have demonstrated the ability to ascend and descend gradients of 10-15%, especially when they are rubber-tired, suspended, or cable-propelled. Aerial modes are by far the most flexible for overcoming steep gradients, with many systems built on terrain with an average gradient of more than 80%. Through careful design, aerial and inclined plane modes can overcome gradients in excess of 100%. However, while inclined plan systems do require some amount of incline (otherwise they're essentially standard rail systems), aerial modes may be operated over completely flat terrain, such as when crossing a water body (Doppelmayr Seilbahnen GmbH, 2016).

4.3.10 Other Performance Factors

Many additional performance factors could be considered during a transit mode selection process, as much more data on performance does exist or could be calculated. However, information regarding the length of time it takes to implement a transit project, from initial conception, through planning, engineering, funding, and construction, was surprisingly scarce. This may be due to the fact that transit projects in the United States are highly variable and often take years, if not decades, to complete. A recent analysis of the development processes for projects that received FTA funding showed that the time from selection of a locally preferred alternative through project development to the awarding of construction funding took anywhere from 2-14 years. Projects taking more than 10 years used bus rapid transit and commuter rail as the selected modes, and these values didn't even include the initial planning phases or system construction. One of the main challenges that project leaders must overcome during this time is to secure local matching funds in order to qualify for FTA funding, which has been known to delay projects for more than 10 years in some cases. Federally funded projects must also go through the NEPA process, which can take a couple years depending on the scope and setting of the project (United States Government Accountability Office, 2014).

Transit expansion and enhancement projects can be accomplished more quickly without FTA funding, though local entities may not be able to cover the costs of major infrastructure projects without federal funds. Smaller systems, such as aerial and water modes, and surface modes that do not require a great deal of new infrastructure, such as bus routes, can be more easily implemented through local agencies and partnerships. Non-automated surface and water modes tend to have higher labor costs than automated surface modes and aerial transit, so it is critical that transit operators have funding available to cover the cost of drivers and support staff. Surface modes requiring infrastructure development can negatively impact communities during the construction phase, especially as roadwork may lead to traffic disruptions and delays. Generally speaking, the shorter and less impactful the construction phase, the better for the community. Aerial CPT modes, though they require towers and stations to be built, seem to cause less disruption than, for example, streetcar rail, and can be designed relatively quickly and constructed within a year (Creative Urban Projects, 2013). Many infrastructure-intensive projects, by contrast, cause major disruptions on the ground and may take several years or decades to plan, and at least a few years to build.

4.4 Environmental Factors

Data on the environmental impacts of transit systems is strikingly limited when compared to the abundance of data relating to performance and economic factors. While energy data was used to estimate carbon dioxide emissions and compare fuel sources, other environmental factors are discussed generally below.

4.4.1 Emissions

Although all transit modes that run on fossil fuels directly, or electricity produced from conventional sources, lead to the release of a variety of pollutants being released into the air, the focus of this section is on carbon dioxide emissions. One reason for this decision was the availability of data, but the other is that, while air quality in U.S. urban areas has generally improved since the 1970s, climate disruption continues to be an ever more pressing and significant threat. Carbon dioxide is a major contributor to warming climatic trends, and the transportation sector is a large contributor to global emissions.

The most comprehensive analysis of typical carbon dioxide emissions per passenger mile discovered in the literature review came from the American Bus Association (ABA). Since the ABA is focused on promoting the use of motorcoaches, the data gathered from their report was compared with values calculated using the NTD dataset. Indeed, the ABA data for motorcoaches included those used for private charters, tours and sightseeing, inter-city service, and commuter services, which may have higher occupancy rates and efficiencies than transit and commuter buses. Their results show motorcoaches as the mode with the lowest energy consumption and emissions per passenger mile (MJB&A, 2014), as shown in Figure 4.21. This may not actually be the case when it comes to public transit buses. As shown in Figure 4.22, the data taken from the NTD was used to estimate emissions per passenger mile through U.S. EIA CO_2 emissions coefficients (U.S. Energy Information Administration, 2016).

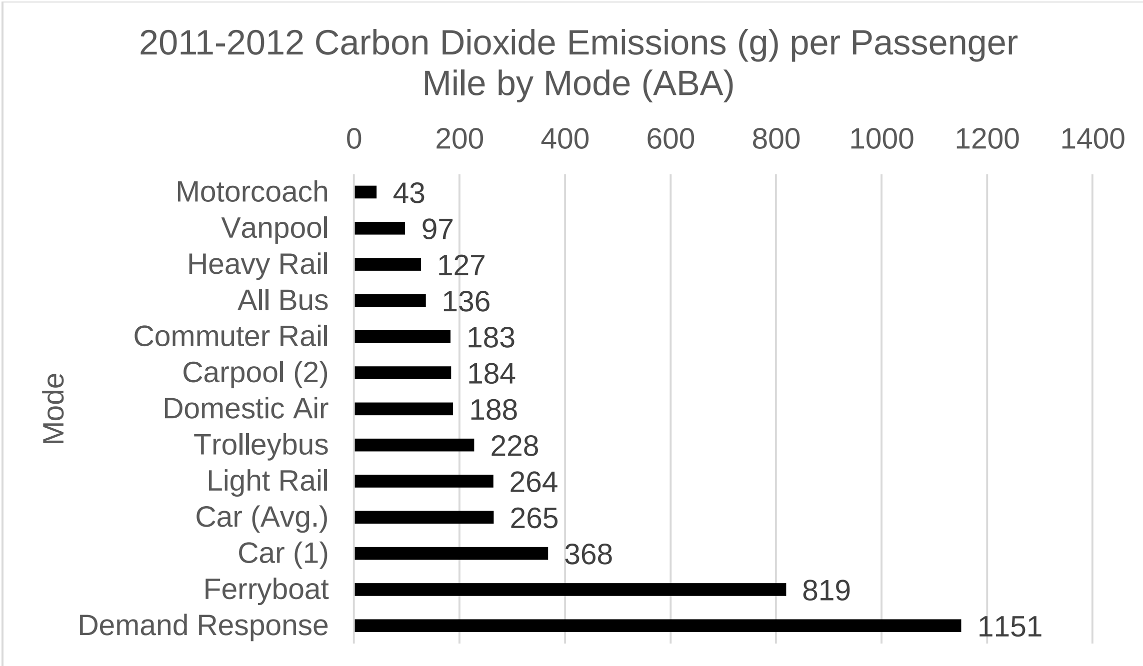


Figure 4.21 – 2011-2012 CO_2 Emissions per Passenger Mile by Mode (MJB&A, 2014)

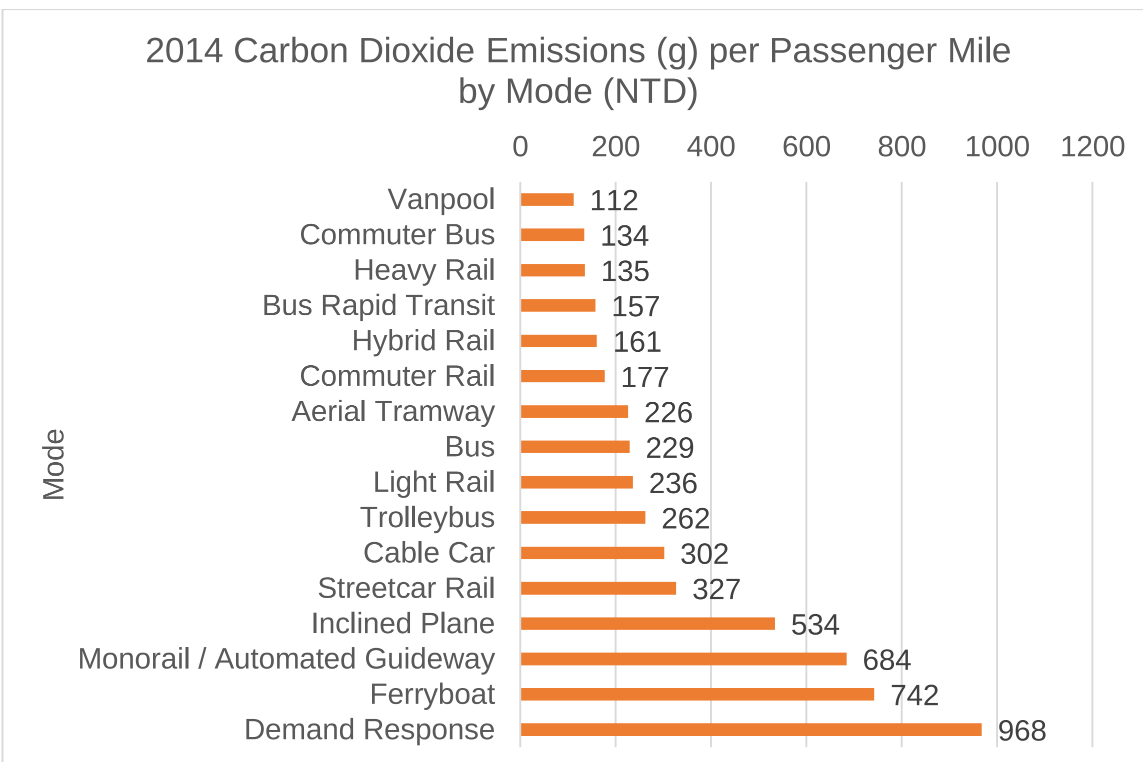


Figure 4.22 – 2014 CO_2 Emissions per Passenger Mile by Mode (Federal Transit Administration, 2016)

Based on the NTD data, vanpool had the lowest emissions per passenger mile of any mode reported to the NTD, followed by commuter bus, and then heavy rail. The all-electric modes actually performed worse in terms of estimated emissions than they did for energy efficiency, due in large part to the conventional fossil fuels (coal, natural gas, etc.) used to produce most of the electricity in the United States. If clean energy sources, such as solar and wind, were used to produce the electricity powering these systems, then the emissions would drop significantly. Bus rapid transit, hybrid rail, and commuter rail had the next lowest CO_2 emissions per passenger mile, followed by aerial tramway, bus, light rail, and trolleybus. The San Francisco Cable Cars performed better than streetcar rail in the U.S. on average, likely due in large part to higher occupancy rates. Inclined plane performed substantially worse than streetcars in terms of emissions, though this could be attributed to their age and steep ascents. Monorail / automated guideway had higher estimated emissions than inclined place, due in part to the very low occupancy rate (6% average nationally). Ferryboat and demand response modes had the highest estimated emissions overall (Federal Transit Administration, 2016).

While the results shown in Figure 4.21 varied somewhat from those shown in Figure 4.22, both were shown for comparison and verification purposes. Several modes were not included in either dataset, and data on emissions from these modes is very limited. However, if the value of 212 BTUs per passenger mile from Doppelmayr is taken to be representative of urban gondola system energy use (it could be a best-case scenario), then gondolas would have the lowest emissions of all transit modes, at just over 40 grams per passenger mile (Doppelmayr Seilbahnen GmbH, 2016). Although they are not yet common in U.S. cities, gondolas seem to offer the greatest potential of any mode included in this report to improve energy efficiency and reduce carbon dioxide emissions of urban transportation systems. Emissions from vehicle and system manufacturing, paving, and other lifecycle activities were not included in this analysis.

4.4.2 Fuel / Power Supply

Fuels and electricity sources used to power various transit systems should also be considered. Dense urban areas, especially non-attainment areas, may suffer from smog and other forms of air pollution. So while electric modes are not entirely emissions-free, they are able to keep from adding to the emissions released in heavily populated areas. As shown in Figure 4.23, transit modes can be classified as all-electric or diverse fuel modes.

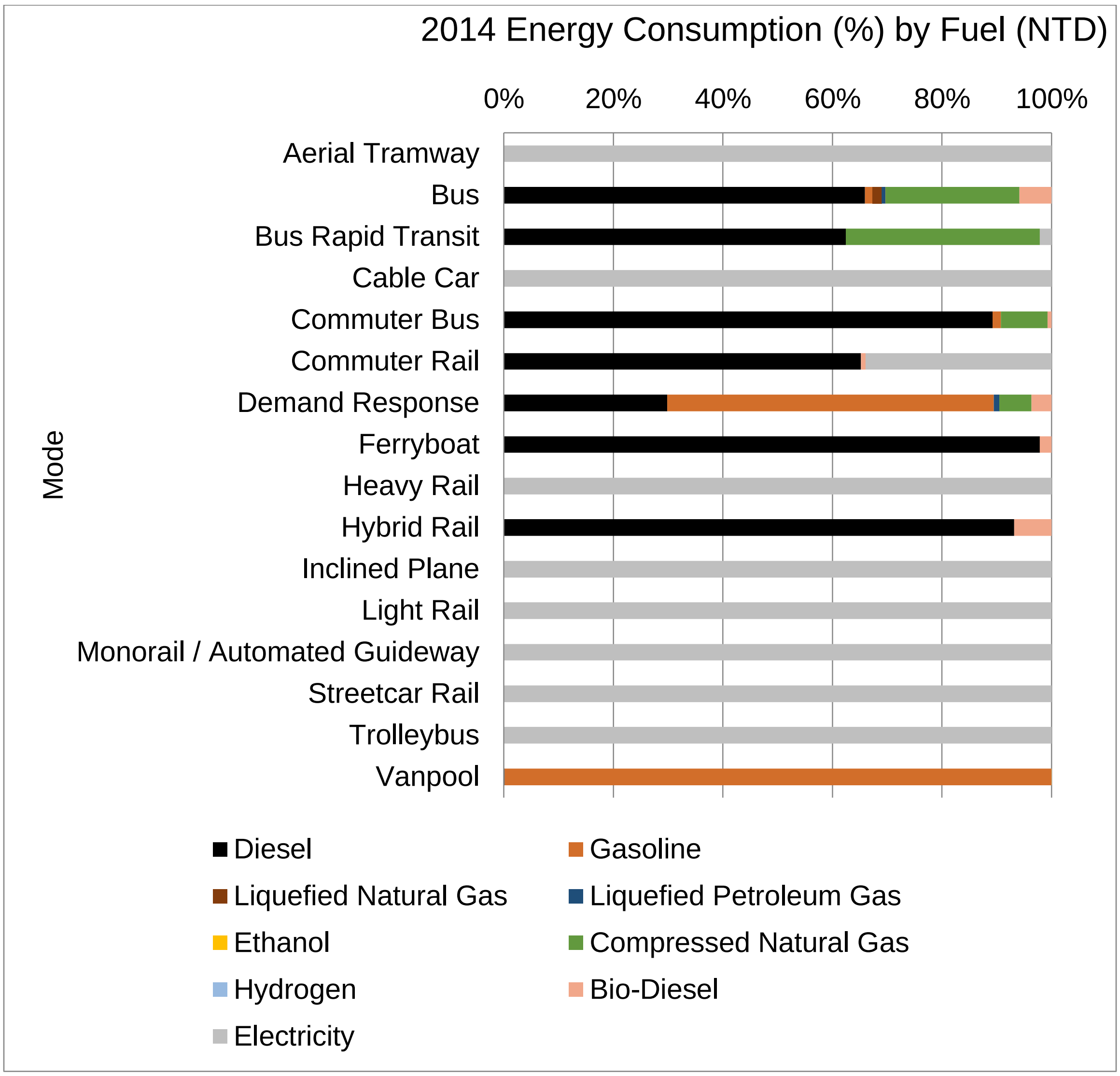


Figure 4.23 – 2014 Energy Consumption by Fuel (Federal Transit Administration, 2016)

Electric modes typically include aerial tramway, cable car, heavy rail, inclined plane, light rail, monorail / automated guideway, streetcar rail, and trolleybus. Electric modes not included on this list are gondola, funitel, and maglev. Some electric or hybrid buses, rail cars, and small vehicles have also become available in recent years. Most buses use diesel, compressed natural gas, or biodiesel as fuel. Ferryboat vessels and hybrid rail vehicles tend to use diesel, with a few using biodiesel. Gasoline is the dominant fuel used in demand response and vanpool vehicles, as well as smaller passenger vehicles, such as taxis and publicos (Federal Transit Administration, 2016). Based on these results, the most efficient electric modes, including heavy rail, aerial tramway (and other aerial modes), light rail, and trolleybus, could be viewed as most appropriate for the urban context, though these results will shift over time as vehicles become more efficient, occupancy rates change, and new technologies emerge.

4.4.3 Land Requirement

Land required to accommodate a transit mode is an important consideration from an environmental, social, and cost perspective. To draw a rough comparison of the land required for vehicle operation and support structures, typical corridor and station land area requirement estimates were calculated on a per mile basis. Corridor land area was estimated using average lane width for surface modes and support tower structure footprint for aerial modes. Aerial modes appear to need a negligible amount of surface space compared to surface modes, since support towers are small and spaced relatively far apart, while lanes are continuous. Elevating surface modes can reduce the corridor land area needed, but may increase the cost and visual impact of the transit system. Elevated rail and bus modes have larger support pillars with smaller spacing than aerial modes, largely due to heavier vehicles and the need to elevate a road or rails. Station area requirements were also estimated using minimum station sizes and average stop spacing, as shown in Table 4.5. The combined results are shown in Figure 4.24.

Table 4.5 – Estimated Station Land Area Requirement by Mode (Vuchic, 2007)

Mode	Minimum Station Length (ft.)	Minimum Station Width (ft.)	Minimum Station Area (sq. ft.)	Average Station Spacing (ft.)
Gondola (MDG)*	95	33	3135	0.4
Funitel*	115	48	5520	0.4
Gondola (3S)*	125	66	8250	0.4
Monorail / Automated Guideway	49	26	1274	1.1
Streetcar Rail	48	36	1728	0.2
Bus	34	36	1224	0.2
Trolleybus	46	36	1656	0.2
Commuter Bus	41	36	1476	2.5
Light Rail	85	44	3740	0.6
Bus Rapid Transit	52	36	1872	0.4
Heavy Rail	66	48	3168	0.8
Commuter Rail	78	50	3900	2.5

*Source: (Creative Urban Projects, 2013)

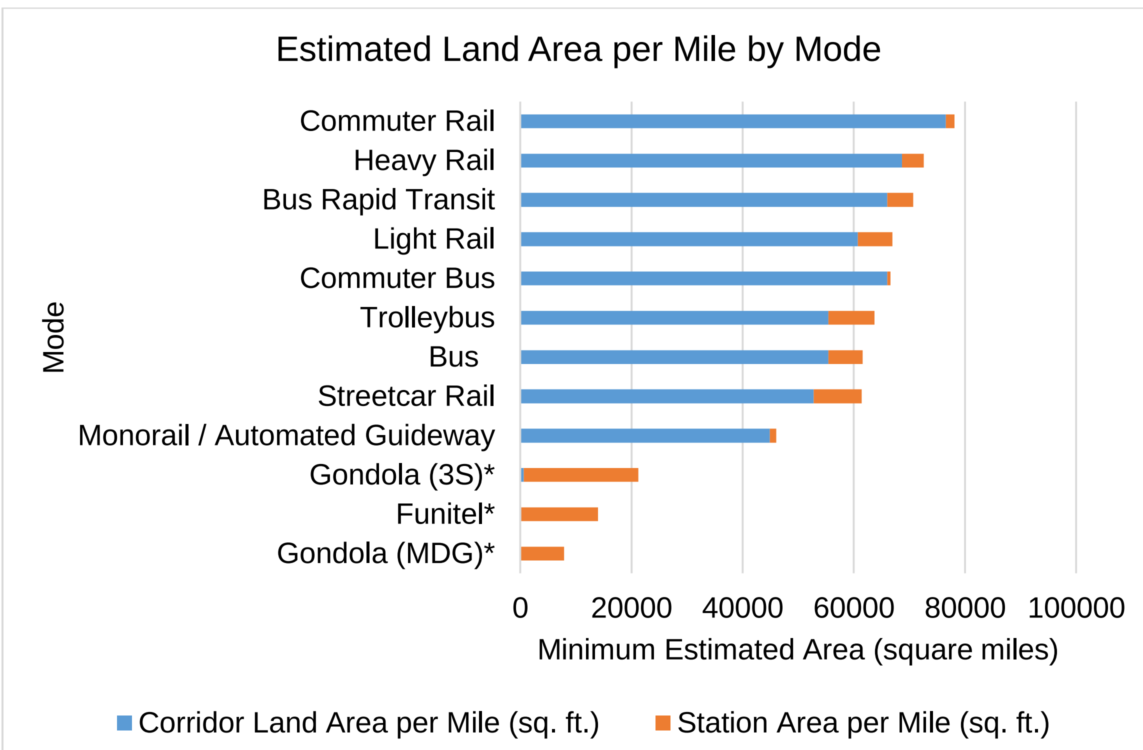


Figure 4.24 – Estimated Land Area Requirement by Mode (Vuchic, 2007)
*Source: (Creative Urban Projects, 2013)

It was estimated that while surface modes have a larger footprint due to the lanes that they operate in, the footprint of aerial modes is almost entirely composed of stations. Although many surface modes use minimal stops that can accommodate one vehicle at a time, rail stations are often designed to be much larger than the minimum requirement. Therefore, the station size requirements for rail modes may be much smaller than what is typically used. Despite this limitation, which may be skewing the results in favor of rail modes, aerial modes clearly require less land overall when compared to surface modes. Water modes also require land only at stations, which may have an even smaller footprint than aerial mode stations (which must house critical equipment). Therefore, it is assumed that water modes require the least amount of land overall. One other limitation to consider in interpreting these results is that many surface modes share their right-of-way with other vehicles. While aerial modes, monorail / automated guideway modes, bus rapid transit, light rail, and heavy rail modes require exclusive right-of-way by definition, streetcars, buses, trolleybuses, commuter buses, and commuter rail modes may share lanes or railroad tracks with other vehicles, including freight and general traffic. As such, the land requirement of modes sharing right-of-way can be proportionally reduced relative to the amount of general traffic versus transit traffic in a particular corridor.

4.4.4 Noise / Vibrations

Noise and vibrations are often difficult to assess for a particular mode, since they are dependent on many factors, including vehicle speed, supports, barriers to sound, and many others. Some modes may generate most of their noise at stations, while others are best heard traveling from place to place. Additional noise may come from construction activity, vehicle horns, braking, turning, and accelerating. A general assessment of the relative noise level of each mode was produced using a combination of data from the Federal Transit Administration and other sources, as described below.

Fast-moving commuter rail modes that are elevated or at-grade tend to be the loudest among existing transit modes, especially when diesel-electric locomotives are used. FTA guidance on noise assessment gives an estimated noise exposure level of 82 dBA for at-grade commuter rail cars, 85 dBA for diesel multiple unit commuter rail, and 90-92 dBA for locomotives at 50 mph and 50 feet away. Commuter rail horns can sound at up to 110 dBA at 50 feet away, so grade crossings are of particular concern. Rail transit and monorail systems are the next loudest modes, especially at higher speeds and when turning, braking, or accelerating. At-grade rail, monorail, and diesel-powered buses were estimated to produce about 82 dBA of sound at 50 mph and 50 feet away by the FTA, but this value increases at higher speeds. Much of the sound and vibration of rail modes can be mitigated when systems are located underground. Ferryboats and water modes may also produce a “medium” level of sound, especially at terminal points, due to their large diesel engines, but they commonly travel through water bodies where few people are around to hear them (Hanson, Towers, & Meister, 2006).

Much of the sound produced by rail modes comes from the metal wheels on metal rails (usually steel), so it is no surprise that rubber-tire transit modes are often quieter than rail transit. Electric buses and trolleybuses, as well as steel wheel automated guideway systems, were estimated to produce 80 dBA of sound at 50 mph and 50 feet away, while rubber tire automated guideway systems produce only 78 dBA at that speed and distance. Vanpools, taxis, and passenger automobiles in general were estimated to produce only 74 dBA of sound at 50 mph and 50 feet. Maglev rail was the quietest mode according to the FTA report, *Transit Noise and Vibration Impact Assessment*, with 72 dBA at 50 mph and 50 feet away (Hanson, Towers, & Meister, 2006). However, this study did not consider any aerial modes of transit.

Aerial modes have several key advantages that make them quieter than other transit modes in general. The primary advantage is the lack of on-board motors for aerial transit vehicles. Since aerial trams, funitels, and gondola cars are propelled by a steel cable, the only significant noise generated by these systems comes from the stations, especially terminal stations with motors that drive the systems. While the sound produced by the cars moving through the air is negligible, except perhaps when vehicles move over support towers, even the sound coming from stations is relatively low.

4.4.5 Aesthetics

Aesthetics is another area to consider in mode selection, but one that is fairly subjective and, therefore, lacking in quantitative data. However, this factor is perhaps one of the simplest to deal with on a qualitative level. Aerial and elevated transit modes are often the most visually noticeable, and in many cases disruptive, of the transit mode categories. Larger elevated systems tend to be more disruptive than aerial systems, which have smaller and less frequent support structures. Surface modes may be less visible from a distance, but can contribute to visual clutter on the land. They may be more noticeable to people on the ground, as they are more likely to be in an individual's line of sight when they are traveling on the surface, but modes that don't use dedicated infrastructure are hardly noticeable in the absence of actual vehicles. Water modes are can also go largely unseen, except in areas with high traffic volumes along their navigable waters, but even when they are a noticeable community presence they may be viewed more favorably than common surface modes. For example, people will go to the shore or marina to watch various types of boats pass by, but it is not common for people to go bus watching. Perhaps the most discrete transit modes are those that operate in underground tunnels, although large stations may be just as noticeable as elevated, aerial, and surface modes, or even more so. While modes with underground alignments may only be noticeable where stations provide surface access, this can limit the accessibility and presence of these systems to the point of reducing ridership and awareness of these transit options.

Aesthetics are typically discussed in terms of the visual impact of a system on the urban landscape, but customer views (literally) should also be considered. Underground transit systems may be less noticeable, but they also offer very little visual stimulus for transit riders. Darkness, graffiti, rats, litter, and other sights that many people see as undesirable may be more common in underground systems than any other types. Surface modes offer a glimpse of sunlight, and are less likely to harbor vermin, but many riders will find themselves looking at traffic congestion while aboard surface transit vehicles if there aren't more attractive sights to see. Some corridors are clearly more visually pleasing to riders than others. Water modes tend to offer passengers a chance to escape the visual clutter of urban streets, and may provide lots of sunlight, as well as spectacular views. Aerial and elevated modes provide a perspective of the city from above, which is otherwise only available from tall buildings or aircraft and may be highly sought-after among tourists and residents alike.

4.4.6 Other Environmental Factors

It may be necessary or desirable to account for other environmental impacts of various transit modes, including impacts on resources, water, and wildlife. However, information on these impacts is very limited. Resource impacts can presumably be associated with the size of a system and its energy consumption. Larger, more powerful transit systems often require more resources for their construction and operation, though higher ridership may offset some of these increases on a per passenger-mile basis. Resources are needed for transit vehicles, as well as for stations, transitways, and fuel. Aerial and water modes can be less resource-intensive, since they have minimal infrastructure requirements when compared to surface modes. On the other end of the spectrum, rail modes tend to have large stations and require railroad tracks to be laid wherever rail cars are operated. Modes using exclusive lanes also require more resources for their construction than those operated in existing right-of-ways.

Transit may impact water systems by generating runoff and pollution, and by changing the natural flow within a watershed. Impacts on water quality and quantity should be taken into account. Aerial modes, with their small footprint and minimal amount of added impervious surface, typically have a negligible impact on water resources. Water modes may also have a low impact, except in cases where they are discharging pollutants directly into water bodies. Underground transit modes also seem to have few impacts on stormwater runoff, though flooding may be a concern for these systems, especially in coastal areas. Surface modes (at-grade and elevated) requiring the addition of new pavement or other impervious surfaces are likely to require more thorough analysis of water resource impacts during the design and environmental impact assessment phases of such projects. Stormwater best management practices should be used as needed to mitigate any expected impacts to water quality or flooding.

Generally speaking urban transit systems don't often have major impacts on wildlife, except in areas of frequent animal presence. Urban areas rarely have major wildlife populations, so the risk of urban transit having a noticeable wildlife impact is low. However, modes operated in more rural environments or sensitive areas may require thorough analysis and mitigation of wildlife impacts. Migratory corridors and habitats with endangered species or significant biodiversity should especially be avoided, when possible. Fast-moving surface modes pose the greatest risk to terrestrial wildlife, while boats with open propellers may endanger aquatic life. None of the aerial transit modes included in this report are expected to have any major wildlife impacts, except in cases of habitat loss (more common in rural and eco-tourism areas than in urban settings) or conflicts with flight paths. Context-sensitive solutions should always be used to ensure that the most appropriate transit solutions are implemented, without negatively impacting other lifeforms, ecosystems, and habitats in a significant way.

4.5 Social Factors

Social factors describe various ways that transit can impact individuals and communities. An abundance of data was found for measuring the safety of many transit modes, yet information on reliability, accessibility, resiliency, and other social factors was very limited. As such, these concepts are discussed more generally below.

4.5.1 Reliability

Reliability is one of the most complex factors related to transit service, yet also one of the most important. Not only are there countless ways to measure reliability, with few if any being used across all transit modes, but there are hundreds of factors impacting the reliability of a particular service. The context of a system and its corridors, as well as operator characteristics, all play a pivotal role in determining how reliable a transit service is, but reliability also varies over time. Maintenance and investment come into play as infrastructure and vehicles age. External factors, such as traffic congestion, signals, transit priority, events, and incidents, can also impact reliability from one minute to the next. Despite all these variables, the relative reliability of transit modes can be described at a very high level, based on exclusivity of right-of-way and availability of service (if it is typically scheduled or on-demand), as shown in Table 4.6.

Table 4.6 – Transit Mode Right-of-Way, Availability, and Reliability

Modes	Right-of-Way	Availability	Reliability
Automated Guideway, Funitel, Gondola, Water Taxi	Dedicated	On-Demand	High
Aerial Tramway, Bus Rapid Transit, Commuter Rail, Ferryboat, Heavy Rail, Hybrid Rail, Inclined Plane, Light Rail, Maglev Rail, Monorail, Water Bus	Dedicated	Schedule	Medium-High
Demand Response, Jitney, Publico, Taxi	Shared	On-Demand	Medium-Low
Bus, Commuter Bus, Streetcar Rail, Trolleybus, Vanpool	Shared	Schedule	Low

Exclusive right-of-way is given slightly higher weight than on-demand availability, thus a medium-high and a medium-low reliability group of modes were created. Modes that use dedicated transitways (waterways are considered exclusive in this case, due to typically low levels of congestion) and are offered on-demand, rather than on a schedule, are seen as being the most reliable at a high level. Continuously moving modes like gondola and funitel are perhaps the most reliable of these, but automated guideway and water taxi systems may also be set up so that passengers can walk up, get onboard, and go. The lack of traffic means that travel times should be relatively consistent as well. Transit systems that generally operate on a schedule are viewed as somewhat less reliable than this first group, in that there is a level of uncertainty and generally a wait associated with using these modes. Higher-frequency services reduce wait times, so the more frequent these systems are the better, from a reliability standpoint. Some systems using the medium-high reliability modes may offer them as an on-demand service, in which case they should be placed in the high reliability group.

Demand response, jitney, public, and taxi services are classified as on-demand, but they are almost always operated in shared right-of-ways. Further, these modes are not typically as on-demand as the high reliability modes. Many of these services require advanced reservations, sometimes a day or more in advance of the scheduled pickup. Depending on the advanced notice requirements, these “on-demand” services may actually have longer waits than most scheduled services do. Low reliability transit modes based on this classification system include bus, commuter bus, streetcar rail, trolleybus, and vanpool, unless these services are offered on-demand or in dedicated transitways. It is important to note that these classifications are relative, and that not all reliability-related factors are included. However, this system does provide a high-level framework for comparing transit mode alternatives with regard to system reliability.

4.5.2 Safety

Safety is arguably more important than reliability, as the differences between transit modes can literally have life or death consequences. Fortunately, and likely due to the critical nature of this factor, data relating to transit safety is much more abundant than data on reliability across modes. Figure 4.25 shows fatality rates for highway, transit, and commercial air transportation in the United States from 2000 to 2012, which shows that transit and airplane trips have had up to 90% fewer deaths per passenger mile than highway transportation recently (Bureau of Transportation Statistics, 2016).

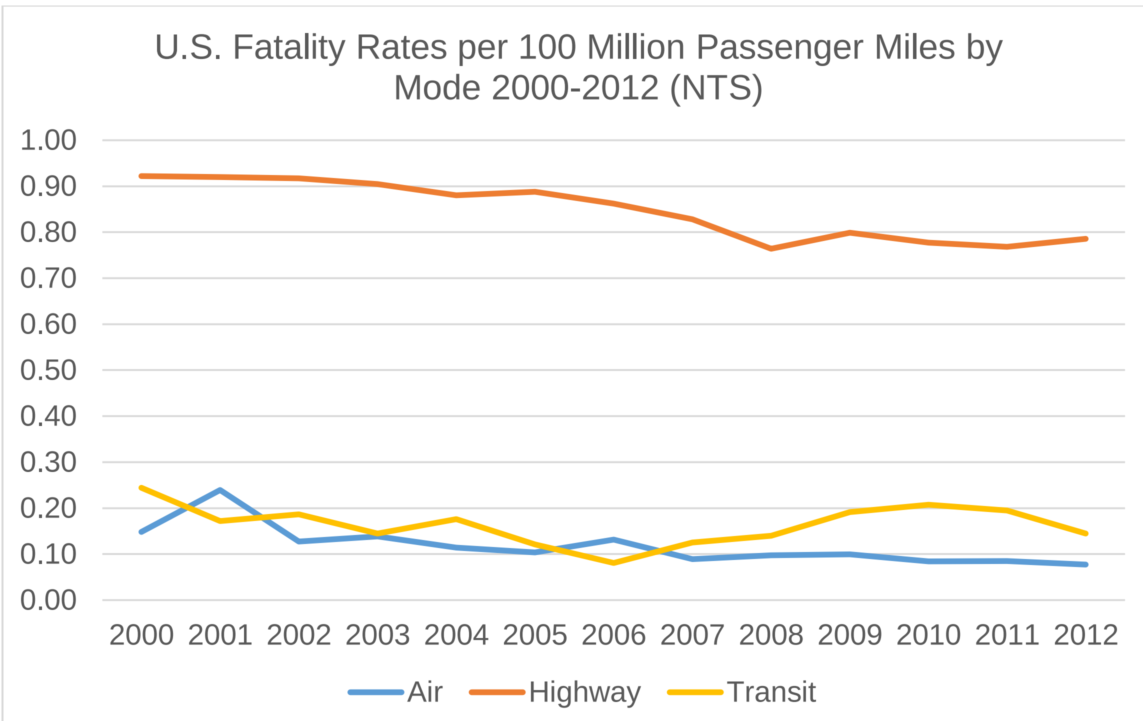


Figure 4.25 – U.S. Fatality Rates per 100 Million Passenger Miles by Mode 2000-2012 (Bureau of Transportation Statistics, 2016)

Although transit has consistently outperformed highway transportation in terms of safety, there are noticeable differences in fatality and injury rates between transit modes, as shown in Figures 4.26, 4.27, and 4.28.

To estimate fatality rates for each mode reported to the NTD, average data from 2013-2015 was used, since all modes were reported on during this period (except for jitney and commuter rail). To understand these totals in the context of the prevalence and use of systems for each mode, they were scaled with respect to the average passenger miles traveled per year from 2013-2015. The results are shown in Figure 4.26.

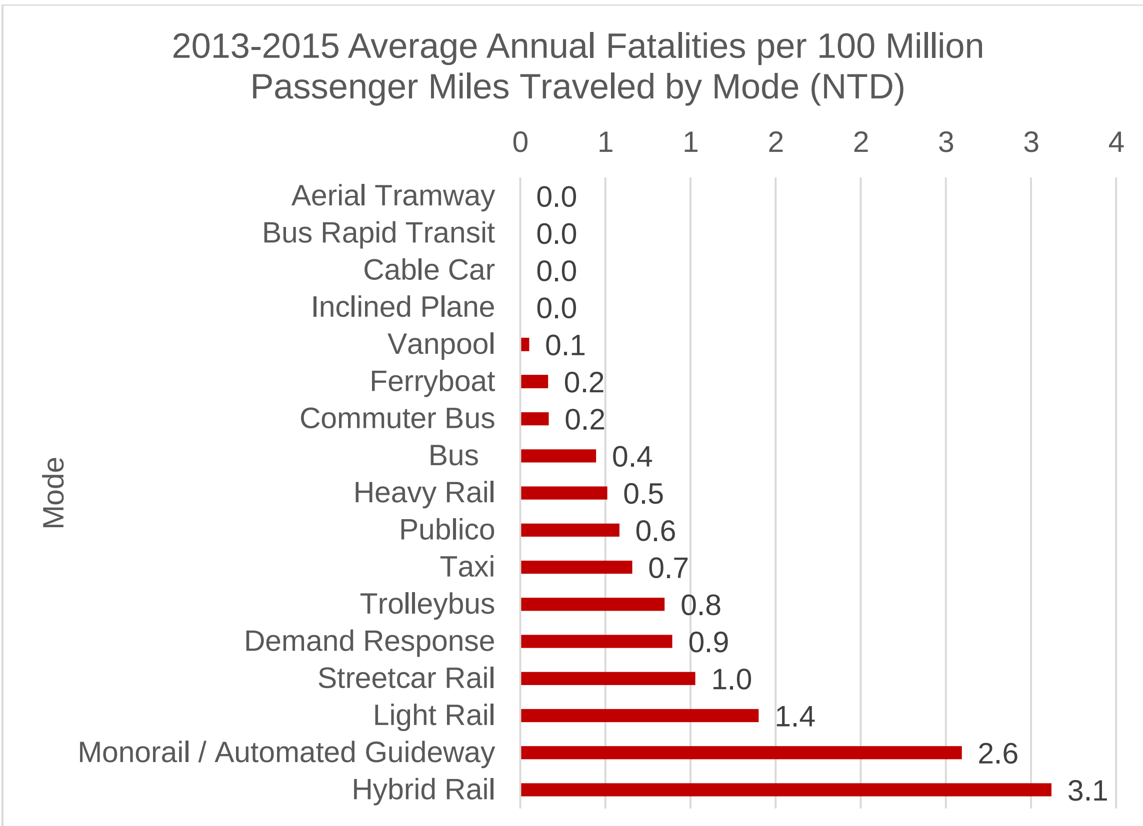


Figure 4.26 – 2013-2015 Average Fatality Rate by Transit Mode in the U.S. (Federal Transit Administration, 2016)

It is clear from this analysis that hybrid rail had the highest fatality rate of 3.1 fatalities per 100 million passenger miles on average. Recalling that only 2 fatalities occurred each year on average during this period, this result could be skewed by the newness and rarity of hybrid rail systems in the U.S. The same can be said for monorail / automated guideway, which had the second-highest rate of 2.6 fatalities per 100 million passenger miles despite having only 0.7 fatalities per year on average from 2013-2015. For comparison, one fatality per year would result in a rate of over 200 fatalities per 100 million passenger miles for inclined plane but only 0.7 fatalities per 100 million passenger miles for bus rapid transit. Light rail had the third highest rate of 1.4 fatalities per 100 million passenger miles, followed by streetcar rail at a rate of 1.0. Close behind these were demand response (0.9) and trolleybus (0.8). Then came taxi (0.7) and publico (0.6), which are somewhat similar in nature. The most common modes (by passenger miles traveled) of heavy rail and bus were next with rates of 0.5 and 0.4, respectively. The lowest fatality rates among modes that did have reported fatalities during the analysis period were calculated for commuter bus (0.2), ferryboat (0.2), and vanpool (0.1). No fatalities were reported for aerial tramway, bus rapid transit, cable car, or inclined plane during this period (Federal Transit Administration, 2016).

Although data is lacking to calculate comparable fatality rates for modes not reported in the NTD, the global examples of urban gondola, maglev rail, commuter rail, water boat, and water taxi systems do offer some insights into the safety of these technologies. Not only have urban gondola systems reported zero fatalities worldwide since the first system began operating in 2004, but enclosed aerial lifts in the U.S. (including the many examples at ski resorts and tourist destinations) haven't had a fatality since 1978. The authors of *Cable Car Confidential* offer up additional insights regarding the safety of cable-propelled transit (CPT). In Switzerland, transit passengers are three times more likely to be injured in a tram, bus, or train than in cable-propelled transit, and 50 times more likely to be injured in a car. In North America, there were only six deaths involving CPT systems (including open-air chairlifts) from 1990-2010; none of the deaths involved systems with enclosed cabins. During the same period there were

5,681 transit fatalities in North America. The rates of fatalities per 100 million passenger miles were calculated as roughly 0.69 for transit versus only 0.17 for CPT (Creative Urban Projects, 2013). No examples of urban funitels yet exist, but this is a newer technology that has primarily been demonstrated on ski resorts to this point, without major incident.

The Bureau of Transportation Statistics (BTS) also provides information on transit safety and passenger miles traveled by mode, including commuter rail. As shown in Figure 4.27, from 2009-2012 there were between 0.59-1.01 (0.84 on average) fatalities per 100 million passenger miles for commuter rail systems in the U.S. This figure was worse than the combined figure for bus and trolleybus (0.37-0.48 with an average of 0.43), as well as heavy rail (0.55-0.60 with an average of 0.58). Commuter rail consistently performed better than light rail (1.10-1.81 with an average of 1.50) during the period of analysis, and better than demand response (0.24-1.19 with an average of 0.97) in every year but 2011 (Bureau of Transportation Statistics, 2016).

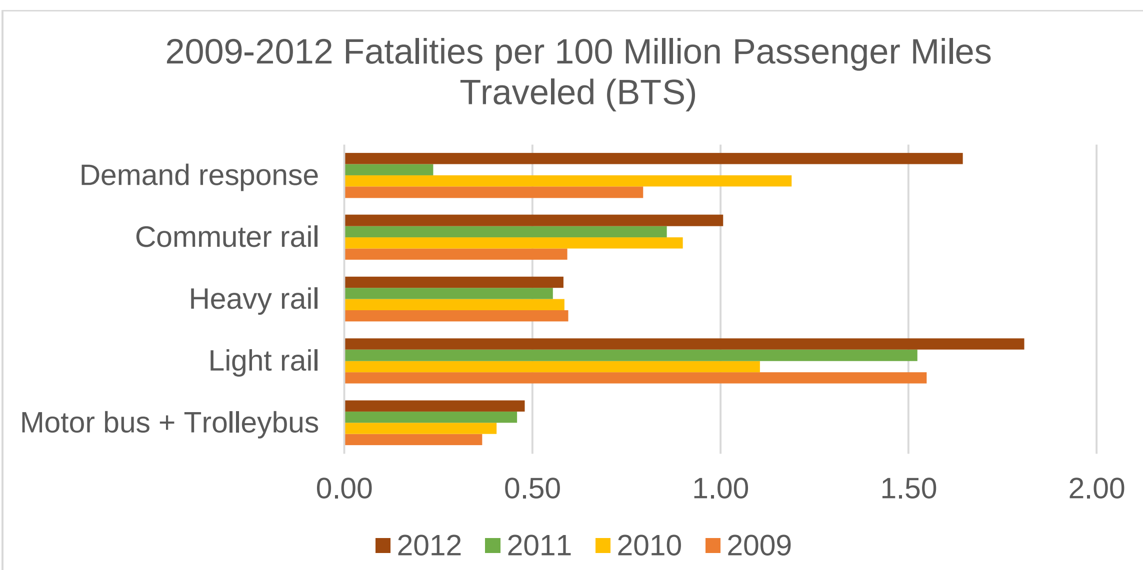


Figure 4.27 – 2009-2012 Fatalities per 100 Million Passenger Miles in the U.S. (Bureau of Transportation Statistics, 2016)

It is interesting to note that the results attained from the Bureau of Transportation Statistics and the National Transit Database conflict with some of the safety levels assigned to modes in Vuchic's textbook, *Urban Transit Systems and Technology*. While Vuchic classified auto modes as "low" (on-street) to "medium" (on-freeway) for safety, which did seem to be the case for demand response vehicles, vanpool data from the NTD revealed this mode to be among the safest operated in the U.S. today. Vuchic also indicated that bus modes have a safety classification of "medium", while light rail was given a classification of "high" and both regional (commuter / hybrid) rail and heavy rail were given a classification of "very high" (Vuchic, 2007). Yet both the NTD and BTS data indicate that bus systems in the U.S. consistently outperform rail systems (except for inclined plane) in terms of fatalities per passenger mile traveled (though heavy rail does outperform trolleybus in the NTD).

Data relating to the safety of maglev trains is much more limited, especially given that few of these systems exist, and that the only commercial maglev systems operating today are located in Asia. Maglev rail test tracks have been built and operated since the 1970s, while commercial operation of low-speed maglev people movers started in the mid-1980s. The high-speed Shanghai Maglev (Transrapid) system has been operating commercially since 2004, often at speeds of 270 mph or higher, without a single fatality reported to date (The Shanghai Maglev Train). The first fatalities reported for a maglev system occurred in 2006 when a Transrapid train on a test track in Germany crashed into a service vehicle at 125 mph and partially derailed, killing 25 passengers. The cause of this incident was ruled to be human error (Landler, 2006). Although this incident was certainly a tragedy, which reveals the devastating consequences of reckless behavior in high-speed transit operations, the fact that this train only partially derailed indicates the lower likelihood of a derailment associated with maglev technology as opposed to conventional rail systems.

Although data on the total passenger miles traveled aboard commercial water transportation vessels was not found, the number of water vessel-related fatalities in the U.S. has dropped substantially since the 1970s from 243 in 1975 to only 14 in 2014. Non-vessel-related waterborne transportation fatalities have also dropped, from 420 in 1970 to 50 in 2014. Far more deaths occur due to recreational boating than commercial waterborne transportation, as is the case with air travel. Since the year 2000, 550-750 people have died in the U.S. each year due to recreational boating incidents. In 2014 this meant 4.7 fatalities per 100,000 boats, which is down from 32.9 in 1965 (Bureau of Transportation Statistics, 2016). Water transit modes appear to be among the safer transit modes, although the fatalities could not be scaled according to passenger miles traveled due to a lack of data in this case.

While deaths are considered by most to be the more devastating consequence of transit crashes and failures, injuries are more prevalent and can have very harmful impacts on society. As shown in Figure 4.28, aerial tramway and inclined plane rail have the lowest injury rates per 100 million passenger miles of any modes reported to the NTD, as no injuries were reported for either mode from 2013-2015. Vanpool and commuter bus also performed well on this measure, with 2.9 and 5.3 average injuries per 100 million passenger miles traveled, respectively, followed by publico (12.8). Hybrid rail (19.2) came next, followed by ferryboat (26.2), light rail (32.9), and heavy rail (34.5). Bus (68.0) had almost double the injury rate of heavy rail, and bus rapid transit and trolleybus had even higher rates of 86.9 and 105.3, respectively. Taxi (122.9) had a higher injury rate still, followed by cable car (133.4). Streetcar rail and demand response were had even higher injury rates of 172.3 and 181.8, respectively, but monorail / automated guideway had the highest rate by far of 277.4 injuries per 100 million passenger miles (Federal Transit Administration, 2016). Scaling by passenger miles may again have penalized less used modes, in this case.

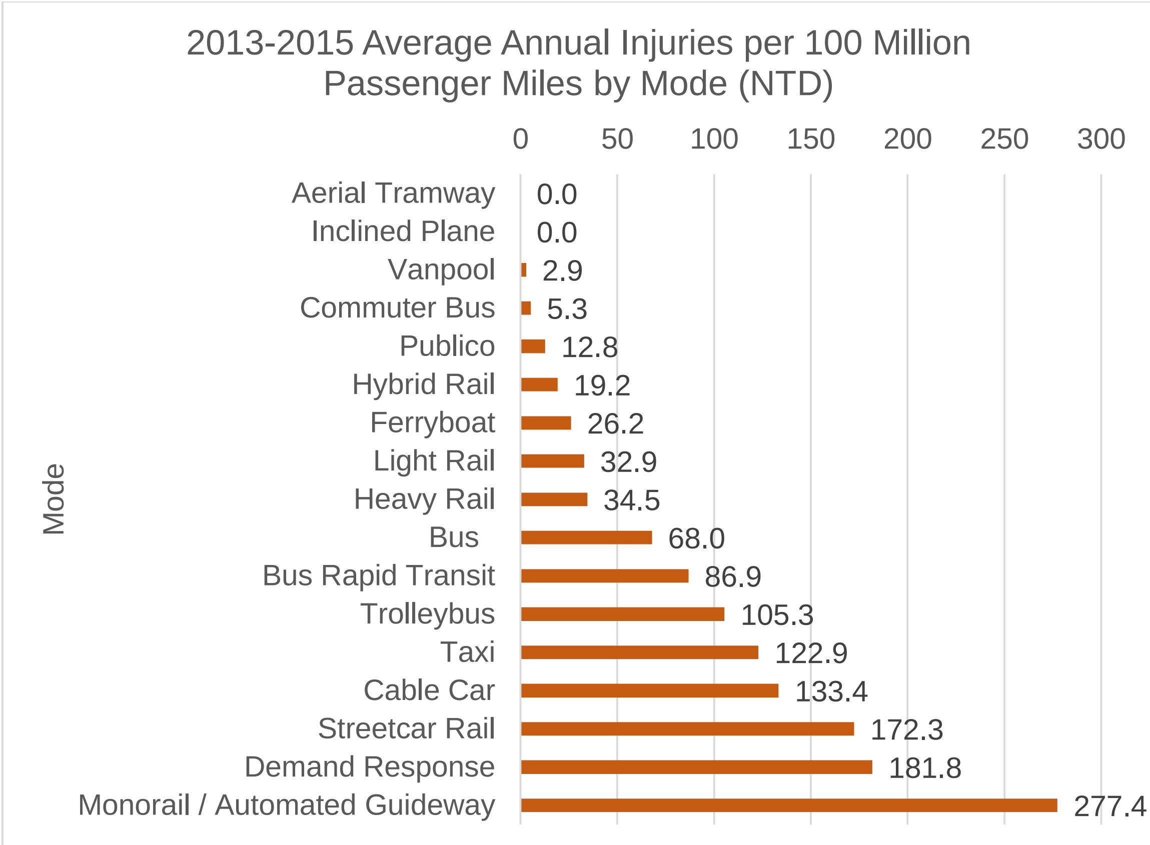


Figure 4.28 – 2013-2015 Average Injury Rate by Transit Mode in the U.S. (Federal Transit Administration, 2016)

4.5.3 Accessibility

Accessibility is a challenging factor to quantify, as overall accessibility seems to depend more on the design of a system in the context of an urban area than on the transit mode itself. A general point can be made that requiring customers to go up or down, rather than remaining on the surface, can limit transit system accessibility. One aspect of accessibility that could be captured quantitatively from the NTS data was the percentage of transit vehicles for each mode operated in the U.S. that were ADA accessible in 2014, or accessible to those with mobility limitations, such as being confined to a wheelchair. The results of this analysis are shown in Figure 4.29 for 2014.

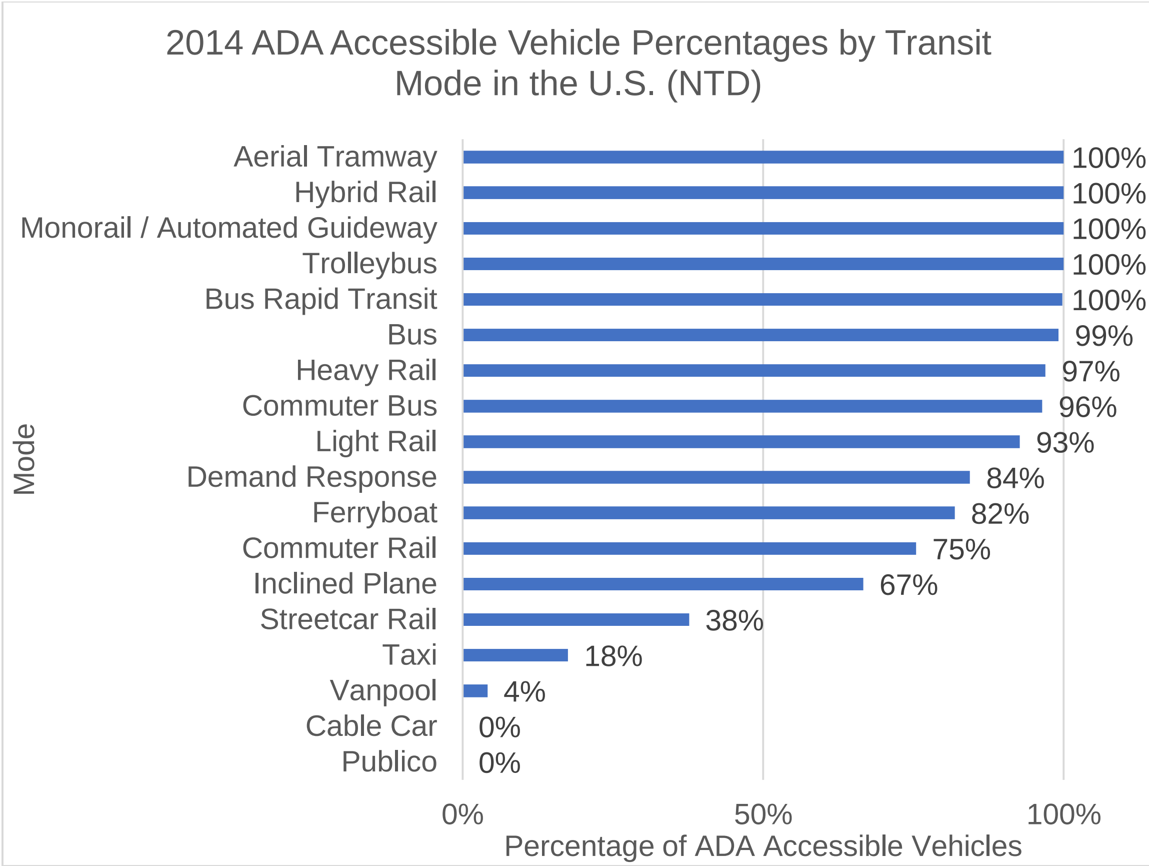


Figure 4.29 – 2014 Percentage of ADA Accessible Vehicles by Transit Mode in the U.S. (Federal Transit Administration, 2016)

Modes in the NTD that had 100% ADA accessible vehicles included aerial tramway, hybrid rail, monorail / automated guideway, trolleybus, and bus rapid transit. Almost all buses (99%), heavy rail (97%), commuter bus (96%), and light rail (93%) vehicles were ADA accessible in 2014. Interestingly, demand response (which encompasses paratransit, but also other types of demand responsive services) had only a slightly higher percentage of ADA compliant vehicles than ferryboat (84% for demand response, compared to 82% for ferries). The percentages of commuter rail (75%), inclined plane (67%), and streetcar rail (38%) vehicles that were ADA accessible in 2014 were considerably lower, though not as low as for taxi (18%), vanpool (4%), cable car (0%), or publico (0%) vehicles (Federal Transit Administration, 2016).

Modes not reported to the NTD can also be classified as generally accessible or not accessible, with exceptions in certain cases. Aerial modes, such as gondola and funitel, tend to be ADA accessible with minor special accommodations (cars can be slowed or stopped as needed in stations without slowing the progress of the entire line). Water modes can also be ADA accessible, but smaller boats are typically less able to accommodate the mobility-impaired. Special provisions may also be required at docks for waterborne systems to be ADA compliant. Modern cable cars, such as Doppelmayr's *CABLE Liner*, and automated people movers are ADA accessible in most cases. Maglev rail systems are also ADA accessible, with few, if any, exceptions. Jitney systems are not typically ADA compliant, unless wheelchair-accessible vehicles are used.

4.5.4 Resiliency

System resilience, or ability to recover from disruptive incidents, is another important factor to consider in transit mode selection. At a high level, resiliency relates to the degree of impact of changes on a system (vulnerability), and the system's ability to overcome those impacts. Changes or disruptions may include stormy weather, drought, extreme heat or cold, natural disasters, mechanical failures, major events, and acts of violence, as well as other shocks to the transit system. Weather-related challenges are among the most common disruptions, with relatively predictable impacts on transit modes. As such, they are the focus of the resiliency analysis described below.

Storms involving snow, ice, strong winds, and/or lightning often disrupt transit service, as shown in Table 4.7. Other consequences, such as the potential buckling of railroad tracks in extreme heat or flooding of underground systems, should also be accounted for when possible. The vulnerability of each mode to these conditions is described in Table 4.7 in terms of the likelihood that a mode will be able to safely operate in each circumstance. The risk of system shutdown under each of the extreme weather conditions was used to assign each mode to a resiliency rating group.

Table 4.7 – Transit Mode Resiliency to Severe Weather

Modes	Snow	Ice	Wind	Lightning	Heat	Resiliency
Aerial Tramway, Cable Car, Funitel, Gondola	Yes	Yes	Likely	Likely	Yes	High
Automated Guideway, Heavy Rail, Maglev Rail, Monorail	Yes	Likely	Likely	Yes	Likely	Medium-High
Commuter Rail, Hybrid Rail, Inclined Plane, Light Rail, Streetcar Rail	Likely	Maybe	Likely	Yes	Likely	Medium
Ferryboat, Water Bus, Water Taxi	Yes	Likely	Maybe	Unlikely	Yes	Medium-Low
Bus, Bus Rapid Transit, Commuter Bus, Demand Response, Jitney, Publico, Taxi, Trolleybus, Vanpool	Unlikely	No	Likely	Yes	Likely	Low

Cable-propelled transit systems, which have been primarily designed for use under extreme winter weather conditions in recent decades, show the least vulnerability of all considered transit modes to snow, ice, wind, and lightning. Aerial tramway, cable car, funitel, and gondola all benefit from the stability of being attached to a steel cable, and the fact that these technologies have been implemented in large part on ski resorts serves as testament to their ability to overcome harsh winter conditions. Where lightning may strike, CPT systems can be designed to protect passengers and the system itself from harm. Where extremely high winds are expected systems with added stability and support can be used. As such, these modes are capable of operating under nearly all severe weather conditions that may occur in urban areas, so have been given a resiliency rating of "high".

Four modes were given a rating of "medium-high", including automated guideway, heavy rail, maglev rail, and monorail transit. Although automated guideway, heavy rail, and monorail systems often depend on friction for propulsion, that these systems often use underground or covered tracks reduces their vulnerability to the elements (except, perhaps, to flooding). Maglev rail and monorail systems are also fairly resilient in winter weather, especially since their vehicles are designed to minimize the chances of derailment in even the slickest conditions. Many of these systems use linear induction motors for propulsion, making them less dependent on friction for movement. As such, only extremely heavy accumulation of snow or ice would prevent them from operating. High winds may be more of a concern for maglev systems than non-levitating modes, but these conditions are unlikely to occur in most urban areas.

All rail modes that are exposed to snowy, icy, or very windy weather without the added protection of shelter or derailment-deterring design were grouped into the “medium” resiliency category. While rail modes often operate under extreme weather conditions, they are vulnerable to derailing due to a lack of friction or strong winds that can blow trains off of their tracks. While these conditions are rare, especially in urban areas, derailment will cease operations immediately and for long periods. Rails do help to stabilize train cars, allowing them to operate more safely than rubber-tire modes in mild to severe winter weather. Like all enclosed-vehicle transit modes, commuter rail, heavy rail, hybrid rail, inclined plane, light rail, maglev rail, monorail, and streetcar rail systems are designed to operate and protect passengers even if lightning strikes a train.

Waterborne transit modes are fairly unique in their vulnerabilities. Snow has little to no effect on most boats, and ice is only a concern in extreme cases of ice storms or freezing waterways. However, high winds often mean larger waves and greater risk of capsizing, which can be especially treacherous conditions for small vessels. Drought, tides, and flooding can also impact water transit services, preventing their operation in severe cases. Waterborne transit is the most vulnerable and least resilient group of transit modes when it comes to lightning. As boats are typically not enclosed or able to protect passengers from lightning strikes, these services do not typically operate when lightning is present. Water transit modes were given a “medium-low” resiliency rating.

Bus and auto modes, including bus rapid transit, commuter bus, demand response, jitney, publico, taxi, trolleybus, and vanpool, are usually fine to operate in lightning and windy conditions, but snow and ice can and often do prevent the safe operation of these modes. Many U.S. cities have effective means of clearing snow from roadways, but these systems may fail during and after major snow storms. When snow and ice accumulate on roadways, operating buses and other trackless transit vehicles may pose a serious risk to passengers and drivers, as well as others nearby. Snow buses and other vehicles designed specifically for operating in the snow and ice are available, but these are rarely found in urban transit fleets. Given these facts, the bus and auto modes were given a resiliency rating of “low”.

While general resiliency ratings are assigned here, resiliency should be considered in the context of the proposed transit service area. Warm climates that get little or no snow may not even need to consider the performance of their system in these conditions. Rather, extra attention may be devoted to the impacts of extreme heat, humidity, lightning, flooding, sea level rise, tropical storms, fires, or other potential disruptions. Similarly, snow, ice, and high winds are more common in the northern U.S., so the project context is of paramount importance when it comes to weather resiliency.

Best practices in security and emergency preparedness can also help to minimize the impacts of natural or man-made disasters on transit systems. Although resilient systems may rebound from major and minor setbacks quickly, while adapting to changing conditions, prevention is often the best approach to avoid system disruptions. Selection, design, and engineering of resilient transit systems is a great place to start, but systems must be maintained and secured effectively, and operated safely, to avoid unnecessary, lengthy service interruptions.

4.5.5 Other Social Factors

Social factors such as aesthetics, community views, political influences, equity, and health impacts of transit are often subjective, and more related to planning of a transit system than to the selection of any particular mode. Non-emitting (electric) modes are preferable to emitting modes in urban areas, especially where air quality is degraded. Modes that encourage physical activity might also be preferable for public health. Context-sensitive design and strategic planning and analysis, along with inclusive and effective engagement of stakeholders and the general public, tend to lead to the most optimal outcomes with respect to these social factors.

4.6 Economic Factors

Although it is clear that economic factors are the driving force in decision making in the U.S. today (as demonstrated by the survey results presented in Chapter 3), the practice of valuing economics over society and the environment seems to the author to be destructive, irresponsible, and unsustainable. This is especially true when upfront investment costs, rather than lifecycle costs, are the determining factor in transit mode selection. Low capital costs often seem appealing, but may lead to investing in systems that have higher operating costs and/or externalities, which can reduce system sustainability in the long-term. Economic factors should be included in multi-faceted decision making, but should not be the predominant factor. Ultimately the goal should be to develop transit systems that add value to the communities they serve, while ensuring that resources are distributed equitably and effectively, to where they are most needed and will be well-utilized.

4.6.1 Capital Costs

Capital costs for transit infrastructure vary widely among and within modes, and are largely determined by the characteristics of specific projects. Costs can vary over time, with replacement and maintenance costs (not to mention expansion costs) adding up even after initial construction is complete, and location, with particular portions of some transit systems (often elevated, underground, or otherwise complex segments) costing vastly more than others. National data is used here to describe trends in transit spending in the United States, but specific costs are best estimated for defined transit alternatives. General cost estimates are not only difficult to define, but the use of metrics such as cost per mile may oversimplify what can be a very complex budgeting process, which should at least take into account the desired alignment and capacity of a service. Figure 4.30 shows total capital expenditures by transit mode in the U.S. from 1992-2014, as reported to the NTD and adjusted for inflation.

As shown in Figure 4.30, the most total spending on transit systems in the U.S. has gone to heavy rail ($5.7 billion in 2014), followed by bus and light rail (both at $3.9 billion in 2014), and commuter rail ($2.8 billion in 2014). Spending since 1992 has been increasing for most of these modes, though spending on commuter rail has increased the least of these four modes in recent years (Federal Transit Administration, 2016).

The second panel in Figure 4.30 shows the modes with mid-range total capital expenses, including ferryboat ($255 million in 2014), demand response ($250 million in 2014), streetcar rail ($233 million in 2014), and commuter bus ($173 million in 2014). Below the $100 million mark in 2014 were bus rapid transit ($77 million), vanpool ($35 million), trolleybus ($24 million), hybrid rail ($15 million), and monorail / automated guideway ($14 million). Modes with less than $10 million in total capital expenses in 2014 were cable car ($2.7 million), taxi ($664 thousand), and inclined plane ($538 thousand). No capital expenses were reported for jitney or aerial tramway since 2004 or for publico since 2005 (Federal Transit Administration, 2016).

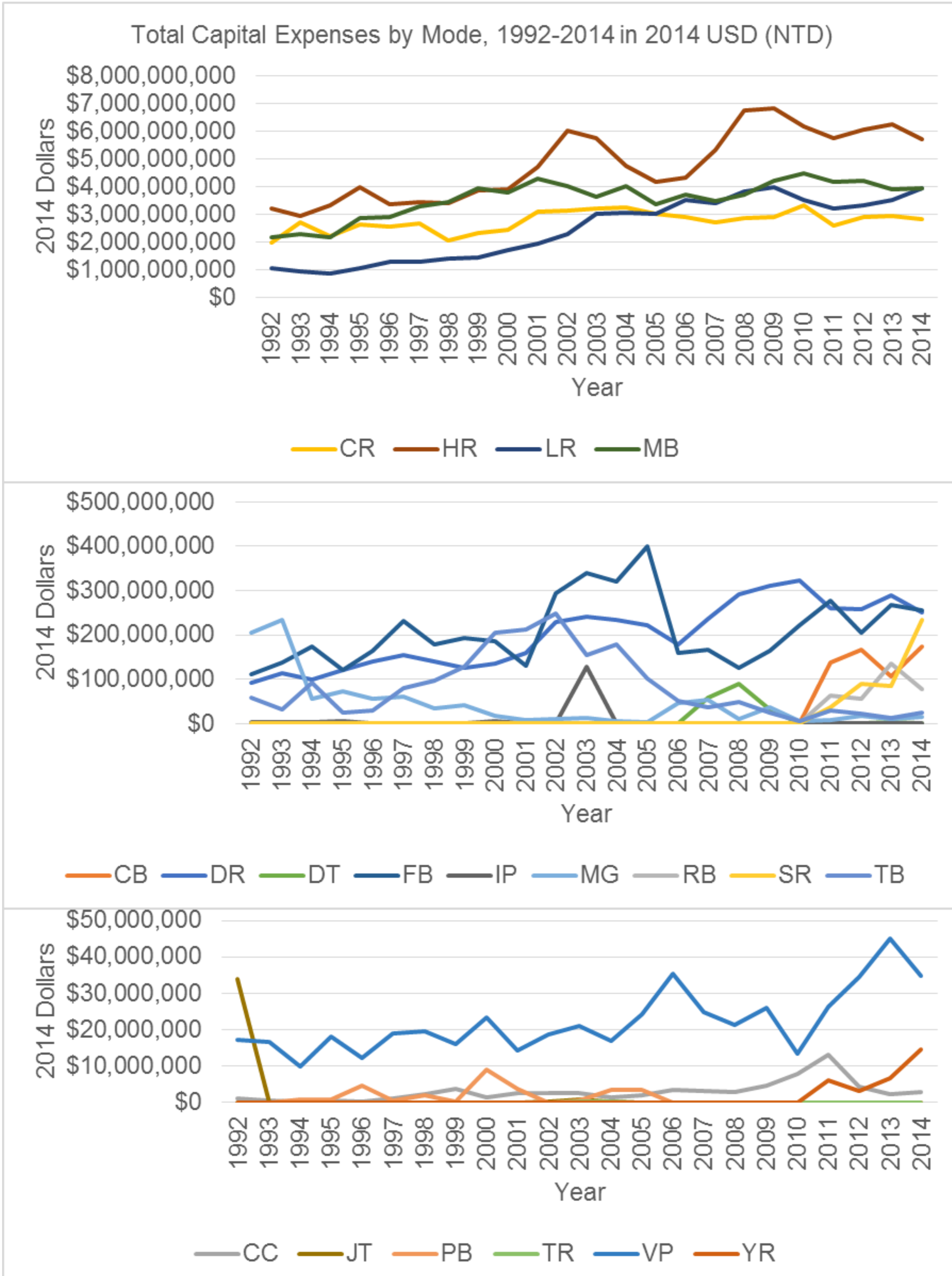


Figure 4.30 – Total Capital Expenses by Transit Mode in the U.S. 1992-2014 (Federal Transit Administration, 2016)

It was also insightful to compare trends in capital spending by mode, as shown from 2011 to 2014 in Figure 4.31. Streetcar rail has had the largest increase in total spending during this period, with 5.52 times (552%) more spent in 2014 than in 2011. Large increases were also noted for hybrid rail (143% more spent in 2014 than in 2011) and monorail / automated guideway (112% more spent in 2014 than in 2011) modes. Moderate increases were also reported for taxi (40%), vanpool (33%), commuter bus (26%), light rail (23%), bus rapid transit (23%), and commuter rail (9%). Spending held steady for heavy rail (0%), but decreased slightly for demand response (-4%), bus (-6%), and ferryboat (-8%). More substantial decreases in spending were noted from 2011 to 2014 for trolleybus (-13%), inclined plane (-29%) and cable car (-79%) modes (Federal Transit Administration, 2016).

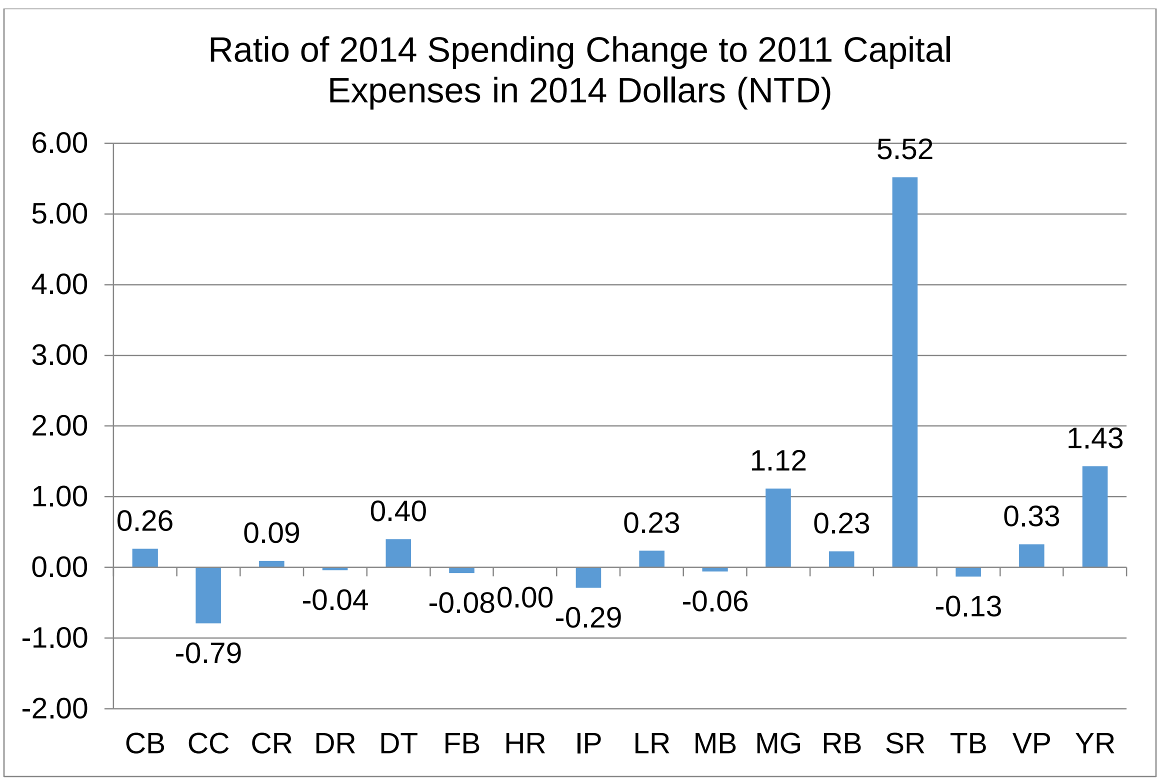


Figure 4.31 – Ratio of 2014 Spending Increase to 2011 Capital Expenses by Mode (Federal Transit Administration, 2016)

Of course, the prevalence of each mode has a major impact on its total capital expenditures. To adjust for this, average 2014 capital expenses were divided by total miles of transitways for each mode, as shown in Figure 4.32. Modes that did not have any reported transitways in 2014 were excluded from this analysis. Commuter bus had the lowest capital costs per transitway mile in 2014, at $1,063 per mile, followed by bus at $2,118 per mile. Trolleybus ($7,525 per mile) and commuter rail ($8,039 per mile) were next, followed by hybrid rail ($14,390 per mile) and bus rapid transit ($18,274 per mile). Streetcar rail capital expenses per transitway mile ranked 6th highest out of 12 modes included in this analysis, at $28,714 per mile, Monorail / automated guideway was next at $44,375 per mile, and then light rail came in at $59,873 per mile. Inclined plane had the 3rd highest capital costs per transitway mile, at $119,547, just below heavy rail at $125, 523. The highest capital costs per transitway mile by far were the San Francisco Cable Cars at $311,134 per mile (Federal Transit Administration, 2016).

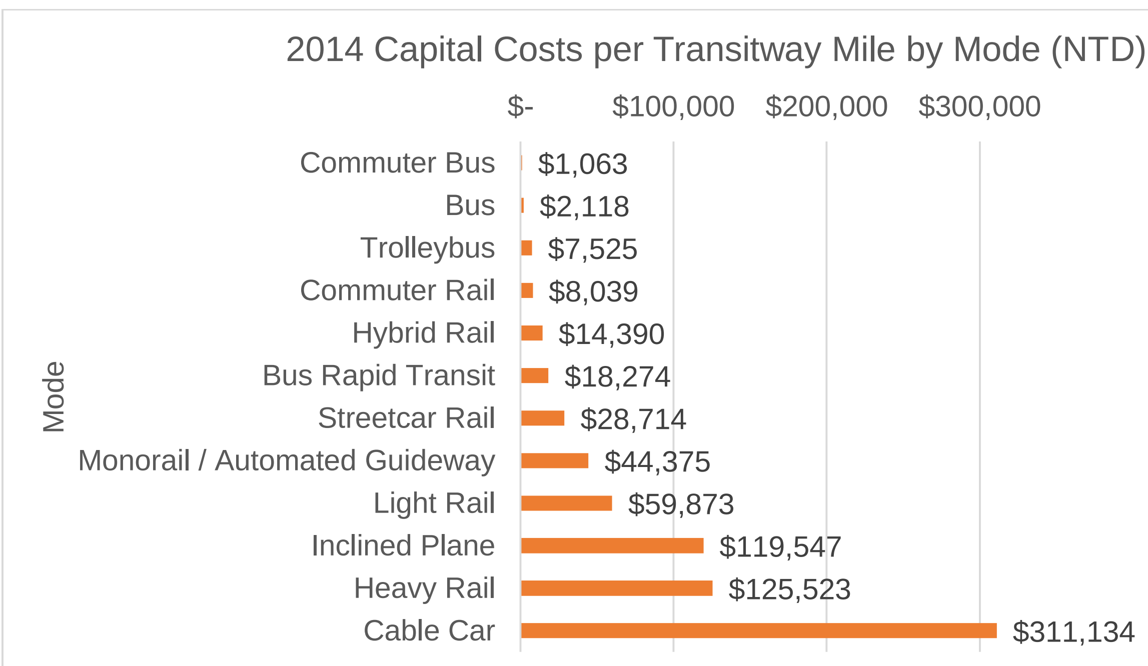


Figure 4.32 – 2014 Average Capital Costs per Transitway Mile by Mode in the U.S. (Federal Transit Administration, 2016)

4.6.2 Operating Costs

Operating costs are especially relevant to transit agencies and local municipalities, since fare revenue and local funding sources often cover a large portion of transit system operating budgets. In this case, an appropriate scaling factor seems to be the number of passenger miles traveled per mode, though this does appear to produce results favoring high-speed, long-distance modes. Operating expenses are considered on a per trip basis in the next section, which focuses on cost effectiveness.

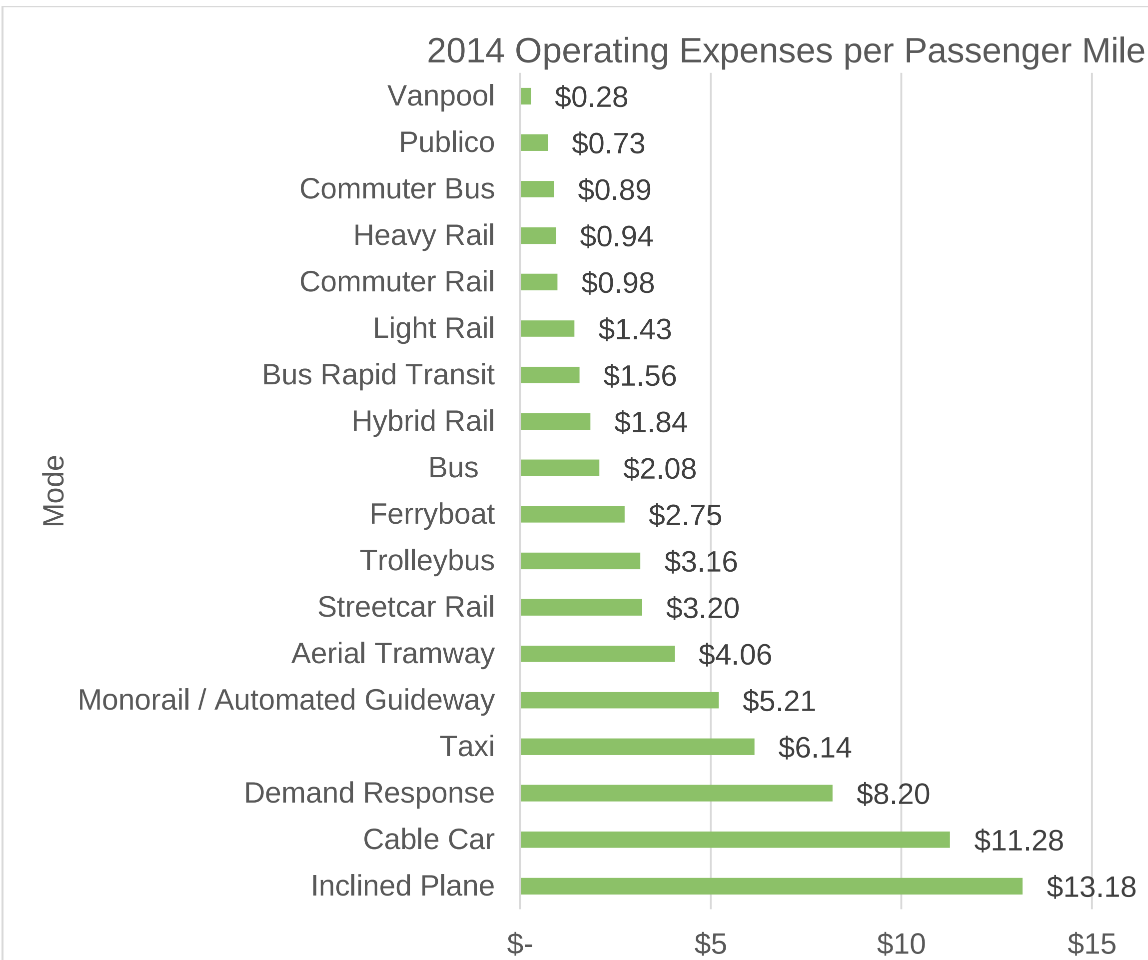


Figure 4.33 – 2014 Operating Expenses per Passenger Mile (Federal Transit Administration, 2016)

As shown in Figure 4.33, in 2014 vanpool had the lowest scaled operating expenses of modes reported to the NTD at $0.28 per passenger mile. Publico ($0.73), commuter bus ($0.89), heavy rail ($0.94), and commuter rail ($0.98) had the next lowest per passenger mile operating expenses that year. Light rail came next at $1.43 per passenger mile, followed by bus rapid transit ($1.56), hybrid rail ($1.84), and bus ($2.08). Above those modes were ferryboat ($2.75), trolleybus ($3.16), streetcar rail ($3.20), and aerial tramway ($4.06). Of the modes in the NTD in 2014, monorail / automated guideway had the 5th highest operating costs per passenger mile ($5.21), while taxi ($6.14) came in 4th and demand response ($8.20) came in 3rd. The two modes with the highest operating costs per passenger mile in the U.S. in 2014 were cable car ($11.28) in 2nd and inclined plane ($13.18) in 1st (Federal Transit Administration, 2016).

4.6.3 Cost Effectiveness

The ratio of fare revenue to operating expenses, often called the recovery ratio, is a common measure of transit system cost effectiveness. However, this metric only gives a partial understanding of the cost effectiveness of a particular transit service. To better understand the data behind this measure, fare revenue and operating expenses per unlinked passenger trip will also be considered in this section. Figure 4.34 presents the 2014 average recovery ratio for each transit mode in the U.S. reported to the NTD. Interestingly, the only mode to show an average recovery ratio above 1.0 (fare revenues exceed operating costs) was inclined plane with a recovery ratio of 1.10 (low of 0.21, high of 1.33). The next highest average recovery ratios were for publico (0.97) and vanpool (0.76). The recovery ratio for individual vanpool systems ranged from 0.17 to 2.40. Heavy rail (0.59) came after that, followed by cable car and commuter bus (both at 0.54), and then commuter rail (0.50). Heavy rail systems had recovery ratios from 0.14 to 0.78, while commuter bus and commuter rail had even larger ranges of 0.02 to 1.55 and 0.01 to 0.75, respectively. Monorail / automated guideway had a recovery ratio of

0.42 (ranging from 0.13 to 1.26), while trolleybus and streetcar rail came in at 0.35 (ranging from 0.13 to 0.40 and 0.04 to 047, respectively), followed by bus rapid transit (0.32 average, ranging from 0.06 to 0.74). Light rail (0.28 average, ranging from 0.13 to 0.56), bus (0.26 average, ranging from 0.01 to 1.50), ferryboat (0.25 average, ranging from 0.02 to 1.36), and aerial tramway (0.22) came next, followed by taxi (0.14 average, ranging from 0.00 to 0.95), hybrid rail (0.12 average, ranging from 0.07 to 0.20), and demand response (0.07 average, ranging from 0.00 to 1.01) (Federal Transit Administration, 2016).

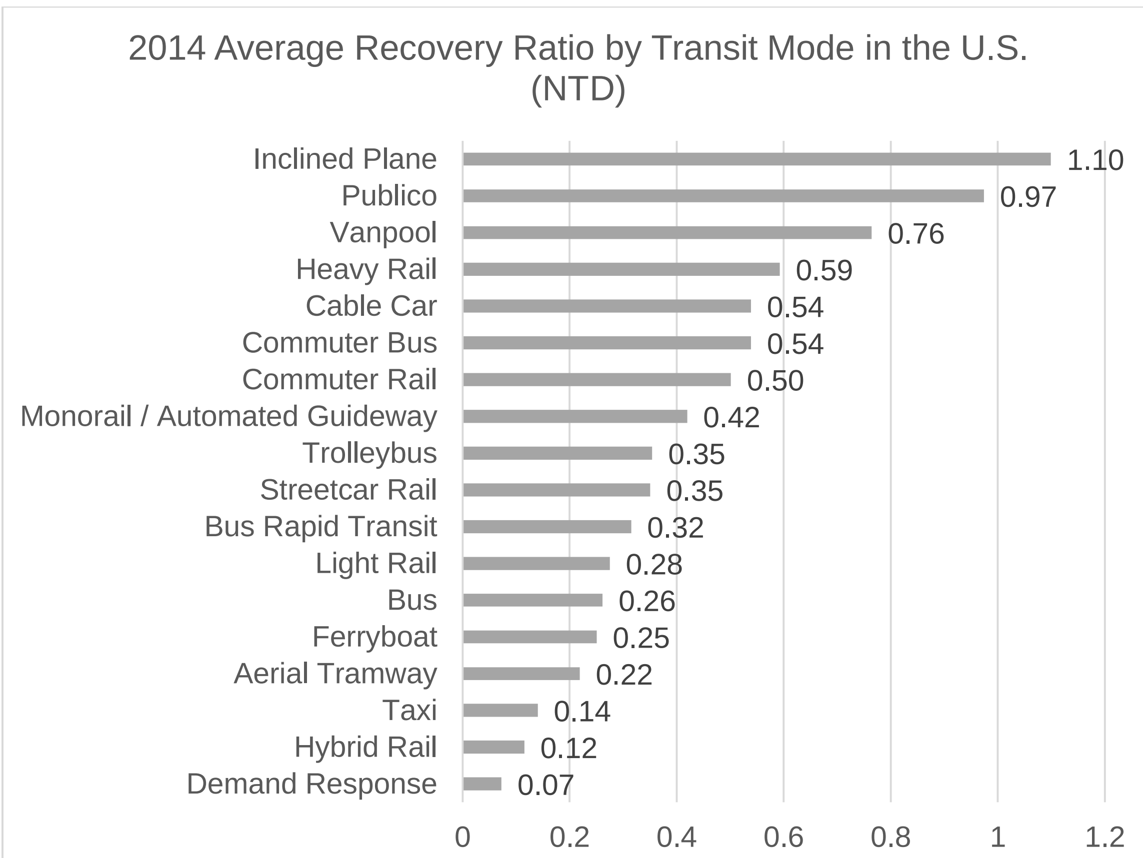


Figure 4.34 – 2014 Average Recovery Ratio by Transit Mode in the U.S. (Federal Transit Administration, 2016)

However, this may be an oversimplification, as the recovery ratio does not provide any information regarding the actual fare revenue or operating expenses per trip. Figure 4.35 shows both of these measures in relation to one another, which allows for deeper insights into the operating costs and revenues generated on a per trip basis. Inclined plane, for example, costs $2.74 per unlinked passenger trip to operate in the U.S., but fare revenues average $3.01 per trip, giving the high recovery ratio of 1.10. Publico has the 2nd lowest operating cost per trip at $1.45, but average fare revenues are only $1.41 per trip. Vanpool had operating costs of $4.64 per trip on average, and $3.55 in fare revenue. Heavy rail had the 3rd lowest operating cost per trip ($2.20), with an average $1.31 in fare revenue. The San Francisco Cable Cars had an average per trip operating cost of $7.11, with an average fare of $3.83. The commuter modes were next, with operating costs of $10.51 for commuter bus and $11.65 for commuter rail, and fare revenues of $5.66 and $5.84, respectively. Monorail / automated guideway got a recovery ratio of 0.42 based on operating costs of $3.34 per trip and fares of $1.40. Trolleybus ($2.61), streetcar rail ($2.91), bus rapid transit ($2.26), light rail ($3.62), and bus ($3.91) had fairly similar costs per trip and average fare revenue ($0.92, $1.02, $0.71, $0.99, and $1.02, respectively), producing similar recovery ratios. The Portland Aerial Tram had the lowest operating cost per trip ($1.30), but also the lowest fare revenue per trip ($0.22), due largely to the fact that most riders (hospital patients, staff, students, etc.) use the service for free. Taxi earned the 3rd lowest recovery ratio by having the 2nd highest operating costs ($23.68) and earning only $3.33 per unlinked passenger trip. Hybrid rail came in 2nd with operating costs of $11.56 and fare revenues of $1.34 per unlinked passenger trip. Demand response had the highest operating cost per passenger trip of $35.17, but only collected $2.56 in fare revenue per unlinked passenger trip (Federal Transit Administration, 2016).

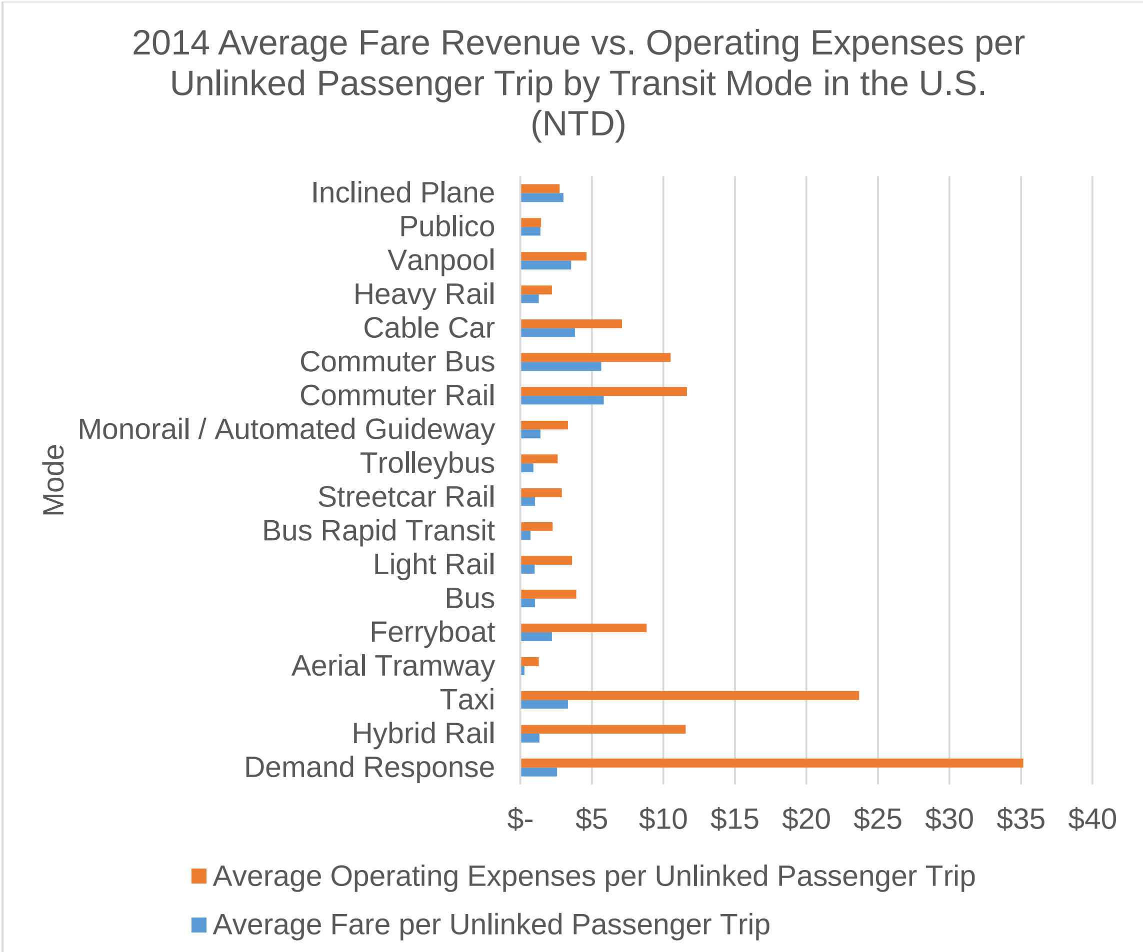


Figure 4.35 – 2014 Average Fare Revenue and Operating Expenses per Unlinked Passenger Trip by Transit Mode in the U.S. (Federal Transit Administration, 2016)

Fare revenue was also analyzed on a per passenger mile basis, to gain insights into customers' willingness to pay for various transit mode services. The results of this analysis are shown in Figure 4.36. It should be noted that fare revenue comprised the majority of directly generated funds for NTD reporters in 2014, but advertising, park and rides, concessions, and other forms of revenue can also be generated through transit service operations (Federal Transit Administration, 2016). Availability of government funding for various transit modes is discussed in the following section.

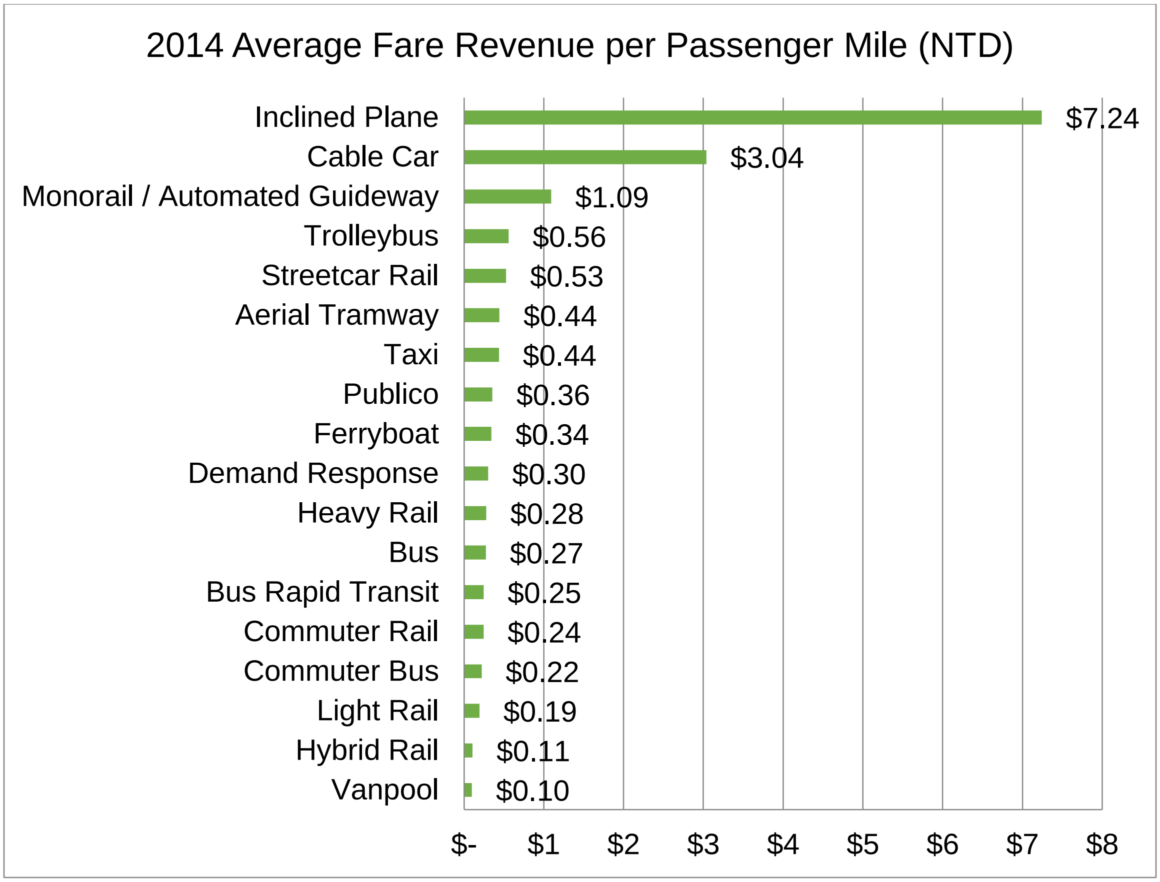


Figure 4.36 – 2014 Average Fare Revenue per Passenger Mile by Transit Mode in the U.S. (Federal Transit Administration, 2016)

Inclined plane rail and cable car rail received the highest fare revenue per passenger mile of any modes reported to the NTD in 2014, at $7.24 and $3.04 per passenger mile, respectively. Monorail / automated guideway ranked third with $1.09 per passenger mile, followed by trolleybus ($0.56), streetcar rail ($0.53), aerial tramway ($0.44), and taxi ($0.44). Slightly below these were the modes of publico ($0.36), ferryboat ($0.34), demand response ($0.30), heavy rail ($0.28), bus ($0.27), bus rapid transit ($0.25), commuter rail ($0.24), commuter bus ($0.22), and light rail ($0.19). The lowest values of fare revenue per passenger mile were calculated for hybrid rail ($0.11) and vanpool ($0.10) (Federal Transit Administration, 2016). From this analysis, it would appear that short-distance modes are able to collect more revenue per passenger mile of service delivered than long-distance modes. People also appear to be more willing to pay a premium on a per-passenger-mile basis for less common and historic modes, such as inclined plane, cable car, monorail / automated guideway, trolleybus, streetcar, and aerial tramway. Modes offering faster speeds and longer trip distances do not appear to be paying off in the U.S., judging by this measure. However, modes such as vanpool and other commuter modes had among the lowest operating costs per passenger mile, allowing them to still have a relatively high recovery ratio.

4.6.4 Availability of Funding

Availability of funding to expand and enhance transit infrastructure is a top consideration for many planning organizations, local municipalities, and transit agencies, since few have the capital available to fund major transit projects themselves, and financing only adds to the cost. The federal government offers several grant programs for supporting the creation, maintenance, and expansion of transit systems across the nation. One of the primary programs currently being offered is New Starts, which can be used to cover up to 80-90% of the total capital costs of systems over $300 million (or seeking $100 million or more in Section 5309 CIG program funds). This program is specifically for fixed guideway systems "using and occupying a separate right-of-way for the exclusive use of public transportation; using rail; using a fixed catenary system; for a passenger ferry system; or for a bus rapid transit system." The New Starts guidance document specifically refers to heavy rail, light rail, commuter rail, streetcars, trolleybus, fixed guideway bus rapid transit, and ferries as being eligible for these grants, and it is not clear how likely a project would be to get funding if a mode other than those listed was proposed, such as aerial tramway, automated guideway, cable car, gondola, funitel, inclined plane, maglev rail, monorail, water bus, or water taxi. Similar guidance is provided for the Small Starts (for projects under $300 million or seeking less than $100 million in Section 5309 CIG program funds) and Core Capacity programs (United States

Department of Transportation, 2016). Funding from these programs has gone to fund innovative systems like the Portland Aerial Tram and some automated guideway systems in the past, but naming a subset of acceptable transit mode options in the grant guidance document may discourage agencies from considering excluded modes.

Additional funding opportunities are offered through the FTA, including dedicated funding for buses and bus facilities, low- and no-emission vehicles, mobility on-demand demonstrations, passenger ferry services, and flexible funding for congestion mitigation and air quality, the National Highway Performance Program, and surface transportation projects (including highway, transit, intercity bus, bicycle, and pedestrian projects). Grants for planning, transit-oriented development, and temporary emergency relief are also provided through the FTA, along with funding specifically for rural and tribal areas. Perhaps the most relevant funding source for innovative transit modes would be the public transportation innovation funding "to develop innovative products and services assisting transit agencies in better meeting the needs of their customers." However, little information is provided about this particular program. Funds are said to be allocated on a discretionary basis, with rules and requirements potentially varying with each competitive opportunity. Eligible activities may include research, development, deployment, and evaluation of transit technologies (United States Department of Transportation, 2016).

4.6.5 Economic Development

Economic development is a common goal for making improvements to infrastructure in a particular area. However, some transit modes may support higher rates of economic growth than others. The typical approach to promoting more rapid development is to use modes that have a more permanent presence in the community and cannot be easily re-routed, which seems like a sound philosophy. Context plays an important role in deciding which modes are appropriate for any given area, though, so the benefits of features such as rails on the ground, faster speeds, and overhead catenaries should be weighed against the potential risks that they might pose to pedestrians, cyclists, and motorists, as well as the environmental and social impacts that they may have on the community. Fast-moving transit vehicles are not desirable in areas where they could easily injure or kill more vulnerable users. At the same time, transit riders may be frustrated and discouraged by slow-moving vehicles that must sit in traffic congestion, so modes with dedicated right-of-way are generally preferable in dense urban areas.

While context-sensitive planning and design of transit systems is always critical, there may be economic development benefits associated with innovative modes that are yet to be realized in the United States. During a trip to Medellin, Colombia for the World Urban Forum in 2014, the author learned about the transformation of this city from a time it was proclaimed to be the most dangerous city in the world (during the height of violence caused by the Medellin Cartel and others) to present day, when it had been recently honored by the United Nations as the Most Innovative City in the World. Investments in infrastructure and social programs had helped to turn this city around, with a major component of this change being driven by the debut of the world’s first urban gondola line in 2004. Innovative systems such as the Medellin Metrocable and high-speed maglev rail lines in Asia draw people from around the globe.

Similarly, even antiquated systems can draw tourists to an area, as demonstrated by the San Francisco Cable Cars or the numerous historic streetcars seen in cities like New Orleans. However, performance is also an important aspect of any transportation system, so one must remember that historic transit systems and other slower or less reliable systems may not meet the needs of local residents and workers who would benefit year-round from better transit options. As these individuals will not only be the ones funding infrastructure projects through their tax dollars, but also the people most impacted by the consequences (both positive and negative) of transit mode selection and implementation, transportation professionals and decision makers involved with public infrastructure projects should work closely with the local public to ensure that modes are considered and expanded that best meet the needs of the community at large, and will continue to fulfill those needs over the life of the project.

Areas that are likely to experience rapid growth may serve themselves well by choosing modes that can support this development, but it is not always the case that "if you build it, they will come". Even high-capacity heavy rail systems have been built in low-density areas of U.S. cities, and development has continued to stagnate for decades despite this amenity. Although there may be equity considerations that justify the location of major transit infrastructure in economically depressed, low-density areas, from an economic perspective, this can have a limiting effect on transit ridership and revenue generation, as well as economic development. Some would argue that resources would be better spent in areas that can generate and/or attract high numbers of transit users, so that the transit system can afford to operate safely and reliably, and continue to grow as needed without being stretched too thin. Ultimately, a balance should be sought between the environmental, social, performance, and economic concerns involved in any transit planning and mode selection processes, for optimal results to help generate additional riders and public support for transit.

4.6.6 Job Creation

Job creation in the transit industry not only provides social support for communities, but may produce economic benefits as well. However, job creation can also increase the cost of operating transit services, so these factors should be balanced appropriately for the project context. As shown in Figure 4.37, in the U.S. in 2014, more employee hours per passenger mile were used to operate the historic modes of inclined plane and cable car, which could be partially attributed to the lower capacities of the vehicles used for these modes. Trolleybus, monorail / automated guideway, and demand response had the next highest ratios of employee hours per passenger mile, followed by streetcar rail, ferryboat, and bus. With less than 0.01 employee hours per passenger mile were the modes of light rail, bus rapid transit, heavy rail, commuter rail, commuter bus, and vanpool (Federal Transit Administration, 2016).

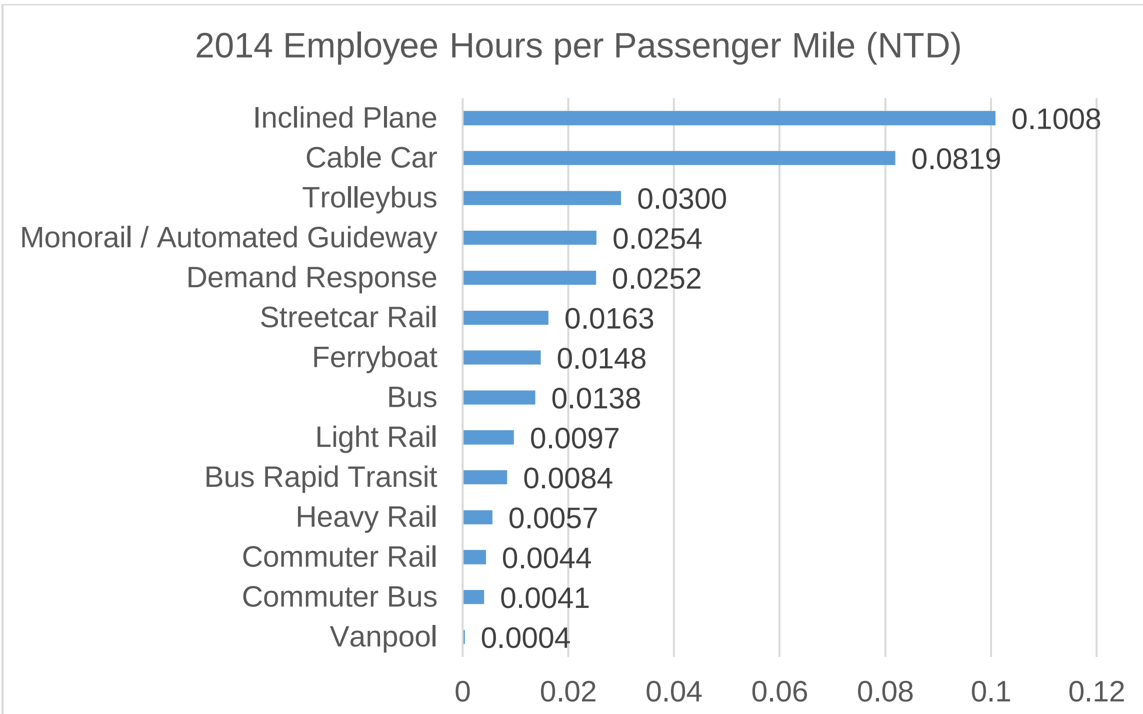


Figure 4.37 – 2014 Employee Hours per Passenger Mile (Federal Transit Administration, 2016)

To better understand how staff time is being used for each mode in the NTD, Figure 4.38 was created to compare employee hours by category. Vehicle operations accounted for more than 60% of employee hours for bus, bus rapid transit, cable car, commuter bus, demand response, and ferryboat. Meanwhile, 56% of streetcar rail and 52% of light rail staff hours are spent on vehicle operations, followed by 49% for inclined plane and 46% for trolleybus. Not surprisingly, monorail / automated guideway systems used only 26% of their employees' time for vehicle operations, but vanpool had the lowest proportion of staff time for vehicle operations at 19%.

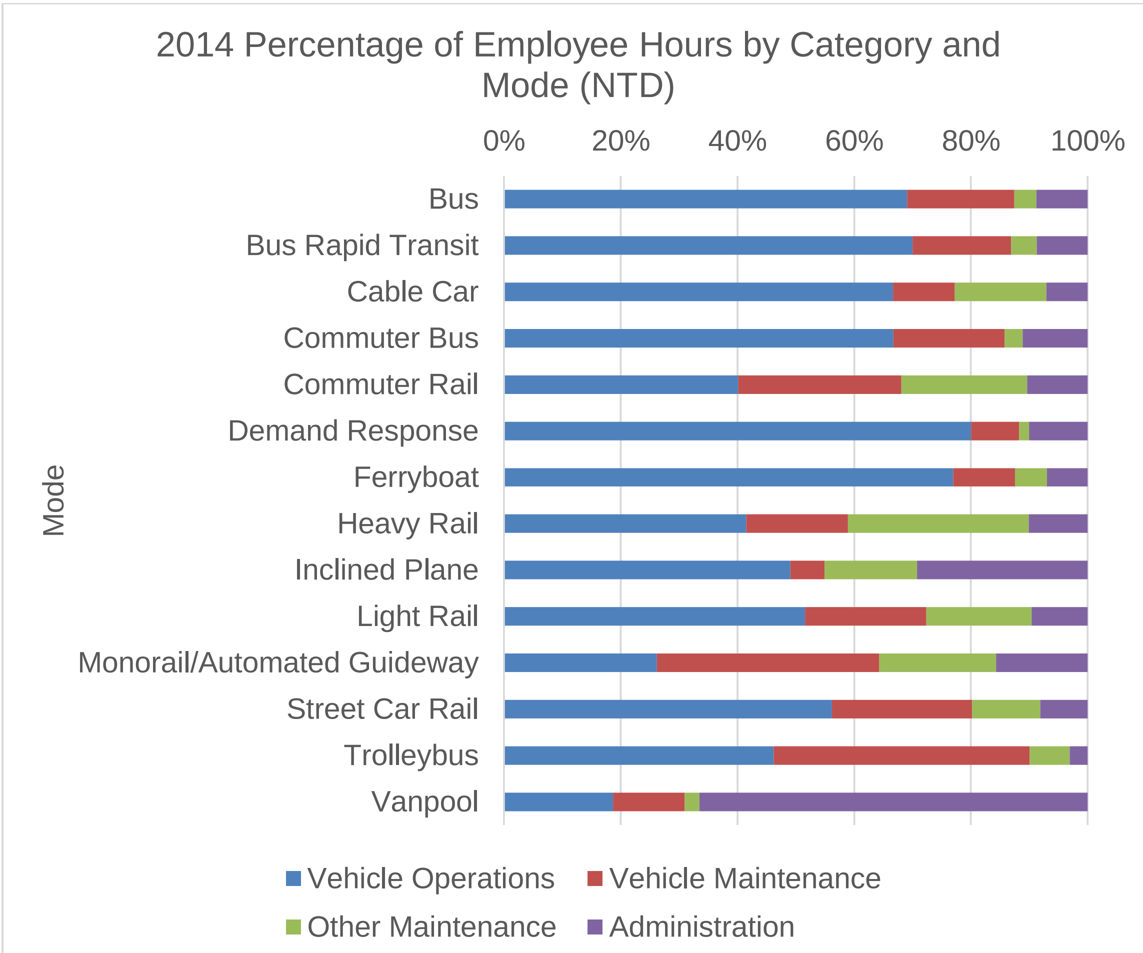


Figure 4.38 – 2014 Percentage of Employee Hours by Category and Mode (Federal Transit Administration, 2016)

Inclined plane systems had the lowest percentage of time spent on vehicle maintenance at 6%, followed by demand response at 8%. Next came cable car and ferryboat, both at 11%, then vanpool at 12%. Bus rapid transit and heavy rail systems used 17% of employee hours for vehicle maintenance, followed by bus (18%), commuter bus (19%), and light rail (21%). Higher still were streetcar rail (24%), commuter rail

(28%), monorail / automated guideway (38%), and trolleybus (44%). Other maintenance, such as for stations and other transit facilities, accounted for only 2% of demand response system staff time, and 3% employee hours for commuter rail and vanpool systems. Bus and bus rapid transit came in next with 4% of employee hours, followed by ferryboat with 5% and trolleybus with 7%. Other maintenance accounted for 12% of streetcar rail staff time, followed by cable car and inclined plane (16%) and light rail (18%). Monorail / automated guideway used 20% of staff time for other maintenance, followed by commuter rail (22%) and heavy rail, with the highest proportion of 31%.

Lastly, administration accounted for the largest portion of vanpool system staff time (67%), followed by inclined plane (29%) and monorail / automated guideway (16%). Commuter bus had 11% admin hours, while commuter rail, demand response, heavy rail, and light rail each had 10%. Bus and bus rapid transit each had 9%, followed by streetcar rail with 8%, cable car and ferryboat with 7%, and trolleybus with 3% (Federal Transit Administration, 2016).

Another factor to consider related to job creation is whether the jobs created are mostly part-time or full-time jobs. To analyze this aspect of job creation, annual hours per employee were calculated for each mode from 2014 NTD data, as shown in Figure 4.39. A typical 40-hour work week adds up to about 2080 hours per year, not accounting for paid time off. By comparison, 2857 hours were accrued for trolleybus staff in 2014, followed by 2202 for cable car employees, suggesting that these modes have many employees working overtime. Modes with employees working slightly less than full-time on average were commuter rail, light rail, bus rapid transit, monorail / automated guideway, streetcar rail, ferryboat, and heavy rail. Demand response and vanpool systems worked their employees about 30 hours per week on average, followed by inclined plane, commuter bus, and bus (Federal Transit Administration, 2016). It is very curious that trolleybus and bus would lie on opposite ends of this range.

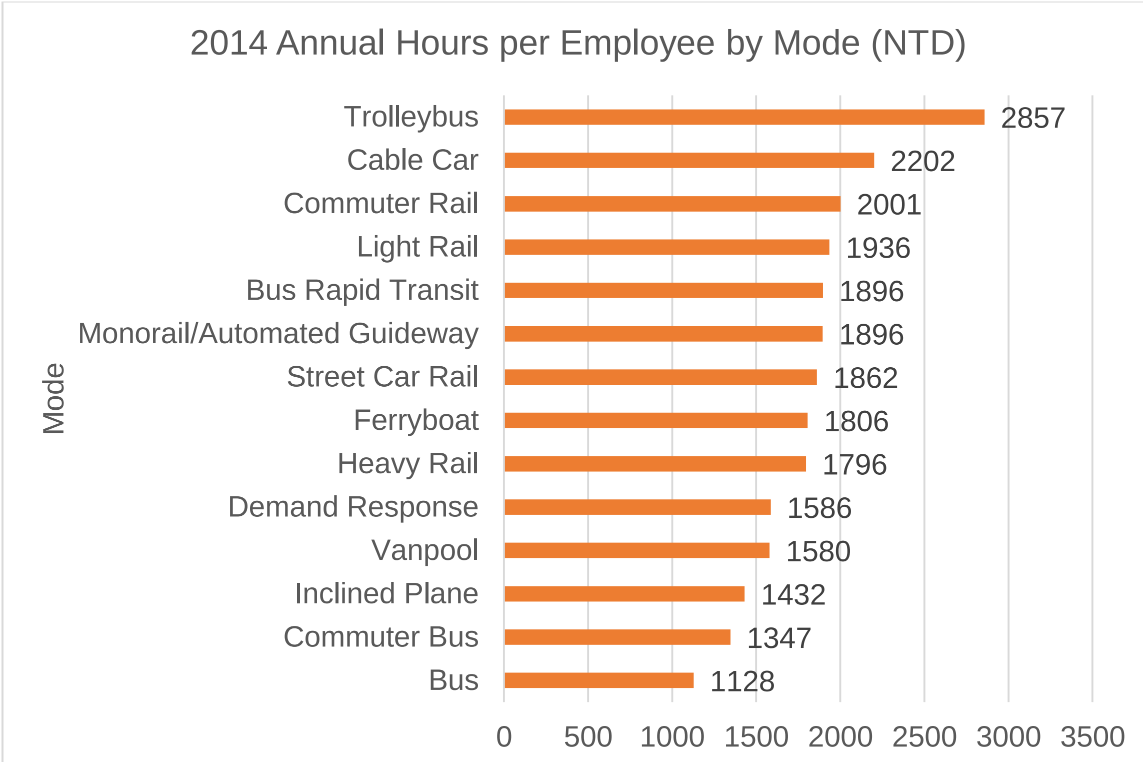


Figure 4.39 – 2014 Annual Hours per Employee by Mode (Federal Transit Administration, 2016)

The average hourly rate of pay (based on salaries, not including benefits) was also calculated for each mode reported to the NTD in 2014, as shown in Figure 4.40. Vanpool had the highest rate of pay at $87.10 per hour, which may relate to the large portion of employee hours used for administration. Heavy rail was next at $75.93, followed by commuter rail at $74.18. Modes with average pay over $60 per hour included cable car ($68.78), ferryboat ($68.20), bus rapid transit ($64.85), streetcar rail ($63.39), and commuter bus ($61.61). Modes for which employees were paid over $50 per hour were light rail ($56.70), monorail / automated guideway ($56.46), bus ($56.41), and inclined plane ($51.19). On the low end of the pay scale were trolleybus ($47.07) and demand response ($44.93) modes (Federal Transit Administration, 2016).

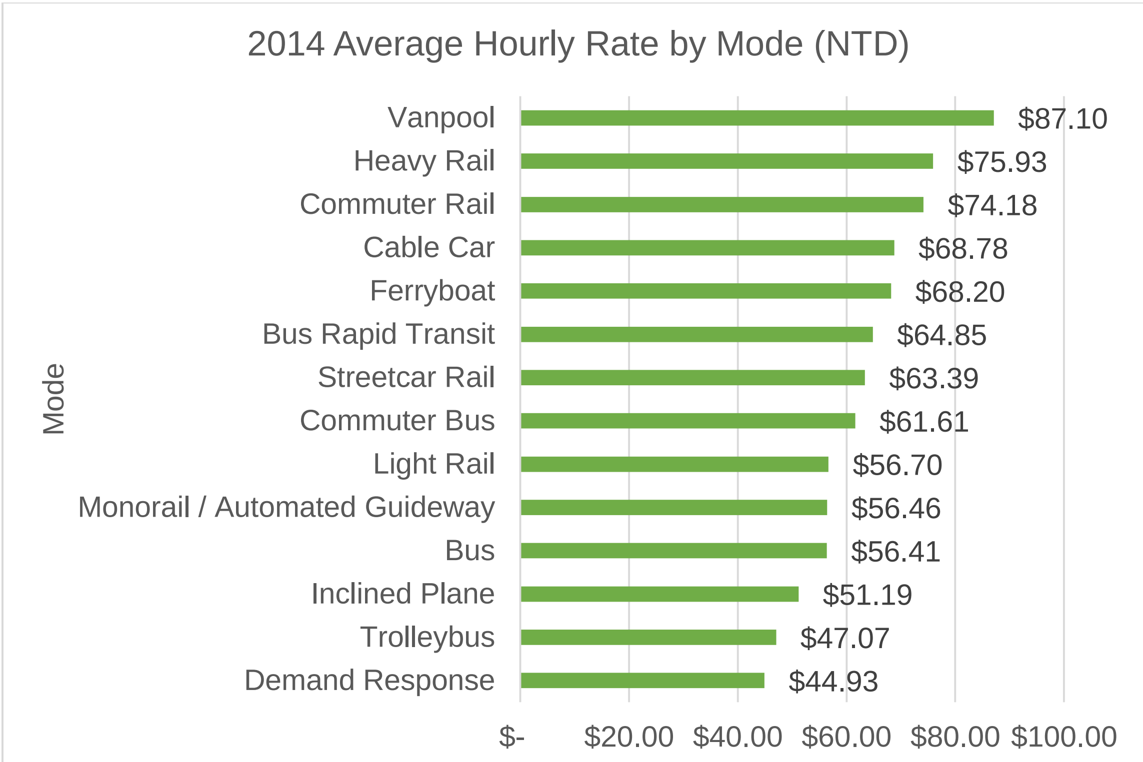


Figure 4.40 – 2014 Average Hourly Rate by Mode (Federal Transit Administration, 2016)

4.6.7 Other Economic Factors

Although economic data was readily available for many of the economic factors considered in this study, information was lacking in several areas. The need for highly skilled workers was a factor that is not easily assessed from available data, although typical employee rates of pay shown in Figure 4.40 could offer some indication of required skill level for operating each mode. Jobs access is largely driven by the planning and decision making for individual projects or systems, while some modes are clearly more innovative than others. Transit systems often rely on imported technology, but some new technologies, such as American Maglev, are being developed in the U.S.

CHAPTER 5

URBAN TRANSIT CASE STUDIES

As demonstrated in Chapter 3, some modes are more familiar to transit professionals in the U.S. than others. More familiar modes tend to have many examples and an abundance of data to draw from, while data and case studies for less familiar modes are more difficult to find. Less familiar modes (those with an average familiarity rating of 3.5 or less) include aerial tramway, funitel, gondola, cable car, hybrid rail, inclined plane, maglev rail, monorail / automated guideway, jitney, publico, ferryboat, water bus, and water taxi. In addition to gathering and analyzing national transit data, case studies are provided in this chapter to offer specific examples of each lesser-known type of transit system in urban areas around the globe.(except for funitel, which has not yet been used in an urban setting). When possible, examples from cities in the U.S. are used, but otherwise case studies are taken from around the globe.

5.1 Aerial Modes

Two aerial tramways are currently operating in the United States, but we have yet to implement any urban gondola systems. Although they are not shown here, many gondola systems have operated successfully on ski resorts and in tourist areas around the U.S. for several decades. Funitel is a newer technology that has been demonstrated on ski resorts around the world, including the Gold Coast Funitel at Squaw Valley Ski Resort in California, which can transport up to 4,000 people per hour per direction. Funitels offer lower profiles and better wind resistance than gondolas and aerial tramways, so may be strategic for implementation in certain urban areas.

5.1.1 Aerial Tramway

The only two examples of urban aerial tramways in the U.S. are the Roosevelt Island Tram in New York and the new Portland Aerial Tram in Oregon.

5.1.1.1 Roosevelt Island Tram

The Roosevelt Island Tram was originally built in 1976 as a temporary transportation system, while a subway line was being built. However, challenges with construction of the subway led to cost and construction time overruns, which eventually led to the abandonment of the project. Instead, the temporary Roosevelt Island Tram was reinforced to become a permanent, iconic installation within New York City’s vast public transit network (Richman, 2012). This line connects the island of Manhattan with nearby Roosevelt Island, with a one-way ride time of three minutes. The system, which is popular with residents and tourists, was renovated in 2010 at the cost of $25 million (Creative Urban Projects, 2013). An image of the Roosevelt Island Tram is shown in Figure 5.1 below, with a summary of system characteristics provided in Table 5.1 on the following page.

Figure 5.1 – Roosevelt Island Tram (Photo by: Drew XXX on flickr)

Table 5.1 – Roosevelt Island Tram Characteristics (Creative Urban Projects, 2013)

Year Built	1976 (refurbished in 2010)
Length (miles)	0.6
Stations	2
Max / Average Speed (mph)	17 / 12
Capacity (pphpd)	1,000
System Cost	$25 million (for 2010 renovation)
Cost / Mile	~$40 million
Fare	$2.25
Annual Ridership	2,400,000

5.1.1.2 Portland Aerial Tram

The Portland Aerial Tram was opened to the public in 2007, making it the newest urban aerial tramway in the United States. This 0.6 mile line connects the City of Portland's largest employer, the Oregon Health and Science University (OHSU), to a streetcar station across a major highway, near the waterfront. Although the $4.00 fare applies to tourists and riders from the general population, students and employees of OHSU ride the system for free. Although the final system costs were approximately five times the initial estimates, due mostly to its fully customized design, this aerial tramway has quickly become an iconic symbol of Portland's creative, multimodal transportation system, and won multiple architectural awards. The unique appearance, fare structure, travel time savings, and convenience of the system have contributed to its popularity, demonstrated by it having more than twice the projected ridership expected (Creative Urban Projects, 2013). An image of the Portland Aerial Tram is shown in Figure 5.2 with a summary of system characteristics provided in Table 5.2 on the following page.

Figure 5.2 – Portland Aerial Tram (Photo by: Cacophony on Wikipedia)

Table 5.2 – Portland Aerial Tram Characteristics (Creative Urban Projects, 2013)

Year Built	2007
Length (miles)	0.6
Stations	2
Max / Average Speed (mph)	22 / 12
Capacity (pphpd)	980
System Cost	$57 million
Cost / Mile	~$92 million
Fare	$4.00
Annual Ridership	1,350,000

5.1.2 Gondola

Gondolas offer higher capacities than aerial tramways in general, making them well-suited to congested urban areas. The on-demand nature of gondolas allows them to have short waiting times, which helps to offset their potentially longer travel times due to slightly slower operating speeds than aerial tramways. Since no urban gondolas have yet been implemented in the United States, the following case studies include gondola lines in Medellin, Colombia and London, England.

5.1.2.1 Medellin Metrocable Line K

Line K of the Medellin Metrocable, the world's first urban gondola system, is fully integrated with the city's larger public transit network (which includes light rail and bus rapid transit, among other modes). This line serves some of the densest residential areas of Medellin, which are largely composed of dwellings constructed on steep terrain high above the major commercial and job centers that lie in the valley below. As a result of greater access to transportation, jobs, clean water, and reliable electricity, residents of these neighborhoods and the larger metropolitan area have seen notable economic benefits from this public investment, as observed first-hand by the author during her visit to Medellin in 2014. Stations serve as community resources and gathering places, with many food, entertainment, and educational amenities available on-site or nearby. Line K also provides a direct connection to Line L, which connects to Park Arvi, an eco-tourism destination that was previously only reached via a roughly four-hour drive through the mountains. Higher fares of about $4.00 are charged for one-way trips on this line, since it is predominantly used for tourism and leisure. Overall, Line K provides an excellent example of how a gondola system can be efficiently and affordably built using public funds, but the costs are likely lower than would be expected for U.S. cities. A photo of Medellin Line K is shown in Figure 5.3, with more details provided in Table 5.3.

Figure 5.3 – Medellin Line K

Table 5.3 – Medellin Line K Characteristics (Creative Urban Projects, 2013)

Year Built	2004
Length (miles)	1.2
Stations	4
Max / Average Speed (mph)	11 / 11
Capacity (pphpd)	3,000
System Cost	$26 million
Cost / Mile	~$21 million
Fare	$1.00
Annual Ridership	12,000,000

5.1.2.2 London Emirates Air Line

The Emirates Air Line was built in less than a year, in anticipation of the 2012 London Olympics. The system was designed to provide an additional means of crossing the Thames River and connect two major Olympic venues (the O2 Arena and the ExCel Centre), but is only partially integrated with the larger transit network in London (which includes heavy rail and bus, among other modes). This lack of integration, along with higher than average fares and lower than average operating speeds have contributed to declines in ridership since the peak of over 180,000 trips during the week ending August 11, 2012. The number of passenger journeys in recent weeks has ranged from 20,000-45,000 (Transport for London, 2016). Custom support towers that soar up to 250 feet above the ground contributed to increased project costs (the highest per mile of any gondola system built at the time), but these were partially offset by Emirates Airlines paying 60% of the total cost in exchange for advertising rights (Creative Urban Projects, 2013). The cost of this project is likely higher than would be expected in a U.S. city, though complexity and customization of the system does tend to drive costs up. Although this project ended up with higher construction costs and lower ridership than planned, it provides a useful example of how private funding can be leveraged to support public infrastructure expansion. An image of the Emirates Air Line is shown in Figure 5.4, with more details provided in Table 5.4.

Figure 5.4 – London Emirates Air Line (Photo by: Karen Roe on flickr)

Table 5.4 – London Emirates Air Line Characteristics (Creative Urban Projects, 2013)

Year Built	2012
Length (miles)	0.7
Stations	2
Max / Average Speed (mph)	14 / 8
Capacity (pphpd)	2,500
System Cost	$90 million
Cost / Mile	~$132 million
Fare	$6.85
Annual Ridership	1,538,579* (in 2015)

*Source: (Transport for London, 2016)

5.2 Rail Modes

Lesser-known rail modes include a combination of heritage modes, such as cable car and inclined plane, as well as newer transit modes, including hybrid rail, maglev, and monorail / automated guideway. While new transit modes are more likely to be considered in today's alternatives analyses, modern versions of heritage modes are also available.

5.2.1 Cable Car

Unlike the historic cable cars that are being operated in San Francisco, modern versions of the cable car, such as the CABLE Liner by Doppelmayr are available. This modular mode offers a similar experience to light rail transit, but with additional benefits of cable-propelled transit technologies. One example system is being used to connect Bay Area Rapid Transit (BART) to the Oakland International Airport, while another is used as a shuttle to and from the MGM CityCenter in Las Vegas.

5.2.1.1 BART to Oakland International Airport

The Doppelmayr CABLE Liner system was used to implement automated guideway service between the BART system and Oakland International Airport. The 3.2 mile trip takes 8.5 minutes on average, with peak headways of six minutes. The system has achieved higher ridership than any of the buses that have served the airport in recent years, with approximately one million riders in the first year of operating. The BART to Oakland International Airport connector uses a pinched loop system, which allows train cars to move from one side of the double guideway system to the other at terminal entrances. The four three-car walk-through trains are propelled by four cable loops driven by motors at the mid-station (Doolittle) (Doppelmayr Seilbahnen GmbH, 2016). An image of the completed airport connector system is shown in Figure 5.5, with more details available in Table 5.5.

Figure 5.5 – BART to Oakland International Airport CABLE Liner (Doppelmayr Seilbahnen GmbH, 2016)

Table 5.5 – BART to Oakland International Airport CABLE Liner Characteristics (Doppelmayr Seilbahnen GmbH, 2016)

Year Built	2014
Length (miles)	3.2*
Stations	3
Max / Average Speed (mph)	31 / 23
Capacity (pphpd)	1,500
System Cost	$484 million*
Cost / Mile	~$151 million*
Fare	$6.00*
Annual Ridership	1,000,000* (first year)

*Source: (San Francisco Bay Area Rapid Transit District, 2016)

5.2.1.2 Venice People Mover

Information about CABLE Liner systems is fairly limited, especially since many systems operated with connections to airports, hotels, and resort areas are free and privately owned and operated. One rather unique application of this technology was found in the Venice People Mover. This short (half mile) line connects the island of

Tronchetto with Piazzale Roma near the historic quarter via the Marittima passenger terminal, which is one of the largest cruise ship ports in the Mediterranean region. This system operates from 6:00 am to 11:00 pm daily, in an area that attracts about 15 million tourists per year. The cost of this project (as taken from the Doppelmayr contract amount) was a modest $35 million per mile, perhaps due to the single-track design with bypassing at the intermediate station (Doppelmayr Seilbahnen GmbH, 2016). An image of the system is shown in Figure 5.6, with additional information provided in Table 5.6.

Figure 5.6 – Venice People Mover (Doppelmayr Seilbahnen GmbH, 2016)

Table 5.6 – Venice People Mover Characteristics (Doppelmayr Seilbahnen GmbH, 2016)

Year Built	2010
Length (miles)	0.5
Stations	3
Max / Average Speed (mph)	18 / 10*
Capacity (pphpd)	3,000
System Cost	$18 million
Cost / Mile	~$35 million
Fare	$1.65*
Annual Ridership	1,000,000**

*Source: (Imboden & Imboden, Venice People Mover, 2016)
**Estimated based on July 2010 daily ridership taken from Wikipedia

5.2.2 Hybrid Rail

Five examples of hybrid rail are reported to the NTD currently, though at least two of these systems are branded as commuter rail and at least one as light rail. Given that hybrid rail shares many characteristics of both these modes, but is less familiar in general, this is not surprising. Two of these systems in the U.S. are described below, including New Jersey Transit's River LINE and Capital MetroRail in Austin, Texas.

5.2.2.1 NJ Transit River Line

The New Jersey Transit River Line was originally planned to be an electrified light rail line between Camden and Trenton, along the Delaware River. However, to reduce capital costs and respond to community opposition to electrified light rail, NJ Transit changed the mode for this project to hybrid rail (using diesel-electric multiple unit trains from Swiss manufacturer Stadler in partnership with Bombardier on light rail tracks). Each train car seats 90 people, and 2-car trains are used during peak hours to accommodate 180 people per train. The peak 15-minute headways limit this system's operating capacity to just 720 passengers per hour per direction. Although ridership has reportedly been higher than initially projected (Light Rail Now Project, 2004), in 2014 the average number of passengers per vehicle for the River Line was just under 35 (39% of vehicle capacity). Still, this figure compares favorably to NJ Transit's light rail lines, which both averaged about 23 passengers per vehicle (Federal Transit Administration, 2016). An image of the River Line system is shown in Figure 5.7, with additional information provided in Table 5.7.

Figure 5.7 – NJ Transit River Line (Photo by: David Wilson on flickr)

Table 5.7 – NJ Transit River Line Characteristics (Light Rail Now Project, 2004)

Year Built	2004
Length (miles)	34
Stations	20
Max / Average Speed (mph)	60 / 30*
Capacity (pphpd)	720
System Cost	$1.1 billion
Cost / Mile	~$32 million
Fare	$1.60*
Annual Ridership	2,869,700**

*Source: Timetable from NJ Transit (New Jersey Transit, 2015)
**Source: National Transit Database 2014 Data (Federal Transit Administration, 2016)

5.2.2.2 Capital MetroRail Red Line

After decades of planning, several votes, and many delays, the Capital MetroRail Red Line opened to the public in March of 2010. This 32-mile line connects Leander, a northwestern suburb of Austin, to the downtown convention center area of Austin. Like the NJ Transit River Line, Capital MetroRail's Red Line operates on existing railroad tracks with temporal separation from freight rail vehicles. Although daily ridership was predicted to average between 1,600-2,000 passenger trips, the system was averaging only 1,000 daily trips when it first opened. In 2014, daily ridership was averaging slightly above 2,000 trips per day. Unfortunately, operating on existing freight rail meant that this hybrid rail line does not pass through some of the densest parts of Austin, which could have helped generate higher ridership (Light Rail Now Project, 2010). Peak headways of 31 minutes contribute to a limited capacity for this system of 460 passengers per hour per direction (Capital Metropolitan Transportation Authority, 2015). An image of the Red Line system is shown in Figure 5.8, with additional information provided in Table 5.8.

Figure 5.8 – Capital MetroRail Red Line (Photo by: Larry D. Moore on Wikipedia)

Table 5.8 – Capital MetroRail Red Line Characteristics (Light Rail Now Project, 2010)

Year Built	2010
Length (miles)	32
Stations	9
Max / Average Speed (mph)	60 / 32
Capacity (pphpd)	460
System Cost	$120 million
Cost / Mile	~$4 million
Fare	$2.00-3.00
Annual Ridership	763,600*

*Source: National Transit Database 2014 Data (Federal Transit Administration, 2016)

5.2.3 Inclined Plane

The late 19th Century and early 20th Century were clearly the golden age of inclined plane railways in the United States. Several systems built in the 1800s are still operational today, such as the Lookout Mountain Incline Railway near Chattanooga, Tennessee, but many more have ceased operations. Inclined plane rail is used at many tourist destinations outside of urban areas, but some systems have been used within the urban core of U.S. cities. One example of an operational historic urban inclined plane system is the Duquesne Heights Incline in Pittsburgh, Pennsylvania. This system opened to the public in 1877 at a cost of $47,000, length of 794 feet (with 400 feet of elevation change), grade of 30.5 degrees, and speed of 6 mph. An inclined plane system has recently opened in a New York City subway station, and the historic system built to reach Montmartre, Paris was also rebuilt, as described below.

5.2.3.1 New York City

At 125 feet below street level, the 34th Street – Hudson Yards Station is one of the deepest of the New York City MTA heavy rail system. One solution to the challenge of bringing transit users to the city surface was to install a custom-made pair of inclined elevators capable of holding 15 people standing or 5 wheelchairs at a time, which make this station ADA-compliant and helped to reduce tunneling costs (MTA Transit & Bus Committee, 2014). The elevators are shown in Figure 5.9 and detailed in Table 5.9.

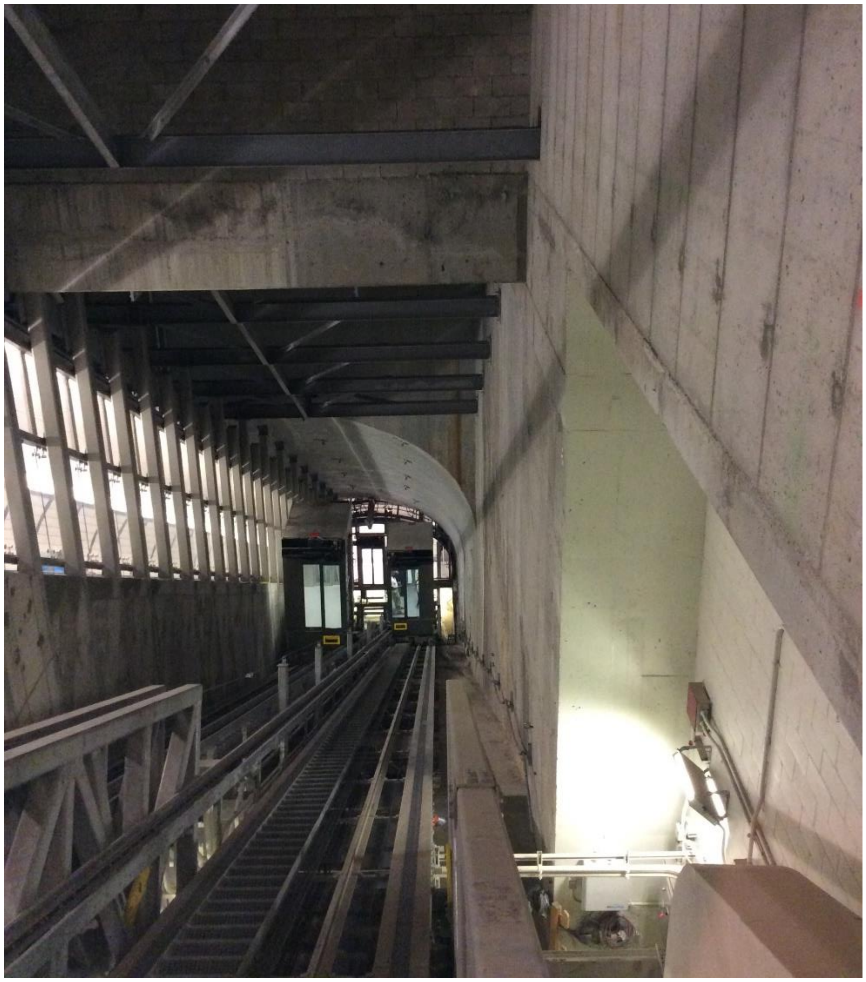


Figure 5.9 – MTA Inclined Elevators (Photo by: Epicgenius on Wikipedia)

Table 5.9 – MTA Inclined Elevator Characteristics (MTA Transit & Bus Committee, 2014)

Year Built	2014
Length (miles)	0.03
Stations	2
Max / Average Speed (mph)	1 / 1
Capacity (pphpd)	450
System Cost	$2.7 million
Cost / Mile	~$90 million
Fare	Free
Annual Ridership	Not Available

5.2.3.2 Paris

The inclined plane railway serving the Montmartre neighborhood in Paris, France was originally built in 1900, but was rebuilt in 1935 and 1991. It is an autonomous line that runs adjacent to a large staircase along two parallel tracks, bringing passengers from the Place St-Pierre up to the foot of the Basilica of Sacre-Coeur, as well as within walking distance of other local destinations. This funicular system is integrated with the Paris Metro and uses the same fare structure. Each of the two independently moving vehicles holds up to 60 passengers (Imboden & Imboden, Montmartre Funicular, 2016), and the system serves roughly 2 million trips annually (BootsnAll Travel Network, 2010). The inclined plane rail system is shown in Figure 5.10 and detailed in Table 5.10.

Figure 5.10 – Montmartre Funicular (Photo by: Anthony Atkielski on Wikipedia)

Table 5.10 – Montmartre Funicular Characteristics (Paris Convention and Visitors Bureau, 2015)

Year Built	1900 (rebuilt in 1935 and 1991)
Length (miles)	0.07
Stations	2
Max / Average Speed (mph)	8* / 3
Capacity (pphpd)	3,000**
System Cost	$7.8 million* (for 1991 renovation)
Cost / Mile	~$112 million*
Fare	$2.00
Annual Ridership	2,000,000***

*Source: (Gennesseaux, 1992)
**Source: (LEITNER AG, 2016)
***Source: (BootsnAll Travel Network, 2010)

5.2.4 Maglev Rail

No commercial maglev rail operations have yet been built in the United States. A few demonstration projects do exist in the U.S., such as the American Maglev Technologies Test Track in Powder Springs, Georgia. Asia has implemented more commercial maglev systems to date than any other continent, so the case studies included here include a high-speed maglev train in Shanghai and Linimo in Aichi, Japan.

5.2.4.1 Shanghai High-Speed Maglev

After almost three years of construction, the world's first commercial high-speed maglev train opened as a connection to the Pudong International Airport in Shanghai, China. The system uses German Transrapid maglev technology and currently operates 464-passenger trains at a peak of 15-minute intervals at speeds of up to 267 mph. One-way trips take approximately 7.5 minutes, meaning an average speed of 152 mph (Shanghai Maglev Transportation Development Co., Ltd., 2005). Unfortunately, the lack of integration between the Shanghai Maglev Train and the Shanghai Metro has contributed to low ridership of only 20% the offered capacity (Zhong, 2007). The high-speed maglev rail system is shown in Figure 5.11 and detailed in Table 5.11.

Figure 5.11 – Shanghai Maglev Train

Table 5.11 – Shanghai Maglev Train Characteristics (Coates, 2005)

Year Built	2004
Length (miles)	19
Stations	2
Max / Average Speed (mph)	267 / 152
Capacity (pphpd)	1,850*
System Cost	$1.2 billion
Cost / Mile	~$65 million
Fare	$7.50*
Annual Ridership	2,500,000 (first year operating)

*Source: (Shanghai Maglev Transportation Development Co., Ltd., 2005)

5.2.4.2 Linimo

Originally built for the Expo 2005, the Linimo system was Japan's first example of commercial High Speed Surface Transport (HSST), which is proposed as an alternative to traditional heavy rail. Linimo is an unmanned autonomous transit mode, but it should not be confused with the autonomous high-speed trains. This system has a top speed of 62 mph, but averages 15 minute travel times for a 5.5 mile trip, giving it an average speed of 22 mph (Yasuda, Fujino, Tanaka, & Ishimoto, 2004). The system is said to be exceptionally quiet (Aichi Rapid Transit Co., Ltd., 2016), and easily able to ascend grades of up to 6% along the track since it is propelled through linear induction, rather than friction forces. A few challenges have been noted with this system, including the inability to operate when the train is overweight, since it cannot levitate, as well as safety concerns with operating in wind speeds over 55 mph (Maglev Board, 2016). The Linimo Fujigaoka terminal station is accessible from the Chubu Centrair International Airport by train or bus, and provides a connecting service to northeastern suburbs of Nagoya (Aichi Rapid Transit Co., Ltd., 2016). The Linimo maglev rail system is shown in Figure 5.12 and detailed in Table 5.12.

Figure 5.12 – Linimo Maglev Train (Photo by: Chris 73 on Wikipedia)

Table 5.12 – Linimo Train Characteristics (Yasuda, Fujino, Tanaka, & Ishimoto, 2004)

Year Built	2005
Length (miles)	5.5
Stations	9
Max / Average Speed (mph)	62 / 22
Capacity (pphpd)	3,500
System Cost	$955 million*
Cost / Mile	~$174 million*
Fare	$1.62-3.54**
Annual Ridership	4,380,000* (estimated from daily)

*Source: (Glenn, 2011)
**Source: (Aichi Rapid Transit Co., Ltd., 2016)

5.2.5 Monorail / Automated Guideway

Monorail and automated guideway systems should not be confused. Monorail systems are defined as being supported by a single rail guideway, while automated guideway systems are defined as being guided by autonomous systems. They are grouped here only for the sake of continuity and conformity to NTD standard practices. At least four automated guideway systems have already been discussed, including all of the inclined rail and maglev case studies. Monorail systems are currently used in Seattle, Washington and Jacksonville, Florida, but these systems are over 25 years old. The most recently built public monorail system is in Las Vegas, as described below. The case of a much longer monorail line in Daegu, South Korea is also shared in this section.

5.2.5.1 Las Vegas Monorail

The Las Vegas Monorail was originally proposed as a one-mile system linking the MGM Grand and Bally's Hotel, which came to fruition in 1993. The system has since been expanded, and the nonprofit Las Vegas Monorail Company has been formed to oversee management and operations of the public system, which officially opened in July 2004. The current system provides direct connections between many prominent destinations, including the Las Vegas Convention Center and several hotels and casinos. While a one-way single ride ticket costs $5.00, Nevada residents can ride the monorail for just $1.00 each way (Las Vegas Monorail, 2016). To date, the $650 million cost of the monorail has been paid for primarily through private funding from participating businesses and tax exempt revenue bonds, making this system the first and only privately owned public transportation system in the U.S. operating without public subsidies (Federal Highway Administration). However, only $342 million of this amount went toward the actual construction of the monorail system, plus $142 million for construction of other fixed facilities, including stations built to the standards of participating hotels and casinos. Almost $190 million was set aside for operating the system, with another $11 million for utilities. Financing and project reserve costs also drove up the total price tag of this project (Austin Monorail Project, 2003). The Las Vegas Monorail is shown in Figure 5.13 and detailed in Table 5.13.

Figure 5.13 – Las Vegas Monorail (Photo by: Kim Pederson on The Monorail Society)

Table 5.13 – Las Vegas Monorail Characteristics (Las Vegas Monorail, 2016)

Year Built	2004
Length (miles)	3.9
Stations	7
Max / Average Speed (mph)	50* / 18*
Capacity (pphpd)	3,330
System Cost	$484 million**
Cost / Mile	~$124 million**
Fare	$5.00
Annual Ridership	5,100,158 (in 2015)

*Source: (MGM Resorts International)
**Source: (Austin Monorail Project, 2003)

5.2.5.2 Daegu Metro Line 3

The third line of the metro system in Daegu, South Korea, which opened in April 2015, is a driverless Alweg monorail system called the Sky Rail. This system is one of the longest commercially operated monorail lines in the world at roughly 15 miles long, with 30 stations (an average of 0.5 miles between stations). With 3.5-4 minute headways and vehicle crush capacities of up to 398 passengers, this system offers an impressive capacity (at least by U.S. standards) of 6,800 pphpd (UITP, 2013). The Sky Rail is a crosstown transit line that intersects with and connects to the other two metro lines running through Daegu (Daegu Metropolitan Transit Corporation, 2008). Although annual ridership data does not appear to be available at this time, the system was initially estimated to serve 84 million passengers in its first year of operation. The total cost of the Daegu Sky Rail system so far has been about $792 million, but stretched out over 15 miles of tracks that comes to only $26 million per mile (Kable Intelligence Limited, 2016). The Daegu Sky Rail is shown in Figure 5.14 and detailed in Table 5.14.

Figure 5.14 – Daegu Monorail (Photo by: Kim and Carol Pedersen on The Monorail Society)

Table 5.14 – Daegu Monorail Characteristics (Kable Intelligence Limited, 2016)

Year Built	2015
Length (miles)	15
Stations	30
Max / Average Speed (mph)	43* / 19*
Capacity (pphpd)	6,800*
System Cost	$792 million
Cost / Mile	~$26 million
Fare	$1.05**
Annual Ridership	84,000,000 (estimated)

*Source: (UITP, 2013)
**Source: (Daegu Metropolitan Transit Corporation, 2008)

5.3 Rubber-Tire Modes

Rubber-tire modes were the most familiar transit modes among survey respondents, though many were not familiar with jitney or publico modes. This is not surprising, since jitneys have essentially been regulated out of (legal) service and the only publico system reported to the NTD is in Puerto Rico. Unfortunately, very little information is available on the characteristics of these services. As such, full case studies are not provided for these modes, but rather a brief discussion of the nature of each mode is included in this section.

5.3.1 Jitney

Jitney services were wildly popular in U.S. cities starting around 1910, but strict regulation quickly decimated this budding industry, such that the majority of jitney services existing in the United States today operate more or less illegally. The recent invention, rapid growth, and attempted regulation of ride-sourcing services, such as Uber and Lyft, closely mirrors the struggle between government regulators, who often work in the interest of existing transit providers, and jitney service providers seen 100 years ago. While ride-sourcing service providers operate with minimal government interference in some areas, certain jurisdictions have gone so far as to make ride-sourcing illegal and to set up undercover sting operations to bust drivers who violate the law. A major factor in the persistence of jitney services despite the potential risks involved is that there is a need and a market for affordable and accessible transit services, especially in low-wealth and immigrant communities. Members of these communities complain that regulated taxi services will not accept their requests for service, and many of these communities have little or no access to bus, rail, or other reliable mass transit modes (McNulty, 2013).

Even if taxis did serve these areas, they typically come at a cost that is driven up as a result of their need to comply with company rules and government regulations.

Deregulation of jitneys and traditional taxi services, especially related to fixed-route requirements, could encourage more jitney services to operate legitimately, while also reducing costs and barriers to entry for traditional taxi service operators and providers. Over-regulation has driven jitneys to operate covertly to survive, resulting in no available data for this mode.

5.3.2 Publico

The primary difference noted by the author between jitney and publico modes is that publico exists only in Puerto Rico. Although these modes go by different names, they are remarkably similar services, both being variations of the “share taxi” mode. Publico services in Puerto Rico operate legally and are regulated by local government bodies, but the characteristics of this service are not significantly different from jitney. For clarity and simplicity, it may make sense for the NTD to combine publico with jitney, either under the name of jitney or share taxi. Treating publico separately may be causing confusion among transit professionals, as well as the general public. Bridj, Uber Pool, Lyft Line, and similar services, which use smartphone apps to coordinate shared rides, are further blurring the lines between jitney and publico modes, especially when public agencies partner with them. These services should be grouped together under the label of share taxi or jitney, thereby clearing up confusion about the minute differences between them and adding legitimacy to these services for transportation professionals, decision makers, and the general public.

Most rubber-tire modes operate on public streets without any separate right-of-way, so a cost per mile is not easily calculated. Furthermore, vehicles may be purchased at different times and are not required to be the same, so calculating capital costs for establishing a system becomes increasingly complex. The upfront capital needed to start a publico service includes the cost of vehicles, storage and maintenance facilities, and investments into dispatching and other needed operational technologies. Stations are often minimal or non-existent. New passenger vans may cost in the range of $30,000, but vehicle costs can be reduced or increased by purchasing used vehicles, multiple vehicles at once, and those with specialized equipment or configurations. Due largely to the flexible nature of publicos, insufficient data was available to calculate average speed, capital costs, system length, capacity, or other needed information for a complete case study, so case studies for this mode are also omitted.

5.4 Water Modes

While water modes can offer similar, if not superior, service to other transit modes, they are fundamentally difficult to compare with many surface and aerial modes. Their lack of fixed guideways makes them more similar to bus modes, in that it is possible, but not entirely logical, to calculate a cost per mile. This value, along with capacity and other measures depend heavily on the service characteristics defined by the operator and the operating environment (a boat that is moving against a current may not be as fast as the same boat moving with the current, for example). Case studies with these values calculated based on available data are provided below for each water transit mode, but the results may be more project-specific and less generally representative of water modes than those for the previous case studies.

5.4.1 Ferryboat

Ferries typically transport passengers, as well as their vehicles in many cases, between two fixed points on a water body, which may be a river, bay, or open ocean. There are hundreds of different ferry services operated in the U.S., including in urban and rural areas. Reporting to the NTD for ferry services groups all ferries for a single operator together, making it difficult to isolate individual services in urban areas. Further, a single ferry service may use multiple vessels purchased at different times, and with different characteristics. Case studies for the Staten Island Ferry in New York City and the Seattle to Bainbridge Island Ferry are provided below.

5.4.1.1 Staten Island Ferry

The Staten Island Ferry originally began operating in 1905. Today the system provides a 5.2-mile passenger ferry service between St. George Ferry Terminal on Staten Island and Whitehall Terminal in Manhattan, using four different classes of ferryboats. With a peak headway of 15 minutes and two Barberi Class boats able to accommodate up to 5,200 passengers, a peak capacity of over 19,000 pphpd could be achieved with the existing fleet. Ferry service is available 24 hours a day, every day of the year, and has an on-time performance record exceeding 96%. The most recent ferry purchase, the Spirit of America, holds 4,400 passengers and cost $40 million to build (The City of New York, 2016). Assuming that four boats would be needed for the system to operate at 15 minute intervals, the cost would come to about $31 million per mile, but this would not account for backup fleet vessels that are good practice to have, even if they are not always needed. Figure 5.15 shows one of the outgoing Kennedy Class ferries, which have been in operation for over 40 years (The City of New York, 2016). More details about this passenger ferry line are provided in Table 5.15.

Figure 5.15 – Staten Island Ferry (Photo by: Ingfbruno on Wikipedia)

Table 5.15 – Staten Island Ferry Characteristics (The City of New York, 2016)

Year Built	1965-2006
Length (miles)	5.2
Stations	2
Max / Average Speed	16 knots / 12 mph
Capacity (pphpd)	19,000
System Cost	$40 million (for newest boat)
Cost / Mile	~$31 million
Fare	Free
Annual Ridership	22,000,000

5.4.1.2 Seattle to Bainbridge Island Ferry

Washington State Ferries offers several passenger and automobile ferryboat services throughout the Puget Sound. One such service connects the City of Seattle with nearby Bainbridge Island to the west. This route is currently served by Jumbo Mark II vessels built in the late 1990s for around $80 million each (Nalder, 1999). Similar, but somewhat smaller vessels (with a capacity of 2,000 passengers compared to 2,500 for the Jumbo Mark II ships) were more recently constructed for between $122-144 million each (WSDOT, 2016). Assuming a present-day cost of $150 million for the larger vessels, costs for the two boats needed to operate this 9-mile line would be about $33 million per mile, not including the costs for the two terminal stations and any required maintenance and storage facilities. Despite the vessel capacity of 2,500 passengers, peak 45 minute headways limit the capacity of this service to around 3,750 pphpd. Adult single-trip fares are $8.20 for this route (and vary over time), but start at $14.30 for a vehicle and driver, going to over $150.15 for vehicles exceeding 80 feet in length (WSDOT, 2016). An image of the Bainbridge Island Ferry entering Seattle is shown in Figure 5.16, with more detailed characteristics outlined in Table 5.16.

Figure 5.16 – Seattle to Bainbridge Island Ferry

Table 5.16 – Seattle to Bainbridge Island Ferry Characteristics (WSDOT, 2016)

Year Built	1997-1998
Length (miles)	9
Stations	2
Max / Average Speed	18 knots / 15 mph
Capacity (pphpd)	3,750
System Cost	$122-144 million per boat
Cost / Mile	~$33 million
Fare	$8.20-150.15+
Annual Ridership	6,269,964* (in 2013)

*Source: (Puget Sound Regional Council, 2014)

5.4.2 Water Bus

Water bus is proposed as a new NTD classification to include smaller vessels serving multiple stops along a “fixed” route. Water taxi is also proposed to include on-demand water transportation services. Although these modes are treated separately here, water bus services are often called water taxis, and some water taxi services may be called water bus. The case studies shown below should help to clear up some of this confusion, but these terms are often used interchangeably. One example of a water bus service comes from Long Beach Transit in California, and another operates on the St. John’s River in Jacksonville, Florida.

5.4.2.1 Long Beach AquaLink

Long Beach Transit offers two water bus services, which it markets as water taxi services. One smaller vessel, the AquaBus, circulates between five stops on the Queensway Bay, with service intervals of 30 minutes or more and $1.00 one-way fares. The larger AquaLink catamaran has headways of one hour or more, but provides service to four stops along a larger figure-eight route for $5.00 one way. Both vessels are operated seasonally during the summer, as well as parts of spring and fall (Long Beach Transit, 2016). The AquaLink service between the Long Beach waterfront and the Alamitos Bay Landing is the focus of this case study, but these services could be thought of as a local water bus route (the AquaBus) paired with a commuter water bus route (AquaLink). Since the AquaLink route is a one-way figure-eight, the round-trip distance of approximately 10 miles was divided by two in an effort to calculate comparable per-mile system costs. A new ADA-compliant dock was recently opened for the AquaLink (Morris, 2016), but no costs for this project were found. Despite having a very low capacity of 75 pphpd, long headways of 1 hour, and seasonal operation, the AquaLink serves about 55,000 passenger trips annually (Morris, 2016). This service is currently operated by the Catalina Express and is not reported to the NTD. An image of the new AquaLink II vessel is shown in Figure 5.17, and its characteristics are outlined in Table 5.17.

Figure 5.17 – Long Beach AquaLink (Photo by: Everything Long Beach)

Table 5.17 – Long Beach AquaLink Characteristics (Long Beach Transit, 2016)

Year Built	2001-2011*
Length (miles)	5 (estimated)
Stations	4
Max / Average Speed	25* knots / 7 mph
Capacity (pphpd)	75**
System Cost	$2.2 million** per boat
Cost / Mile	~$0.9 million**
Fare	$5.00
Annual Ridership	55,000***

*Source: (Vigor, 2016)
**Source: (Abro & Patton, 2012)
***Source: (Morris, 2016)

5.4.2.2 St. John's River Taxi

A variety of water taxi services have been offered in the City of Jacksonville, Florida, which lies on the St. John's River, since the opening of Jacksonville Landing in the late 1980s. City government increased regulation of the water taxi services in the early 2000s, such that a single operator would be selected to provide water taxi service (Galnor, 2002). Most recently Lakeshore Marine assumed control of the St. John's Water Taxi service. Although the service is still called a water taxi, boats with capacities of 50-100 passengers currently serve four stop locations in downtown Jacksonville, with a fifth stop at the Stadium District offered during events. On event days, $5.00 one-way fares and $10 round-trip fares are collected for longer trips to and from the stadium (during regular service round-trip fares are only $7.00). The water bus service operates every 30 minutes, six days of the week (excluding Mondays when only private tours are offered) (Lakeshore Marina Services, LLC, 2014). The regular route is an estimated 1.5 miles long (divided in two for comparison with two-way services), with a round-trip taking approximately 30 minutes (Times-Union Editorial, 2016). Based on this information, an average speed of 3 mph was calculated, although the top speed of these vessels was not found. An image of the St. John's Water Taxi is shown in Figure 5.18, with characteristics detailed in Table 5.18. Unfortunately, cost and annual ridership data was not available for this transit service, and it is not currently reported to the NTD.

Figure 5.18 – St. John's River Taxi (Lakeshore Marina Services, LLC, 2014)

Table 5.18 – St. John's River Taxi Characteristics (Lakeshore Marina Services, LLC, 2014)

Year Built	1987 (new contract in 2014)
Length (miles)	0.75 (estimated)
Stations	4-5
Average Speed	3* mph
Capacity (pphpd)	200
System Cost	Not Available
Cost / Mile	Not Available
Fare	$5.00
Annual Ridership	36,000 (8 months in 2014)

*Source: (Times-Union Editorial, 2016)

5.4.3 Water Taxi

True on-demand water taxi services seem to be rare in the U.S. and to have even less data available than water bus systems, perhaps because most water taxis are privately owned and operated. In fact, one of the originally selected case studies had to be eliminated from this section, as the on-demand water taxi was no longer in service. In the case of on-demand services between more than two possible points, system length and cost per mile cannot be calculated, as trip length will vary widely between trips. The Boston Water Taxi and Destin Water Taxi services are profiled below.

5.4.3.1 Boston Water Taxi

Despite large concentrations of urban populations being located on or near navigable bodies of water, few on-demand water taxi services exist in the United States. The Boston Water Taxi is one of the few systems in the U.S. offering this type of service. This company operates year-round, providing on-demand pick-ups in a similar manner to land-based taxi services. Customers call for a pick-up at one of more than two dozen docks within the Boston Harbor, and a vessel should arrive within 10 minutes. One-way fares are $12, but discounts are offered for children and multi-trip pass holders. This service is shown in Figure 5.19, with additional information provided in Table 5.19.

Figure 5.19 – Boston Water Taxi (Photo by: Fletcher6 on Wikipedia)

Table 5.19 – Boston Water Taxi Characteristics (Boston Harbor Cruises, 2016)

Year Built	Not available
Length (miles)	Not applicable
Stations	28
Average Speed	Not available
Capacity (pphpd)	Not available
System Cost	Not available
Cost / Mile	Not applicable
Fare	$10.00-20.00
Annual Ridership	Not available

5.4.3.2 Destin Water Taxi

The Destin Water Taxi began service in 2011 within the Destin Harbor. This on-demand service will pick up from any harbor side waterfront residence, condo, or hotel, as well as many other destinations within the harbor. One-way fares are $5.00 for adults and children, but infants ride for free. Dogs, bikes, and strollers are also allowed, as long as there is space and no other passengers object. Passengers may also bring alcoholic beverages aboard and consume them aboard the vessel. This service is not available from November through February, but does operate 7 days a week from 11am until the late evening or early morning hours in the spring, summer, and early fall. The Destin Water Taxi is shown in Figure 5.20, and the available system characteristics information is shown in Table 5.20.

Figure 5.20 – Destin Water Taxi (Destin Water Taxi)

Table 5.20 – Destin Water Taxi Characteristics (Destin Water Taxi)

Year Built	2011
Length (miles)	Not applicable
Stations	Anywhere in the Destin Harbor
Average Speed	Not available
Capacity (pphpd)	16 passengers per boat
System Cost	Not available
Cost / Mile	Not applicable
Fare	$5.00
Annual Ridership	Not available

Part 3 – Transit Mode Selection Process and Tools

CHAPTER 6

TRANSIT MODE SELECTION PROCESS

As is clear from the preceding chapters, transit mode selection is a complex and heavily context-dependent process. The goal of Chapter 6 is to provide high-level guidance for thinking through the crucial factors and goals that should be considered throughout the mode selection process for transit expansion and enhancement projects. The process proposed here may be used as a general comprehensive framework for transit mode selection, but specific projects may require more or fewer factors to be taken into consideration, depending on the project purpose, stakeholders, and context.

6.1 Process Overview

The proposed process follows the same four previously outlined categories of factors to consider in transit planning and mode selection, including performance, environmental, social, and economic factors. However, unlike most existing mode selection processes (as indicated by the survey results), this process prioritizes performance, environmental, and social goals for consideration before economic goals and constraints. This proposed shift in priorities is based upon the principles of sustainability, in particular the ‘Russian dolls’ model of sustainability, which recognizes that social and economic systems cannot survive without a supporting environment (Levett, 1998). Money is useless in a world without enough clean air and water for the survival of life on Earth. An alternative model of sustainability is the ‘triple bottom line’, which treats environmental, social, and economic values equally (Elkington, 1994). Although this is not the author’s preferred approach, it at least places environmental and social concerns on the same level as economic concerns. Placing economic concerns above all others has led to many negative outcomes, so a shift in priorities is needed to move our world toward a better, more sustainable future for all.

The transit mode selection process begins with an opportunity for transit expansion, which may arise due to increased demand, availability of funding, or economic development interests, among other drivers. The reasoning and goals behind a transit expansion are naturally a central focal point of any transit planning process. Depending on the transit expansion opportunity, some performance characteristics are likely to be known or easily estimated. The space, timing, capacity, and maintenance requirements, as well as the desired efficiency of the system can be roughly outlined. Next the potential environmental impacts on air, land, water, noise, and aesthetics should be evaluated and mitigated relative to local ecosystems, including human and wildlife habitats. Transit service should be as safe, reliable, resilient, accessible, and community-oriented as possible for all entities that may come into contact with it. Once these goals are taken into account, costs and revenue streams can be estimated based on expected demand and fare prices. Increased employment and development opportunities may also be included in this high-level analysis. The process in Figure 6.1 may be used as many times as needed to identify feasible transit modes.

Figure 6.1 – Proposed Transit Mode Selection Process Framework

6.2 Performance Considerations

Key performance characteristics serve as a logical starting point for the mode selection process, since any mode must be able to accomplish the basic goals of the proposed project to be viable. As shown in Figure 6.2, the mode performance factors considered below include spatial factors (available space, terrain, route and trip length, and stop spacing), temporal factors (build time, operating hours, schedule, wait times, and travel times), capacity and productive capacity, efficiency, and maintenance factors.

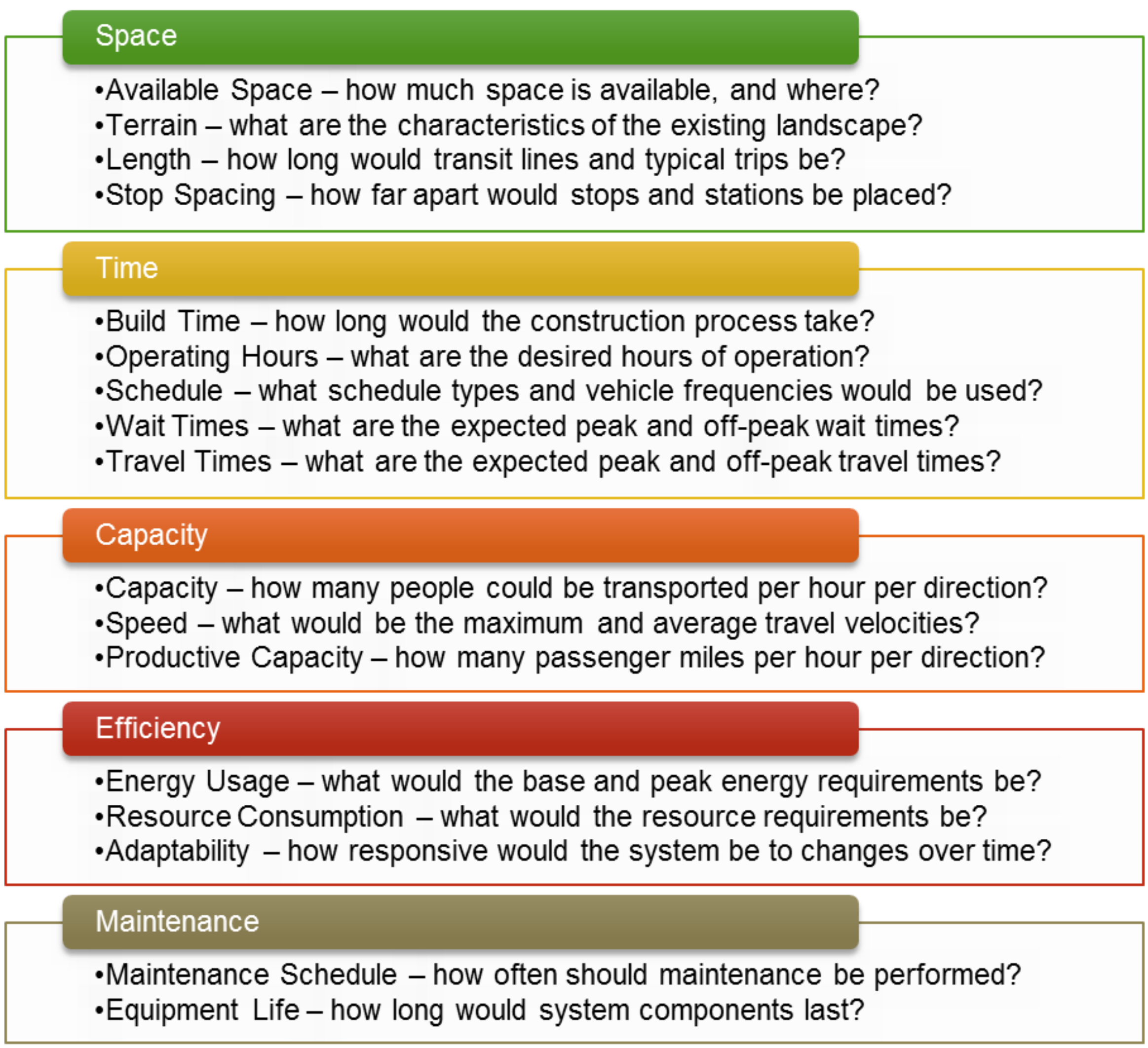


Figure 6.2 – Performance Considerations

6.2.1 Space

The term “space” is used here to describe spatial factors that are relevant to the transit mode selection process, including available space, terrain, route and trip length, and stop spacing. These considerations are described more in the following subsections.

6.2.1.1 Available Space

Available space refers to potential right-of-way within the proposed project service area. While low-density areas tend to have an abundance of space available on the surface, with minimal crowding, finding surface space in a dense urban area is often very challenging. Even when urban corridors have space available, crowding and traffic congestion may limit transit vehicles’ progress. One way to overcome surface crowding is to provide exclusive space for transit vehicles, but this requires construction of a new corridor or elimination of general traffic from an existing corridor, which can be extremely contentious. Another potential solution is to use aerial modes or elevated surface modes to allow transit vehicles to pass over obstacles and congestion on the surface. Tunneling is also an option, but one that may drastically increase project capital costs.

Multiple possible alignments should be considered within the proposed service area, including those in the air, over land, and on the water. Some alignments may require a combination of one or more of these options. Although most transit systems in the U.S. operate on the surface, as cities densify space on the surface is becoming more crowded and less accommodating for transit. In this respect, aerial and water modes may offer strategic advantages over surface modes in urban areas. Aerial modes can travel over (or through or under) almost any obstacle, and do not require elevation changes on the surface to be practical. In areas where navigable waters are present, a variety of vessels can be used for different types of water transit services. Although crowded ports and harbors may have some congestion, as well as speed limits, most U.S. waterways are less crowded than urban arterial roadways.

6.2.1.2 Terrain

When considering the terrain of a potential transit service area, several factors come into play, including topography and the resulting infrastructure improvements needed to fit a given mode to an alignment. Topography is a primary constraint in transit route design, with steep terrain requiring modes with the most vertical and horizontal flexibility while flat areas can accommodate nearly all available transit modes. Aerial modes can overcome almost any natural or man-made barriers, such as steep grades, deep depressions, mountains, or water bodies. Surface modes, especially rail modes, may require elevated structures or tunnels to overcome these terrain constraints. Water modes cannot leave the water, but water can be transported to wherever it is needed.

6.2.1.3 Length

Similar vehicles may be used for short-, medium-, and long-distance travel, but route distance is a defining factor of a transit service in many ways. Characteristics of long-distance modes are different from those of short-distance modes, not only when it comes to trip length and stop spacing, but also speed and acceleration. Factors affecting comfort on a transit trip are also typically more important for long trips than short ones.

Long-distance trips (such as those over 10 miles) with average stop spacing of two (2) miles or more are most likely to benefit by using high-speed (>25 mph) modes. Medium speeds (10-25 mph) are appropriate for medium-distance trips (2.5-10 miles) with average stop spacing of 1-2 miles, since a small amount of time would be saved with faster speeds. Top speeds are rarely achieved on short trips with stop spacing of less than one mile, so the benefits of high-speed transit modes for these trips would be minimal. Although limited-access right-of-ways can address many of the safety concerns associated with transit moving at higher speeds, this approach may divide communities in addition to connecting them, as transit systems can easily become barriers between people and destinations.

6.2.1.4 Stop Spacing

Transit stop or station spacing is another defining factor of transit modes and services. Express transit lines are able to provide faster average speeds, largely as a result of greater stop spacing, while local services are slowed by frequent stops. While stop spacing can vary for any given mode, as the results presented in Table 4.5 showed, the modes of bus, trolleybus, and streetcar rail tend to have the shortest stop spacing of less than 0.25 miles. Modes with short to moderate stop spacing of about 0.5 miles were the aerial modes, bus rapid transit, and light rail. Stop spacing of about 1 mile was found to be typical for monorail / automated guideway and heavy rail modes. Long-distance commuter modes had the largest stop spacing of about 2.5 miles or more.

6.2.2 Time

Time is a driving factor in the lives of many individuals, who depend on transportation to get them where they need to go in a timely and reliable manner. Transit services that take much longer than a private vehicle to travel the same distance may not be seen as viable transportation options by time-sensitive travelers. Time relates to many temporal factors, including the time it takes to build or upgrade a transit system, the hours of operation that will be offered, the service schedule and frequencies, time spent waiting on transit vehicles, and passenger travel times.

6.2.2.1 Build Time

Build time may not be an immediately obvious consideration for selecting a transit mode, but when new transit service is urgently needed, this factor becomes critically important. Large infrastructure projects can take years, or even decades, to be fully implemented, especially if federal funding is requested. Modes that require little or no new infrastructure, on the other hand, can be implemented almost overnight.

Bus, commuter bus, jitney, publico, taxi, and vanpool services tend to have the shortest implementation time, since they are often operated within existing right-of-ways.

Water modes can also be put into service quickly, especially if existing docks are used, but large vessels can take up to a year or more to build (Gilmore, 2005). Commuter and hybrid rail systems running on existing rail lines can also be implemented as soon as vehicles are acquired and necessary maintenance facilities and stops are constructed. Aerial modes are often designed and built in less than two years, thanks to their system simplicity and minimal infrastructure (Creative Urban Projects, 2013).

Systems that require dedicated right-of-way and significant capital investment, such as bus rapid transit and most rail modes, tend to take multiple years if not decades to complete. Requirements for federal funding, including detailed planning studies, demand estimates, environmental review, and identification of matching local funds, can result in new transit construction projects stretching over multiple decades. Projects that do not use federal funds can often be completed in less time than those that do, but not in every case. Several examples are provided below:

- The 9.6-mile Silver Line Bus Rapid Transit project in Grand Rapids, Michigan includes 33 stations at a total cost of $40 million. It took several years to secure funding for the project, but construction began in April of 2013 and the BRT line opened in August of 2014 (Federal Transit Administration, 2016).
- The Atlanta Streetcar received notice of a $47.6 million federal funding award in mid-October 2010 to support the construction of a 2.7-mile downtown (one-way) loop with 12 stations. This project had a total budget of $92.6 million, which included four (4) streetcar vehicles with a capacity of 195 passengers each, operated every 10 to 15 minutes. Construction of this transit line began in early 2012, while scheduled service began about two years later, in early 2014 (Atlanta Streetcar, 2016).
- Unlike commuter rail that uses existing rail lines, commuter rail systems requiring construction of a new rail corridor can take several years to complete, depending

on the project size and context. The Eagle Commuter Rail project in Denver, Colorado entered into a full funding grant agreement for over $2 billion in August 2011, but does not expect to open this 30-mile corridor to the public until December 2016 (Federal Transit Administration, 2016).

- A 6.6-mile light rail line in Houston, Texas, called the Southeast Line (or Purple Line) connects downtown Houston with Palm Center Transit Center. This mostly at-grade line includes 10 stations at a total project cost of $823 million. Construction of the line broke ground in 2009, then concluded in 2014 (MetroRail, 2016).
- The BART Warm Spring Extension to Fremont, California is one of the few heavy rail projects in the U.S., which involves 5.4 miles of new heavy rail lines (with elevated, at-grade, and subway portions) with 1 new station and the potential to add an intermediate station in the future. The total project cost is estimated at $890 million. The environmental impact report for this project was approved in 1992, but funding was not yet secured at that time. The NEPA environmental review for the extension was completed in 2006. The following year BART came up with an implementation strategy for the project, involving two large contracts. Construction of the Fremont Central Park Subway Contract began in August of 2009 and was completed in April 2013. The design-build Line, Track, Station and Systems contract began in October 2011, and is expected to open for revenue service in the fall of 2016 (San Francisco Bay Area Rapid Transit District, 2016).

6.2.2.2 Operating Hours

Operating hours are largely dependent on transit operators to decide based on system context, purpose, and demand, among other factors. These decisions feed into other considerations, such as the accessibility and reliability of the system. Services that do not operate during times when there is sufficient demand for operations to continue may miss out on revenue, not only from fares that would be paid outside of their operating hours, but also from fares that would be paid during current operations because riders realize they would be stuck without affordable options for their return trip. On the other side of the spectrum, operating during hours when operating costs exceed fare revenue may not be fiscally sustainable for the operator. Ideally, a balance between making services convenient and available when people need them and being financially responsible would be sought. Certain modes do require periodic full system shutdowns for maintenance purposes, so this time should also be factored into the planned operating schedule of these transit services.

6.2.2.3 Schedule

As shown in Table 4.1, at a high level modes can be classified as operating according to either a fixed schedule or consumer demand (while some modes can be used either way). Fixed schedule transit services are most common, even if timetables are not provided publicly (as in the case of high frequency routes that maintain internal schedules but only advertise vehicle headways). Modes that typically operate according to a fixed schedule or frequency include bus, bus rapid transit, cable car, commuter bus, commuter rail, heavy rail, hybrid rail, light rail, streetcar rail, trolleybus, and water bus. Higher-frequency fixed-schedule or headway-based services may approach the short waits and convenience of on-demand services in some cases. On-demand modes are those that respond directly to an individual request, but modes that are continuously moving and generally available within less than a minute (funitel and gondola) could arguably be placed into this group. On-demand modes may include demand response, funitel, gondola, jitney, publico, taxi, and water taxi, but long wait times to access a vehicle can make these modes less convenient than other on-demand or even scheduled services. Modes such as aerial tramway, automated guideway, ferryboat, inclined plane, maglev rail, monorail, and vanpool can be used for either service type.

6.2.2.4 Wait Times

Vehicle frequency is closely tied to wait times, especially for headway-based services for which passengers are expected to arrive randomly. Wait times also change throughout the day, week, and year, but this is largely due to the differences between peak and off-peak headways to serve varying levels of demand. Ultra-short wait times would be less than 1 minute on average, but short wait times (1-5 minutes) are more common in the U.S., as many systems operate with 2-10 minute headways. Moderate wait times would be 5-10 minutes, a typical estimate for services with 10-20 minute headways, while anything over 10 minutes is considered to be a long wait. For U.S. transit services overall, but especially for modes that tend to have lower frequencies, it is not uncommon to see headways of 30, 45, 60 or more minutes. These services usually have published schedules, so random arrivals would not be expected. In general transit riders will time their arrivals to have a wait of 10 minutes or less for high-headway transit services, but if vehicles arrive early or late, or fail to arrive at all, these services might be considered to have ultra-long waits of 15 minutes or more.

6.2.2.5 Travel Times

Travel times are closely tied to vehicle average operating speed, including dwell time, and should generally be considered in terms of average expected travel times, as well as the travel time distribution. Variable travel times are a sign of unreliability that can be directly perceived by attentive customers. Like wait times, travel times may fluctuate throughout the day, week, and year, as well as over multiple years and decades, but unlike wait times travel times tend to get worse during peak demand, at least for systems that require transit vehicles to share congested corridors with general traffic. Transit services that are able to avoid traffic congestion, through smart routing, transit priority strategies, and/or exclusive right-of-ways, may offer strategic advantages over vehicles that have no way of overcoming congestion. At a high level, travel times between major destinations can be estimated for the new transit system and compared to travel times by car, bike, walking, and other available modes. Many free trip-planning tools exist, which can be used to facilitate this process.

6.2.3 Capacity

As previously explained, capacity can be defined for a transit service in terms of spaces per hour per direction and space-miles per hour per direction, with the latter being called productive capacity. Capacity also relates to maximum and average speeds, with maximum speed influencing the theoretical productive capacity of a transit system and average speeds impacting the actual productive capacity of a system.

6.2.3.1 Capacity

One early step in the mode selection process is to estimate the anticipated demand that a transit service may experience upon startup, as well as throughout its lifecycle. Approximate capacity ranges are acceptable in the early stages of planning; they can be roughly related to anticipated demand, which is estimated based on existing densities, socio-economic factors, attractiveness of proposed modes, and destinations to be served. More detailed models of demand may be produced later in the process. Unfortunately new transit modes may be more challenging and costly to model, as they are often not already present in regional travel demand models. Capacity for system maintenance and operations should also be considered, including facilities and trained staff members to operate a system successfully. Existing modes offer advantages here.

High-capacity modes (>10,000 spaces per hour per direction) should generally be used for systems with anticipated peak ridership levels of 7,500 or more passengers per hour per direction. Expected peak ridership levels of 2,500-7,500 are well-served by modes offering medium capacities of 5,000-10,000 spaces per hour per direction. For peak demands below 2,500, low-capacity modes (<5,000 spaces per hour per direction) are generally recommended.

Estimates of demand and needed capacity must look beyond the first years of service, to understand the potential growth in demand and capacity increases needed to meet that demand. Transit systems are almost always capable of increasing or decreasing offered capacity to meet varying levels of demand. However, when high growth rates are expected in a service area, it may be rational to build a system that can grow to meet demand, rather than needing to be replaced by a higher capacity mode. In general, significant development and high growth rates can be used to justify building a system with a maximum capacity that is far above the starting capacity. In the absence of high growth rates and major development plans, it may be risky to invest in a transit system capable of offering capacities in excess of 50% more than the starting capacity. Since infrastructure is more permanent than transit vehicles, these considerations are particularly important for infrastructure investments.

6.2.3.2 Speed

While average operating speeds, including vehicle dwell times, are most important relative to the actual capacity of a transit service, maximum operating speeds should also be considered relative to theoretical system capacity. Operating speeds should be taken into account with regard to the purpose and context of a transit project. If a project is meant to provide efficient transit service for commuters, then high speeds can reduce travel times and make the system more competitive with automobiles. Travel time gains are accrued over longer distances, so speed is less of a critical factor for local service. Speeds are often perceived by passengers in a relative sense, such that transit systems offering speeds that are similar to or above those of automobiles will be seen as more attractive than those that only offer higher speeds than walking or biking. In congested areas where automobile speeds are generally slower, transit modes that operate in exclusive right-of-ways, even at average speeds of 10-20 mph, are better able to compete with cars than transit vehicles using shared right-of-ways.

6.2.3.3 Productive Capacity

As shown in Figure 4.10, commuter rail, hybrid rail, and heavy rail offer the highest estimated productive capacities of all existing urban transit modes, with the potential to offer more than 1 million space-miles per hour per direction. Medium productive capacities of 150,000 to 300,000 s-m/h/d were estimated for light rail, commuter bus, bus rapid transit with overtaking, vanpool, and monorail / automated guideway modes. Medium-low productive capacities of 35,000 to 150,000 s-m/h/d were estimated for bus, bus rapid transit single lines, on-freeway automobiles, streetcar rail, inclined plane, trolleybus, CABLE Liner, gondola, and funitel. Low productive capacities (<35,000 s-m/h/d) were estimated for on-street automobile and aerial tramway modes.

6.2.4 Efficiency

The purpose for mass transit at a fundamental level is efficiency; more people can be transported using less space if they travel together in a single vehicle than if they each drive a private automobile alone. For a transit service to be efficient, it should be utilized at least to the point that energy and resources consumed per passenger mile traveled are less for transit riders than they are for solo drivers. Some systems may be more or less efficient during peak travel periods, so estimated average energy usage and resource consumption values may be useful. However, service and mode adjustments may play a critical role in allowing transit systems to operate efficiently while adapting to changing environments and demand.

6.2.4.1 Energy Usage

Energy consumption can increase operating costs and environmental impacts, depending on the fuel source(s) used and their associated emissions. As discussed in section 4.3.6, gondola and heavy rail appear to offer some of the lowest energy consumption rates of any existing urban transit mode, at below 1,000 BTUs per passenger mile. Funitel, aerial tramway, light rail, and trolleybus were next, with 1,000-

1,500 BTUs ppm. In the 1,500-2,000 BTUs ppm range were commuter rail, vanpool, cable car, streetcar rail, and commuter bus. Between 2,000-3,000 BTUs ppm were hybrid rail, bus rapid transit, and inclined plane rail. Bus and monorail / automated guideway had the next highest rates of energy consumption per passenger mile in the U.S., both in the range of 3,000-4,000 BTUs ppm. Ferryboat and demand response services in the U.S. had the highest rates of energy consumption per passenger mile by far, in excess of 10,000 BTUs ppm and 13,000 BTUs ppm, respectively. Any of these modes can appear to be more or less energy efficient with higher or lower levels of ridership and occupancy. While some modes, such as aerial and rail modes, seem inherently more efficient than others, almost any transit mode can be used in an energy efficient way with careful planning and execution.

6.2.4.2 Resource Consumption

Another key performance consideration, which is closely tied to the environment, is the efficiency of transit system resource consumption. Unfortunately, limited data is available regarding the resource impacts of various transit modes. It is clear that larger modes with more infrastructures require greater initial resource investments than modes operating on existing right-of-ways, in shared spaces, and with minimal infrastructure. Further, the less durable a system is the more it will require repair and replacement of parts. Disposable items, such as engine oil, tires, brakes, and other wear parts can also add to the amount of resources needed to operate a system over time.

6.2.4.3 Adaptability

Adaptability refers to a transit system's responsiveness to changes in the environment, demand, and other changes over time. Can the system increase its capacity to meet growing demand over the course of its lifetime? When the system needs to be replaced, can some elements continue to be used as they previously were, or perhaps repurposed? Will long-term changes, such as fuel scarcity or the impacts of global climate disruption, limit the ability of certain modes to operate? Modes that can be easily re-routed, including most rubber-tire modes and water modes, may offer benefits in terms of adaptability, though this may have a negative connotation from an economic development standpoint. On the other hand, bus routes can be upgraded to have exclusive bus lanes and other priority treatments associated with bus rapid transit with relative ease. Bus lanes and transitways can be converted to rail lines in many cases as well, although this often requires the installation of new rail lines and passenger stations. Then again, adapting from a rail mode to a rubber-tire mode may prove to be far more difficult and costly than if the rail lines were not installed in the first place. Planners and decision makers should work to ensure that major infrastructure projects will be used enough to justify the investment and resources needed for the system to operate.

6.2.5 Maintenance

Vehicle and facility maintenance can vary substantially depending on the design of the system, equipment used, quality of construction, system age, and many other factors. The maintenance schedule and equipment life of various transit modes are discussed at a high level in the subsections that follow. Although it is not discussed in depth, consideration should also be given to past investments made in maintenance facilities and staff training. Even new modes with minimal maintenance requirements will require the expansion of maintenance facilities and/or training of staff to some degree, while current modes can sometimes be expanded using existing maintenance and staff training procedures.

6.2.5.1 Maintenance Schedule

Generally speaking, the more moving parts (especially wear parts, such as brakes, tires, oil filters, and so forth) there are to a system, the more maintenance will be required. Many electric modes require less frequent routine maintenance than those powered directly by fuel combustion, but batteries and electric motors will need to be replaced eventually. Of course, internal combustion engines don't last forever either. System components will wear out more quickly at higher levels of use in most cases, so transit lines that are operated at or near capacity may need more frequent maintenance. Mechanical systems can also suffer from a lack of use, though, so regular inspections and maintenance of systems should be performed, even when vehicles sit in a storage facility most of the time. Minor parts replacement should be considered, as the costs of these parts do add up across an entire fleet and over time, but the schedule for major part replacements should also be taken into account. The manufacturers of a particular transit system are a good resource for detailed information on maintenance schedules.

6.2.5.2 Equipment Life

The life of each transit system component will depend on the level of use and abuse it experienced, as well as the quality and characteristics of the system when it was new. There are several examples of heavy rail and commuter rail systems in the U.S. that have been operated since the 1960s or earlier, with minimal system upgrades. Rail vehicles can last 50 years or longer (MacKechnie, 2016), but system upgrades may be desired every 25 years or so to keep the system modern. Vessels used for water transit services can also last this long, as demonstrated by the John F. Kennedy vessels used for Staten Island Ferry service since the 1960s (The City of New York, 2016). Aerial transit modes can last about as long as rail and water modes, but while support towers tend to be structurally sound for up to 50 years, vehicles and cable drive components may need to be replaced every 20-30 years (Creative Urban Projects, 2013). While buses can last 20 years or more, most buses in the U.S. are considered to have reached the end of their life at 12 years or 250,000 miles. This is partially due to the fact that once buses reach this age, their operators become eligible for funding to replace these older members of their fleet. Light-duty vehicles, such as those used for demand response and shuttlebus services, as well as jitneys, publicos, taxis, and vanpools, may last for 7-10 years under heavy use (MacKechnie, 2016). Pavement life should also be considered for rubber-tire bus and automobile modes.

6.3 Environmental Considerations

Environmental context and goals are recommended for consideration after the basic performance goals are defined. Environmental concerns, constraints, and potential impacts should be evaluated in the context of the proposed transit service area, including existing terrain and climate, as described below. Environmental considerations include impacts on air, land, water, noise, and aesthetics, as shown in Figure 6.3.

Air

- Emissions – how much of various pollutants would be emitted into the air?
- Flight Paths – would the system impact birds, bats, and flying wildlife?
- Air Rights – would the system conflict with current or future users?

Land

- Surface Area – how much available land would be used and where?
- Exclusivity – would shared or exclusive right-of-ways be used?
- Land Use – how would the system fit with existing and planned uses?
- Crossings – would people and terrestrial wildlife be able to safely cross?
- Habitat – would the system impact sensitive habitats on land?

Water

- Quantity – what would be the impact on stormwater runoff quantity?
- Quality – would the system add pollutants of concern to waterways?
- Ecosystems – how would wildlife and natural waterways be impacted?

Noise

- Audible Noise – how much noise would be heard as a result, and where?
- Vibrations – to what extent would vibrations be felt, and where?

Aesthetics

- Visibility – how visibly noticeable would the system be?
- Design – how pleasing would the system design elements be?

Figure 6.3 – Environmental Considerations

6.3.1 Air

Impacts on the air are discussed below as they relate to emissions and existing air quality, flight paths, and air rights.

6.3.1.1 Emissions

Air quality has improved significantly in the United States since the passage of the Clean Air Act, but numerous U.S. cities are still classified as non-attainment areas due to lack of compliance with federal air quality standards. Transportation can be a major source of emissions in these areas. Pollution is not generally a desired output from a transit system, but nearly all existing transit modes emit air pollution, either in into the immediate surroundings or into communities where power plants are located. The existing air quality and risk of exposure to pollutants should guide decisions related to transit mode selection and the resulting air quality impacts.

Consistently high air quality may indicate that the plants in an area are able to clean pollutants from the air more rapidly than they are being emitted, as is commonly seen in rural areas that are not overburdened by industrial or other air pollutants. Although places with high air quality levels may be able to cope with higher levels of emissions, special care should be taken to avoid outputting emissions unnecessarily or beyond the cleaning ability of any ecosystem. Sometimes high air quality is a result of wind patterns that facilitate the transfer of pollutants to other areas. Emissions that cannot be prevented at the source can be mitigated in a variety of ways, such as by planting trees to help increase the local air cleaning capacity of an area. Even greater caution should be used in areas with diminished air quality, which may indicate that the ecosystem is already being overwhelmed by air pollutants. No increases in air pollution should be tolerated in these areas, even with mitigation. Transit modes that are powered by electricity, especially when it is generated from clean energy sources, are most appropriate for non-attainment areas and other regions with degraded air quality.

However, much of the electricity produced in the U.S. today still comes from fossil fuels like coal and natural gas, which produce emissions directly from power plants and elsewhere (depending on their supply chain). Until we have transitioned to 100% clean, renewable energy sources, the equity and environmental justice concerns related to shifting emissions away from system users should be considered in the transit mode selection process. No pollutants are released without some negative consequences. In addition to existing air quality, the risk of exposure to air pollution should always be taken into account. The higher the risk of exposure, the less acceptable it is for emissions to be released into an environment.

6.3.1.2 Flight Paths

If any birds, bats, or other flying wildlife are common in the proposed transit service area, or if migration areas are nearby, the impacts of the system on airborne wildlife should be taken into account. Many transit modes do not move fast enough to pose any harm to wildlife, but some do. High-speed transit vehicles can be especially damaging to animals that they come into contact with, so modes that operate at high to medium speeds should be avoided where they would conflict with sensitive habitats. Delicate, slow-moving creatures like butterflies may be especially vulnerable to injury or death if they come into contact with hazardous transit systems.

6.3.1.3 Air Rights

Conflicts with animals should be avoided, but so too must conflicts with human systems and development. Aerial and elevated modes should be aligned in such a way as to avoid impinging upon property owners' rights to build upward on their land. Air rights may be especially challenging in dense urban core areas, which are often less limited in potential development heights and densities, but also surrounding airports, military bases, and other secure air spaces. Since many transit systems are built as airport connectors, care must be taken to ensure that these systems do not interfere with air traffic in any way.

6.3.2 Land

Considerations related to the land in a proposed transit service area should include factors relating to surface area requirements, right-of-way exclusivity, current and future land use, human and wildlife crossings, and habitats.

6.3.2.1 Surface Area

As land area is also limited, especially in urban areas, this factor should be considered in any transit mode selection process, especially where otherwise useful or especially valuable surface area would be used. Aerial and water modes use land primarily for stations, and can generally be built with less surface area than surface modes. Estimates from Figure 4.24 indicated that even 3S gondola systems can be built while consuming less than half as much land as the smallest rail (monorail / automated guideway) systems. Surface modes that share their right-of-way could be thought of as moderately land-consuming, with the exact amount of land required being closely related to station and vehicle sizes and frequencies. This mid-range group would include streetcar rail, bus, trolleybus, commuter bus, and, in some cases, commuter or hybrid rail. The modes requiring the most land area include bus rapid transit, rail modes, and others that require mostly exclusive corridors. Monorail / automated guideway modes typically need the least land of all modes in this group, followed by light rail, bus rapid transit, heavy rail, and commuter or hybrid rail (when exclusive right-of-way is used). Exclusivity is discussed further in the following subsection.

6.3.2.2 Exclusivity

From an operations perspective, exclusivity is the gold standard in transit service. However, the amount of space required for dedicated transit corridors can make this a contentious and expensive proposition in dense cities, as well as in less urban areas.

The amount of land used for exclusive transitways should be justified by anticipated demand, high-frequency service, and/or safety concerns. Communities are likely to have project proponents and opponents, so transportation professionals and community leaders should be prepared to provide information to various community members about the expected tradeoffs between exclusive and shared right-of-ways and their land requirements.

6.3.2.3 Land Use

Existing and planned land uses in a proposed transit service area should be considered in a variety of ways, as the activities occurring in any given area contribute to the likelihood of transit riders entering or exiting the system there. Land use can also influence socio-economic and cultural characteristics of communities, densities, presence of pedestrians and cyclists, and much more. Considering that land use impacts the level of congestion, travel times, and safety for any given mode, among other factors, it is likely to come up many times throughout the mode selection process.

Although most transit routes serve a variety of land uses, some modes are more appropriate in the residential context, while others fit best in major mixed-use or jobs-oriented areas. Residents may desire all-day service in their neighborhood, but prefer lower speeds on residential streets. If late-night service is offered in these areas, quiet modes are most appropriate to avoid disturbing residents. Mixed-use areas are more conducive to 24-hour transit services, with fewer concerns about sound disturbances due to the higher activity levels and other sources of noise in the area. However, mixed-use areas are likely to have active street life, including pedestrians, cyclists, children, and mobility- or sensory-impaired individuals. As such, any medium- or high-speed transit modes must be adequately separated from vulnerable entities. Job centers are likely to have heavily peaked travel patterns (high activity in the morning and afternoon, with relatively little activity otherwise), so peaked commuter transit services may be appropriate for serving these areas

6.3.2.4 Crossings

Crossings may be needed for any transit mode, especially as vehicles traverse urban environments. In many cases bridges and tunnels are used to allow for uninterrupted crossings. However, at-grade surface modes sometimes cross through intersections with travelers using other modes. Since intersections are generally the areas with the highest risk of crashes occurring, special care should be taken to design these crossings for the safety of all users. In addition to providing safe crossings for humans using a variety of transport modes, wildlife crossing areas should be considered with the goal of minimizing or eliminating interactions between transit vehicles and animals. This goal has been accomplished through strategic use of wildlife over- and under-passes along highways and other high-speed transportation corridors. Attention should be paid to the types of wildlife expected to cross transit corridors, as certain species are not willing or able to use over-passes and certain other types of crossings.

6.3.2.5 Habitats

Transit can impact people and wildlife in areas other than intersections and crossings. New right-of-way and stations can conflict with existing neighborhoods, businesses, forests, wetlands, and many other natural and manmade habitats. To the extent possible, transit alignments should avoid diminishing human and wildlife habitats, especially those that are particularly sensitive to change. Endangered species areas and environmental justice communities are the most critical habitats to avoid and protect, not only because there are major legal and social consequences for disturbing such places. Affordable housing and wildlife habitats are important, but increasingly rare finds in urban environments, so they should be protected and expanded whenever possible.

Transit infrastructure is most appropriate for developed urban areas, but can also be used as a tool for urban redevelopment and densification.

6.3.3 Water

Clean water, like clean air, is a vital but limited resource on Earth. While progress has been made to clean up U.S. waterways since the passage of the Clean Water Act, many urban watersheds are still overburdened with stormwater runoff and pollution. Healthy natural waterways can help to reduce runoff pollutants and mitigate flooding, but many urban waters are degraded, which limits their cleaning and stormwater retention capabilities. These issues are discussed more as they relate to stormwater runoff quantities, water quality, and aquatic ecosystems in the following subsections.

6.3.3.1 Quantity

Impervious surfaces generate large amounts of stormwater runoff when it rains, which may cause flooding and diminished water quality, especially in low-lying areas. Prevention is the ideal approach to water quality and quantity concerns, so transit modes that do not significantly increase impervious surface or otherwise negatively impact watersheds should be prioritized. Aerial modes, for example, typically have minimal impacts on stormwater runoff and water quality, unless they use exceptionally large stations. Surface modes that require new paved right-of-way are likely to produce larger quantities of runoff than those using existing travel lanes or rails, so mitigation should be used as needed if such a mode is selected. Water modes do not substantially increase the amount of stormwater entering waterways, but may result in pollutants being directly discharged from vessels into adjacent waters. Stormwater best management practices, including filtration, retention, and other strategies to reduce the amount of polluted runoff reaching our waterways, are highly recommended (and in some cases required) for projects that increase impervious surface area. Ideally the goal would be to maintain, or return to, pre-development stormwater runoff levels.

6.3.3.2 Quality

Furthermore, as with air quality, the existing water quality level should guide decisions regarding acceptable amounts of pollutants that can be discharged into a watershed or water body. While water pollution should be prevented whenever possible, pollutants sent to clean waterways are diluted, and often filtered or settled out before reaching the ocean. Diminished waterways do not have the same capacity to settle or filter pollutants, making pollution less likely to be reduced through natural processes and more likely to reach the ocean. It is recommended that no additional pollutants be discharged into waterways with poor water quality, while medium- and high-quality waterways can accommodate some pollutants, preferably with appropriate mitigation strategies, with exceptions made when it comes to protected or otherwise ecologically sensitive waters. The designated use of potentially impacted waterways should also be given adequate consideration in the transit modes selection process.

6.3.3.3 Ecosystems

Considering water quality and quantity alone may not reveal major concerns with a transit project, but in some cases even small changes to water quality, quantity, or flow can have serious impacts on aquatic ecosystems and wildlife. Sensitive ecosystems should be identified early in the transit planning process, and steps should be taken to avoid impacting these areas whenever possible. Selecting modes with low impacts on stormwater runoff and water quality is generally preferable, but water modes may not be appropriate in all aquatic settings. When aquatic wildlife is present in a navigable waterway, lower speeds and safer vessels can be used to reduce the risk of harm to native fish, aquatic animals, and natural waterways.

6.3.4 Noise

Noise and vibrations are common environmental impacts of transit systems, for riders and the general public, as discussed below.

6.3.4.1 Audible Noise

Noise is almost always an output of any transit system, but this noise is more audible in areas that are otherwise quiet, such as low-density residential neighborhoods. Louder noise can sometimes be tolerated in high-density, active urban environments, since it is more likely to be drowned out by existing noises from the street, as well as industrial and commercial establishments. Sound barriers, slower speeds, and other transit system modifications can be made to prevent system noise from disturbing potentially impacted communities, but these approaches can increase the cost and decrease the productivity of some systems. Prevention is again the best strategy here.

Aerial modes, underground surface modes, maglev rail, and automobile modes are expected to have the lowest levels of noise among available transit modes. Noise from aerial modes largely comes from stations and cars passing over support towers, but otherwise these modes are nearly silent. Underground modes, such as subway lines, may be audible at ventilation points or near major stations, but their physical separation from the street and use in busy urban areas helps to reduce the impacts of noise emitted from subterranean transit vehicles. Maglev rail emits less sound than steel wheels on steel rail modes. Jitneys, publicos, taxis, and vanpool services are also very difficult to audibly distinguish from general traffic in urban areas. Automated guideway and trolleybus modes may be slightly more audible than the previously mentioned modes, but they are generally quieter than other bus modes, demand response vehicles, rail modes, and water modes. Heavy rail, hybrid rail, and commuter rail systems that operate above ground are typically among the loudest transit modes, especially when they are traveling at high speeds.

6.3.4.2 Vibrations

While noise and vibrations are closely related, there are key differences between the impacts of these transit system outputs. Noise can be a disturbance in many places, but vibrations can actually shake buildings, cause items to fall from shelves and walls, and even lead to internal and external system failures in some relatively extreme cases. Noise and vibrations should not only be considered for surrounding communities, but also for transit users. Customers may place a higher value on transit systems that operate quietly, rather than those that screech, squeal, chatter, and vibrate their way through a corridor. Rail vehicles moving at high speeds tend to cause the most notable vibrations, and these can be felt well beyond even underground rail stations. Rubber-tire modes may produce less external sound and vibrations than most rail modes, but degrading street quality can mean that customers experience a great deal of bumps and vibrations along their routes. Light-duty vehicles may not do much to ease the discomfort of traveling on bumpy roads, but these vehicles tend to cause less external noise and vibrations. Aerial and water modes seem to cause fewer vibrations than surface modes.

6.3.5 Aesthetics

Certain communities are more sensitive to aesthetics than others, but the visibility and design of a transit system should always be considered as part of the proposed system's overall environmental impact. As discussed in Chapter 4, the internal aesthetics of a system should be considered in addition to its outward appearance.

6.3.5.1 Visibility

The visibility of various proposed transit modes can be easily estimated and compared at a high level, without the need for detailed renderings. Aerial and elevated modes tend to be the most outwardly visible modes, but they also may offer the best views for customers. The larger these systems are the more noticeable and dominant they become within the urban landscape. Water modes are likely to be fairly noticeable, but only for those near the water, and offer nice views for passengers. Rubber-tire modes, especially those using light-duty vehicles, can easily blend into the urban streetscape. These modes are barely noticeable, except when vehicles are present, although overhead catenaries can be seen for trolleybuses. Larger stations, exclusive lanes, and other infrastructure can also increase the visual presence of rubber-tire modes. While passengers using rubber-tire transit modes can generally look outside of their transit vehicle as they ride, many will find themselves looking at traffic congestion and other less than ideal features of urban streets. Rail modes are generally the most visible transit systems, with rails and overhead catenaries visible even when vehicles are not present. Underground rail systems are much less noticeable, but also offer almost no sight-seeing opportunities for passengers.

6.3.5.2 Design

Transit systems are not always designed to be beautiful, but that doesn't mean that they can't be designed and built that way. In many communities the increased aesthetic appeal of a system with attractive design elements can pay off in terms of public acceptance and higher ridership, but this is not always the case. Utilitarian systems have been built using ready-made components, which still have very high public acceptance and ridership. The key here is to know the communities that will be served and/or impacted by the system, and to discuss design and aesthetics with them early in the planning process, to help guide mode selection and design, so as to avoid public opposition and costly changes or redesigns later in the process. If system design is not a major concern for a particular community, then it may be a waste of resources to use customized or otherwise high-end system components.

Good design does not have to be expensive, so investing in modes that use visually pleasing yet cost-effective design elements will generally pay off in the long-term. Vehicles and infrastructure that are designed to be durable and have a modern, yet lasting, look can be used for longer periods without appearing to be old, worn, or outdated. Design is especially important for the more visible modes, but outstanding design may also be needed for systems that are branded as premium, marketed toward high-wealth communities, and for which higher fares are charged. Custom and high-end design would be most appropriate where it provides strategic system benefits, such as higher ridership, public support, and willingness to pay.

6.4 Social Considerations

Social considerations within the transit mode selection process include reliability and safety, not only for people, including motorists, cyclists, pedestrians, children, seniors, and disabled individuals, but also for wildlife populations in the proposed service area, as shown in Figure 6.4.

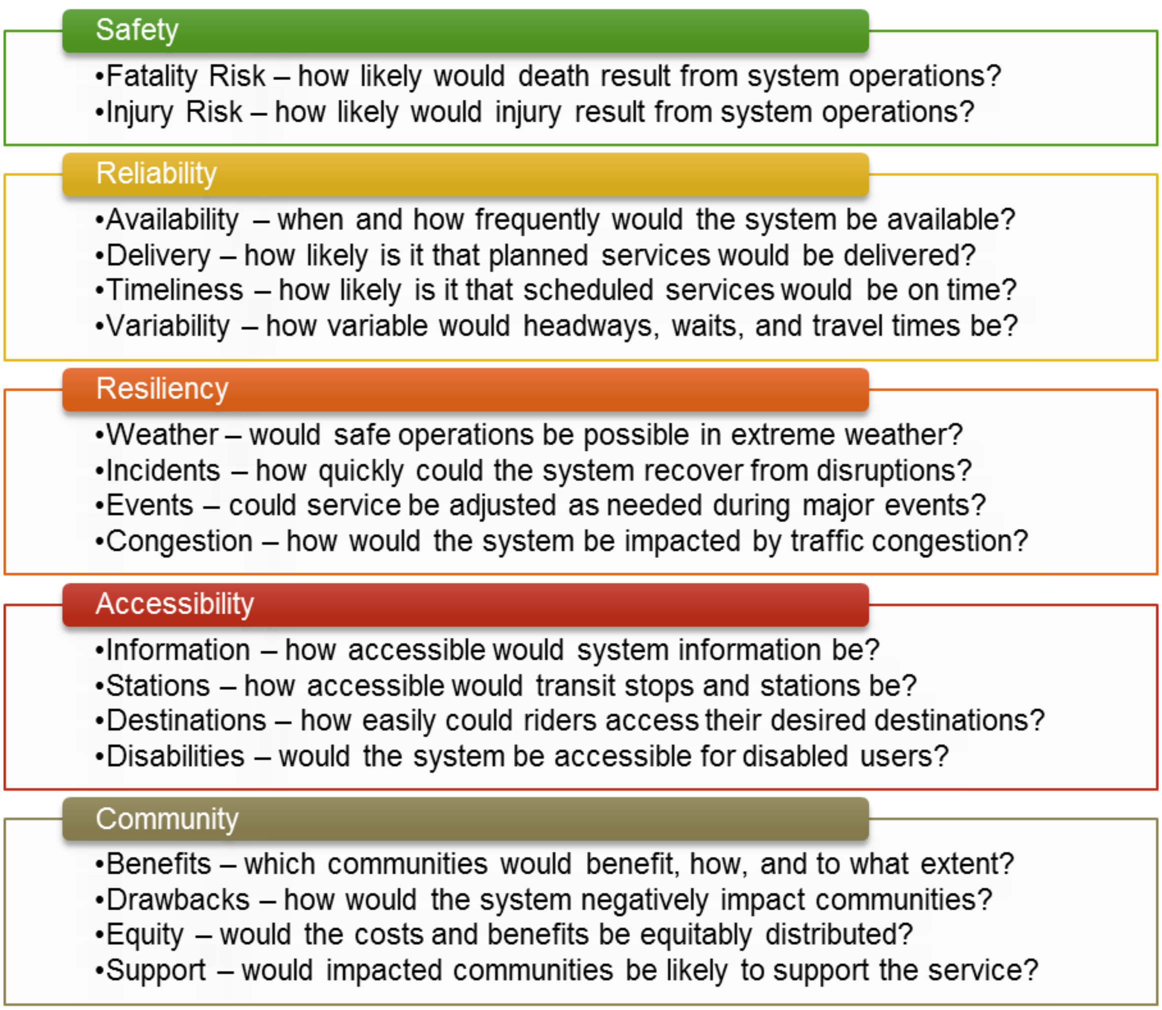


Figure 6.4 – Social Considerations

6.4.1 Safety

Transit is generally a safer mode of transportation than personal automobiles, but some transit modes have had a better safety record than others in recent years, as described in Chapter 4. Considerations related to the safety of a particular transit mode in a given context should at least include the expected frequency of safety incidents and their severity, to predict the level of risk involved with a project. While best practices in design, construction, operations, and maintenance can be used to reduce or eliminate many safety risks associated with a transit system, incidents are likely to occur in any public place. Safety incidents should be carefully tracked, so that data analysis can be used to identify recurrent issues, which the transit operator can work to address. Some safety events are rare, and in some cases unexpected. These occurrences are perhaps the most difficult to prepare for, but logical, consistent, and well-planned emergency response procedures can help transit agencies respond quickly and effectively to nearly any safety incident or risk. Overall, low-risk modes should be prioritized, but mild or infrequent risks can be taken in some cases.

6.4.1.1 Fatality Risk

The severity involved with certain safety incidents is a critical consideration when selecting a transit mode. Severe safety occurrences can result in catastrophic consequences, including the loss of many lives, and must be avoided to the extent possible. As discussed in Section 4.5.2, no fatalities have been reported for any aerial modes in the U.S. (including those on ski resorts) since 1978. Bus rapid transit, cable car, and inclined plane modes also had no fatalities reported from 2013-2015. Very low fatality rates of less than 0.25 fatalities per 100 million passenger miles on average were reported for vanpool, ferryboat, and commuter bus modes during this same period. Low fatality rates of 0.25-0.75 fatalities per 100 million passenger miles were calculated for bus, heavy rail, publico, and taxi modes. Trolleybus, demand response, streetcar rail, commuter rail, and light rail had fatality rates of 0.75-1.5 fatalities per 100 million passenger miles in recent years. The highest fatality rates of 2.5-3.5 fatalities per 100 million passenger miles were calculated for monorail / automated guideway and hybrid rail modes, though the figures calculated for both of these modes may have been increased due to low usage of both of these modes.

6.4.1.2 Injury Risk

Safety incidents that result in any type of injury should be investigated and the root causes addressed. Lessons may be learned from any mistake, to help prevent such occurrences in the future. Safety risks with low severity may be unavoidable when operating a public transit system, but education can be used to encourage safe practices among staff, riders, and the public. Choosing modes with a low risk of injury for passengers and the general public can also be an effective strategy for improving transportation safety. Aerial and inclined plane modes appear to have the lowest risk of injuries per passenger mile, based on data from 2013-2015. Vanpool and commuter bus had low injury rates of less than 10 injuries per 100 million passenger miles during this period. Medium-low injury rates of 10-35 injuries per 100 million passenger miles were calculated for publico, hybrid rail, ferryboat, light rail, and heavy rail modes. Medium injury rates (65-135 per 100 million passenger miles) were found for bus, bus rapid transit, trolleybus, taxi, and cable car modes. Medium-high injury rates (170-185 injuries per 100 million passenger miles) were calculated for streetcar rail and demand response modes. The highest injury rate of 277 injuries per 100 million passenger miles was found for monorail / automated guideway systems in the U.S., though this value could again be skewed by the low ridership seen for these modes.

6.4.2 Reliability

Reliability can be broadly defined as when a system operates as expected. Temporal and operational reliability considerations, such as system availability, delivery, timeliness, and variability, are most applicable to the transit mode selection process.

6.4.2.1 Availability

In many ways transit schedules set the stage for transit service reliability. Service frequency has a major influence on reliability, as the consequences of missing a transit vehicle decrease with increasing frequencies. On-demand services offer some benefits over scheduled services, but some on-demand modes are more reliable and available than others. Demand response transit, for example, may require hours or days of advance notice, which may limit its usefulness and reliability. The most reliable on-demand transit services may include automated guideway, gondola, and funitel modes, since customers can walk up to these systems, climb aboard, and go in many cases. Other on-demand modes, such as jitney, taxi, and water taxi, may require a brief waiting period, but this is often much less than what is common for demand response and paratransit services. Further, transit systems that operate all day and night may be considered as more reliable than those with limited operating hours.

6.4.2.2 Delivery

On the operational side of a transit system, it is important from a reliability standpoint that the technology be able to deliver scheduled service when properly maintained. Vehicles and infrastructure systems that are prone to failure not only impact reliability, but may put people's safety at risk. As shown in Figure 4.20, vanpool and commuter rail had the lowest rates of mechanical failures per vehicle operated in maximum service (VOMS), followed by inclined plane, demand response, and hybrid rail modes. Ferryboat, bus rapid transit, and commuter bus had slightly higher mechanical failure rates, with light rail, bus, and trolleybus having higher rates still, followed by heavy rail, monorail / automated guideway, and streetcar rail, which had more than 10 times as many mechanical failures per VOMS as commuter rail in 2014.

Another measure related to service delivery is the ratio of actual revenue miles to scheduled revenue miles. Commuter rail, commuter bus, bus, hybrid rail, and bus rapid transit all delivered up to 5% more revenue miles of service than were scheduled, although this could be partially attributed to the need to operate extra vehicles to replace those that break down or otherwise fail to deliver scheduled service. Inclined plane rail, aerial tramway, and ferryboat all delivered exactly as much service as scheduled, indicating that aerial and water modes can be very reliable when properly maintained. Modes that delivered up to 5% fewer revenue miles than scheduled were light rail, monorail / automated guideway, heavy rail, and streetcar rail. Trolleybus only delivered 91% of scheduled revenue miles (Federal Transit Administration, 2016).

6.4.2.3 Timeliness

Schedule adherence, or on-time performance, is a commonly tracked measure of reliability throughout the transit industry, but it may not apply to headway-based, unscheduled services. Once systems are operated frequently enough, schedules become less important and wait times approach zero. It is more critical, then, that less frequent transit services are on time. When timeliness does apply to a transit system, it should be tracked and analyzed. Vehicles that are regularly early or late to particular stops may indicate issues with scheduling, routing, traffic congestion, driver behavior, and many other factors that can be addressed by the transit operator at some level. Schedule adjustments are one way of addressing differences between scheduled and actual arrival or departure times, to improve on-time performance. However, transit planners and operators should be careful not to add too much slack time into schedules, or vehicles will have to wait for longer periods of time to avoid early departures, thereby reducing system efficiency and increasing overall travel times.

Timeliness may be more closely tied to transit operators and system context than modes, but modes that use exclusive corridors are expected to be on time more often than modes that share their right-of-way with mixed traffic. Corridors with general traffic can be made more efficient for transit vehicles through priority treatments, but the effectiveness of these treatments on timeliness and reliability depend largely on the context, and should not be assumed to have a significant impact. Automation may also help transit vehicles to stay on schedule by eliminating variations among drivers.

<u>6.4.2.4 Variability</u>

Variability applies to many different aspects of transit service reliability, including arrival and departure times, wait times, travel times, vehicle and stop characteristics, crowding, seat availability, traffic congestion, and others. Greater variability generally equates to lower reliability, especially since it may increase customers' perceived levels of uncertainty and risk involved with taking transit. Less certainty and higher risk may drive customers away over the long-term, and could also prevent new customers from using transit. Automation, exclusive right-of-ways, priority treatments, driver training, real-time information, and many other strategies can be used to reduce transit system variability and uncertainty. While some modes may be inherently less variable than others, project context and transit operators also influence variability and reliability of specific transit systems.

6.4.3 Resiliency

Resiliency is closely related to reliability, but refers specifically to a system's ability to avoid or recover from disruptions, such as those caused by extreme weather, incidents, major events, and unusual levels of traffic congestion.

<u>6.4.3.1 Weather</u>

Severe weather may disrupt transit services, so the service area climate and weather patterns are important to consider in any transit mode selection process. Storms involving heavy rainfall can lead to flooding of roadways, railroads, and underground transit systems, such as in New York during Hurricane Sandy. Snow and ice can also be a challenge for surface modes, while aerial and water modes are typically less impacted. Several parts of the U.S. experience extreme winds on a more or less frequent basis, including during hurricanes, tropical storms, and tornados. Most transit modes will not operate during these extreme weather events, due to safety concerns, but transit systems built in areas that experience such natural disasters should at least be built to withstand (or seek shelter from) the expected conditions. Lightning is another concern, most often in warmer climates, especially for water modes. Most surface and aerial modes can be designed to operate safely in lightning if needed, although power loss may be a risk for electrical systems during thunderstorms (backup power systems would improve transit resiliency in this case).

Further, some climates in the U.S. experience extreme hot or cold temperatures, especially the most northern polar climates in Alaska and the increasingly hot southern regions with arid, semi-arid, or subtropical climates. Extreme hot or cold weather can impact infrastructure and mechanical operations, such that operating would mean putting staff, customers, and the public at risk, if it is possible at all. Transit systems in warm-weather climates should be designed to withstand extreme heat, which can cause railroads and pavement to buckle, and engines to overheat. Modes proposed for cold-weather climates should be able to withstand extreme low temperatures, as well as heavy snow and ice. Depending on the temperature range experienced in the service area, including potential impacts of climate change during the life of the system, some modes may be preferable to others. Most transit modes can be operated almost anywhere, as long as sufficient protection from extreme weather is provided as needed. Aerial and rail modes may be slightly better suited for cold climates, while rubber-tire and water modes are likely to be more conducive to warm-weather climates.

6.4.3.2 Incidents

Beyond recurrent operational reliability issues, major events and incidents can wreak havoc on transit systems. Vehicle crashes, derailments, fires, earthquakes, power outages, and other safety and security incidents can cause major disruptions for transit systems, but some modes can handle these events better than others. Modes using exclusive right-of-way tend to be better able to cope with incidents affecting general traffic, as long as their right-of-way isn't damaged or blocked. Sometimes modes that can easily be re-routed around an incident, such as various types of bus and automobile transit services, are preferable from a resiliency standpoint. Transportation professionals should consider the types of disruptive incidents that a system might encounter in a given service area during the transit mode selection process, and plan accordingly. Installing backup power systems, as well as security and safety monitoring equipment can help to avoid and quickly overcome power failure and security incidents.

6.4.3.3 Events

Likewise, sporting events, concerts, parades, festivals, and other major events can cause unexpected surges in demand and/or interruptions in the transportation network. Depending on the prevalence of incidents and large events in the proposed service area, modes with route flexibility may be desirable, for situations where temporary re-routing can be used to minimize negative impacts on transit service reliability. Modes with higher capacities and those using exclusive corridors may also be preferable for areas with major events, to meet demand even during peak travel times.

6.4.3.4 Congestion

Traffic congestion can cause major delays and service disruptions in extreme cases, but even peak daily traffic can be a challenge for modes operated in mixed traffic. As with incidents and events, congestion is most problematic for modes that share their right-of-ways with general traffic. While buses can be re-routed with relative ease, streetcar rail cannot, so congestion becomes an unavoidable problem in this case. Transit routes can be designed to avoid the most congested urban corridors, but this may mean limiting service to high-demand destinations. Aerial modes, bus and automobile modes using exclusive lanes, rail modes (other than streetcar), and water modes are rarely, if ever, impacted by traffic congestion.

6.4.4 Accessibility

Accessibility is another key factor to consider from multiple perspectives during the mode selection process. If people cannot easily get to, or are not even aware of, transit systems, then they are much less likely to use them.

6.4.4.1 Information

The accessibility of information can be thought of in a variety of ways. One factor is the presence or absence of basic visual information, which tells people that a transit system is nearby. More visible modes are preferable to less visible modes in this sense. Transit information may also include the locations of stops and stations, as well as transfer points and connections to other modes or systems. Schedules, routes, fares, vehicle characteristics, ADA accessibility, agency policies, points of contact, real-time arrival and departure information, and many other vital pieces of information should be made available to transit riders and the general public, whenever possible. Computers and phones with internet access are an easy access point for many individuals, but technology-limited individuals will need low-tech means of access available.

6.4.4.2 Stations

In addition to information on station locations, the stations themselves can be more or less accessible, based on the mode that they serve and their design. The most accessible stations are those that are at the street or surface level without any barriers between transit customers and vehicles. Modes that typically use stops and stations with this highest level of accessibility include most bus (bus, commuter bus, trolleybus) and automobile (demand response, jitney, publico, taxi, etc.) modes. At-grade rail and bus rapid transit stations are commonly located on the surface, but often have barriers in place to prevent people from boarding the system without paying. Aerial and water modes may also be located at the surface level, though they may require passengers to move through a barrier and up or down to access transit vehicles. Elevated and subterranean transit modes often have the least accessible stations, since they almost always require customers to ascend or descend from the surface to access vehicles. This is especially challenging for mobility-challenged individuals, as discussed further in Subsection 6.4.4.4.

6.4.4.3 Destinations

Beyond the physical accessibility of transit stations is the accessibility of desired destinations within the network. There are many facets to this factor, which should be considered in the transit mode selection process. First, the destinations served by a transit network should be taken into account. This involves a basic level of analysis, which can be used to dive more deeply into the issue of access. The next step would be to ask how easily each major destination can be accessed from various origins within the network. Are nearby origins provided with direct service to their closest activity centers? Priority should be given to transit modes that can effectively serve high-demand origin-destination pairs, but direct, short-distance trips between major destinations and surrounding neighborhoods and centers should also be well-served.

Deeper levels of analysis could examine the full transit network and the number of transfers required for common trips. Being able to reach a destination without transferring is clearly desirable from the customer perspective, and may simplify transit agency operations at some level. However, simplicity of route and network design should also be given thorough consideration. Simple grid-like networks can offer access to almost any destination within their network, often with only a single transfer. Long and winding routes may allow passengers to remain in their seats throughout the duration of their trip, but grid networks tend to use more linear routes that can often be understood without the need to refer to a route map.

Some modes may be seen as making destinations more accessible than others, but this largely depends on the route design within the context of the existing transit network and urban infrastructure in the proposed service area. On-demand modes, such as demand response, jitney, publico, and taxi are intended to serve any origin and destination within a service area (as will water taxi, so long as a dock is available), but this is not always true in practice. Some communities have difficulty getting taxis and other on-demand services to serve them. The alignments of aerial modes tend to be some of the simplest, due to the technology being more conducive to straight routes. Ferryboat services are typically operated between two fixed points, making them fairly easy to understand and access. However, a challenge with incorporating aerial and water modes, as well as any new surface modes, in a network that does not use these modes currently is that they will inevitably require passengers to transfer in order to use other modes within the transit network.

6.4.4.4 Disabilities

All of the previously discussed accessibility issues are even more challenging when accommodating the full variety of disabilities that individuals may have. Mobility challenges are the most obvious types of disabilities among transit users, but disabilities of the senses, as well as other physical and mental health issues should be considered when possible. The planning and design of transit vehicles, stations, routes, and networks, as well as information services, should ensure maximum access for people with a range of disabilities.

As shown in Figure 4.29, ADA accessible vehicle availability varies substantially between transit modes in the U.S. Aerial and bus modes, as well as hybrid rail, monorail

/ automated guideway, and heavy rail had the highest percentages of ADA accessible vehicles in 2014, with many of these modes having 100% accessible fleets. Light rail systems reported 93% ADA accessible vehicles, followed by demand response (84%), ferryboat (82%), commuter rail (75%), and inclined plane rail (67%). Modes with less than 50% accessible vehicles included streetcar rail (38%), taxi (18%), vanpool (4%), and cable car and publico, both with no ADA accessible vehicles. To be fair, many streetcar and cable car systems use heritage vehicles, which are not ADA accessible despite the availability of modern ADA accessible vehicles.

Transit stations should also be designed and built for optimal accessibility among the mobility challenged, including people with wheelchairs, walkers, crutches, and even those with large luggage, bicycles, or strollers. When elevators are needed to make a station accessible, they should be well-maintained and made available during all hours of operation. Further, stations should be made as safe and accessible for those who are visually impaired, hearing impaired, or challenged in a variety of other ways. Along these lines, provisions should be made whenever possible to accommodate individuals with physical and mental health issues, as well as those who are illiterate or non-English speakers. The use of universally-recognized symbols in addition to or instead of written information can be helpful to this end. Air conditioning, shelter, seating, public restrooms, drinking fountains, and concessions are amenities that are typically appreciated by able-bodied and disabled individuals alike.

Route and network design can also influence the accessibility of a transit system in a variety of ways. A blind and deaf person with sufficient information in advance could board a transit vehicle and know where to alight based on the number of stops that they sense while on board. If, however, stops are skipped or the route differs from the norm from any reason, this individual might get off too early or late without realizing it, which could be very dangerous for them.

Lastly, customer service representatives, and other staff should be available on-site at all major stations to assist customers in need, and all staff members should be trained to recognize and address signs of distress, as appropriate. Drivers can play a similar role aboard their vehicles. Even automated transit systems may benefit from having staff aboard to help customers. Further, hotlines, service kiosks, social media, and other means for customers to interact with and provide feedback to the transit agency can help passengers overcome their challenges, and also guide needed improvements to make transit services more accessible. These services should be available for the deaf and blind, as well as non-English speakers, whenever possible.

6.4.5 Community

Social factors should be considered broadly, but also with respect to specific individuals and communities, including internal and external stakeholders. New or enhanced transit services can impact people in a variety of ways, so considering the effects that a system may have on those who come into contact with it is recommended. Internal stakeholders are transit agency staff and customers, but may also include members of a board of directors, investors, government officials, and others. The perspectives of a number of external stakeholders, especially potential customers and nearby business owners, workers, and residents, should also be considered in the transit planning and mode selection processes.

6.4.5.1 Benefits

As discussed elsewhere in this thesis, transit benefits may include improved access and mobility, reduced emissions, job creation, economic development, and more. Community priorities among potential transit benefits can help to inform mode selection. Each transit system offers a range of benefits to the communities that it serves, but these may vary somewhat by mode. Generally speaking, benefits should be as closely matched to community priorities and desires as much as possible.

While some community members may want a fast and direct service with few stops and be willing to travel more than a mile to a station, others may need a mode that can pick them up and drop them off within a half mile of their home. Some communities may be interested in job creation and economic development more than mobility, in which case modes that use small, slower, manned vehicles and permanent infrastructure may be seen as ideal. Multiple modes can be used in conjunction to provide services for community members with different needs, but the first step is to understand what those needs and desires are before making major investments.

6.4.5.2 Drawbacks

Changes to transit service may be met with employee resistance, especially when fears of job loss arise. Customers may also be skeptical of or opposed to change if they perceive it as negatively impacted them. Some customers would rather have a less frequent bus route with a stop within a mile of their home than travel further, even to access a service offering higher performance. Negative impacts to motorists, cyclists, pedestrians, children, seniors, and disabled individuals should be avoided whenever possible, even though they may not be regular users of the transit system. Laying rail lines in a corridor where cyclists also ride can increase crash risks, due to bicycles slipping on or being caught in the tracks. As another example, very quiet electric transit vehicles that share a corridor with pedestrians could pose a risk to those who are visually impaired, as well as to inattentive individuals. Special care should be taken to ensure that transit systems provide maximum community benefits and accessibility without endangering vulnerable users in the service area.

6.4.5.3 Equity

Equity refers to the distribution of project benefits and drawbacks in a way that is fair for those impacted. An inequitable situation would be one where communities that are well-served by a transit system experience very few drawbacks from it, while other communities get the bulk of the drawbacks, perhaps without any access to the service itself. High-speed commuter transit services that pass through, but do not stop in, low-wealth communities are typical examples of inequitable transit. Ensuring that systems are equitable is not only the right thing to do, in the author's opinion, but analysis of the social and environmental justice of a transit project is required for any project to be eligible for federal funding.

6.4.5.4 Support

An inclusive and well-facilitated public engagement effort is a foundational piece of any high-quality transit planning process, and can help transportation professionals and decision makers understand the interests and concerns of transit users, stakeholders, and the general public early on. Meaningful public engagement may also help to reduce or prevent organized opposition to a proposed project, which could derail it entirely. Transit can be mutually beneficial for transit agencies and the communities they serve, and an effective dialog can help to ensure that this is the case.

6.5 Economic Considerations

As shown in Figure 6.5, economic considerations involve estimating project costs and revenue based on service area activities, densities, and other relevant factors. Further, the impact of a proposed system on service area employment and development should be analyzed and considered in the mode selection process. These factors are recommended for consideration after performance, environmental, and social factors, as costs and revenue are best estimated when potential alignments and their infrastructure requirements, environmental mitigation needs, and social implications are at least preliminarily known. When estimated costs exceed the project budget, additional funds can be sought and/or the proposed transit system can be adjusted as needed to reduce costs and/or increase revenue.

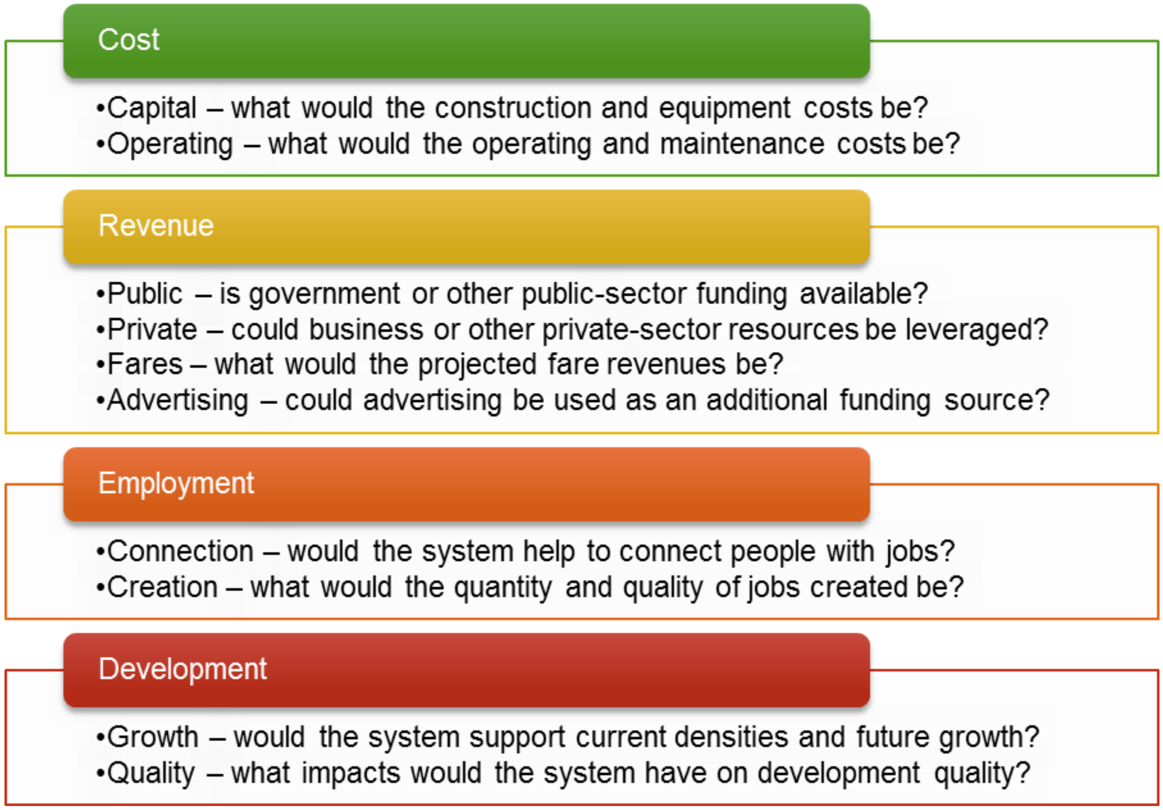


Figure 6.5 – Economic Considerations

6.5.1 Cost

Transit system costs include capital costs, which are needed for project construction and resource acquisition, and operating costs, including for labor, fuel, insurance, and parts to run the system.

<u>6.5.1.1 Capital</u>

Vehicle costs are a major component of capital costs, and they vary with vehicle size and characteristics. Facility costs, including those for transit stops and stations, as well as storage and maintenance facilities, make up another portion of capital costs. Facilities, as well as vehicles, may have different costs based on the size, design complexity, and level of comfort and amenities that they provide. It is important to keep in mind that, while low capital costs may seem appealing, high operating costs can erase and even reverse upfront savings over time.

As discussed in Chapter 4, modes with minimal infrastructure tend to have the lowest capital costs. These modes include bus, commuter bus, demand response, jitney, publico, vanpool, and water modes (although larger vessels and docks mean higher capital costs). Medium-low capital costs were calculated for trolleybus and commuter rail modes, which averaged from about $7,500 to just over $8,000 per transitway mile in 2014. Aerial modes are expected to have moderate capital costs (which can vary substantially based on the technology and level of customization), along with hybrid rail, bus rapid transit, and streetcar rail. Medium-high capital costs are expected for monorail / automated guideway and light rail modes. The highest capital costs per transitway mile in the U.S. are associated with inclined plane and heavy rail.

6.5.1.2 Operating

Operating costs are somewhat more involved, as they include all labor costs (except, perhaps, construction labor costs), as well as the cost of fuel, parts, insurance, and other components needed to keep a transit system functioning. Labor, fuel, maintenance, and other costs increase with higher levels of service, but labor costs are generally less of an issue for modes that use vehicles without drivers (aerial and automated modes), even at peak capacities. Fuel cost savings can be realized over time by selecting more efficient modes and those using clean, renewable energy sources.

As discussed in Chapter 4, maintenance costs may be higher for certain modes, and tend to go up with increased use, fleet size, and system age. Despite using small vehicles with drivers, vanpool and publico had the lowest operating costs per passenger mile of any modes reported to the NTD in 2014, followed by commuter bus, heavy rail, and commuter rail. Light rail, bus rapid transit, hybrid rail, and bus were operated for $1.40 to $2.10 per passenger mile in 2014. Ferryboat, trolleybus, streetcar rail, and aerial tramway had moderate operating expenses per passenger mile ranging from $2.75 to just over $4.00. Medium-high operating costs per passenger mile ($5.20-8.20) were calculated for monorail / automated guideway, taxi, and demand response modes. The highest operating costs of any modes in the U.S. were calculated for cable car and inclined plane, but these systems are historical in nature, and use technologies from over 100 years ago.

6.5.2 Revenue

Like costs, the potential revenue from a transit system is influenced by the selected mode, and income from fare collection and other sources can be roughly estimated based on demand and project context. The combined revenue sources should at least cover the operating costs of a system for it to be economically sustainable.

6.5.2.1 Public

A variety of public funding sources, including government grants, are available, but many of these are limited to specific modes or purposes defined by the awarding agencies, as discussed in Section 4.6.4.

6.5.2.2 Private

Private investment may also be used to provide a substantial portion of the funding needed for transit system construction and/or operations. Businesses can voluntarily tax themselves to generate revenue for community improvements through business improvement districts, while individuals and philanthropic organizations can also contribute funds through private investment and/or donations. Crowd-funding platforms have not been used for major transit projects yet, to the author's knowledge, but these tools provide a means for communities to directly support the development of their transit system, and could play a more notable role in transit funding in the future.

6.5.2.3 Fares

Fare revenue is influenced primarily by demand and pricing. Modes that are embraced by potential customers are more likely to attract higher ridership than those viewed as less desirable. Service frequencies, route characteristics, pricing, and many other factors determine the overall attractiveness of a transit system. Fare structures should be determined based on several considerations, and ultimately must strike a balance between profit and affordability, depending in part on the structure and funding sources of the transit operator. In cases where funding is available to provide a free transit service, it can be justified to build and operate a system that brings in no fare revenue as long as there are sufficient community benefits to offset the costs.

6.5.2.4 Advertising

Other revenue streams can also be generated through transit operations, including through advertising, concessions, and fees charged for other on-site amenities. Advertising revenue is best generated in dense urban areas with a lot of traffic and highly visible transit infrastructure and vehicles.

6.5.3 Employment

While transit is often thought of as a means to connect people with their places of employment, transit systems can also be effective job creators.

6.5.3.1 Connection

The ability to build connections between people's homes and places of employment appears to be more dependent on route and network design than on any particular mode choices. However, depending on the densities and demand for transit in certain areas, some modes will prove to be more effective than others. Employment areas with high transient populations of professionals and office workers may experience high levels of congestion during peak hours. Therefore, high capacity modes that use exclusive right-of-way are likely to be most effective for serving these areas. Efficiency and adjustable capacity are key factors to consider here. Modes such as commuter bus, commuter rail, and vanpool tend to be used to provide heavily peaked, employment-oriented transit services. With the variety of mode combinations that could be used to provide service to a given area, any additions of new modes should complement and integrate with existing systems.

6.5.3.2 Creation

Transit systems directly employ people at many levels, from construction workers, planners, and engineers, to drivers, customer service representatives, and mechanics, all the way up to professional staff and senior leadership. As discussed in Chapter 4, some transit modes tend to be better job creators than others. Heritage modes in the U.S., such as inclined plane and cable car, actually created the most jobs per passenger mile of service consumed among all modes reported to the NTD in 2014. Trolleybus, monorail / automated guideway, and demand response modes had the next highest numbers of employee hours worked per passenger mile. Monorail / automated guideway modes were not expected to create a lot of jobs, as these systems often use driverless vehicles. As with other measures, the low ridership numbers for these modes appear to be driving per passenger mile rates up. Moderately job-creating modes include streetcar rail, ferryboat, and bus, followed by light rail and bus rapid transit. Medium-low job creators in 2014 included heavy rail, commuter rail, and commuter bus. Vanpool had the lowest calculated value of employee hours per passenger mile in this case. Although comparable data was not available for several aerial, automobile, or water modes, these transit systems do contribute to the employment of drivers, customer service agents, maintenance workers, and other staff needed for the systems to operate.

6.5.4 Development

From an economic development perspective, street life and equity are desired goals for a transit system. Transportation professionals should not only consider the existing conditions along a potential transit corridor, but also the plans and opportunities for growth and development. Above all else, transit should be used to promote quality development, which helps to uplift communities and provide equitable access for all.

6.5.4.1 Growth

Transit investments can be used to stimulate additional investment in an area, so from an equity standpoint it is advisable to implement transit services in under-served areas where transportation and economic stimulus are greatly needed. Growth is not always viewed positively, though, especially when displacement of existing residents and communities is likely to occur. Transportation professionals, local leaders, and community members should engage in open dialogues throughout the mode selection and project planning processes, to work toward transit development projects that help communities to grow and develop, while minimizing displacement. This may involve implementing policies that are beyond the realm of the transit agency, to protect existing residents and community resources.

6.5.4.2 Quality

All communities have strengths and weaknesses. Transit can be an effective tool for building upon the social and infrastructural foundations of a community, and at the same time helping to address some of the challenges faced by area residents and visitors. To complement street life that incorporates a variety of modes (people walking, riding bikes, driving, and otherwise traveling through the area), modes that fit well with or avoid these users should be prioritized. Although rail modes are often hailed as being best for economic development, care should be taken to avoid locating tracks in areas where they would pose a significant risk to cyclists. In order to achieve quality outcomes from a transit enhancement or expansion project, quality planning and mode selection processes are needed. Such processes should be thoughtful, comprehensive, context-sensitive, open, and inclusive.

CHAPTER 7

CONCLUSION

Transit mode selection can be a very complex process with dozens of interrelating factors to consider, which can be overwhelming for evaluating a single mode, let alone for comparing multiple potential transit modes. This thesis was written as a guide to help transportation professionals, decision makers, and community leaders make more informed decisions with regard to transit mode selection, based on comprehensive, context-sensitive, and sustainability-oriented processes involving multiple stakeholders.

The goal of this research was not to highlight a single mode that is the best overall, nor does this guide point readers to a single mode that they should use for their project. Rather, this resource helps to walk readers through a flexible transit mode selection framework one step at a time, providing information and guidance along the way to shift readers' focus from what is most familiar, to the modes that are most logical and appropriate for inclusion in more detailed alternatives analyses. When thoughtful consideration is put into the high-level process proposed in Chapter 6, the data and information gathered should facilitate more detailed levels of analysis, which should result in better outcomes for transit providers and the communities that they serve.

This final chapter includes recommendations in Section 7.1 and future research opportunities in Section 7.2. Four appendices are presented after Chapter 7, including a mode selection process checklist (Appendix A), summary sheets for each transit mode (Appendix B), the full survey administered to transit agencies and MPOs (Appendix C), and the extended survey results, including full text responses to open-ended questions (Appendix D). References are included after these appendices.

7.1 Recommendations

Several high-level recommendations emerged through this thesis-writing process, as outlined below.

- Don’t fixate on any one mode – each transit mode is a tool, with its own strengths and weaknesses, meant to be used for specific purposes. No one mode can be all things to all people in all cases. Trying to force buses to navigate congested urban streets, commuter rail to ascend steep grades, boats to operate without water, or aerial modes to provide high-speed, long-distance commuter services will almost certainly lead to failure. Instead, work to understand how each tool can be best used (or not used) in the context of a proposed service area.
- Provide meaningful involvement opportunities – as smart as transportation professionals are (or like to think that we are), we don’t know everything. Even if we had access to all the data we could possibly dream of, there would still be factors we don’t consider. It is very important to provide many opportunities for inclusive, interactive, and meaningful public engagement throughout the transit planning and mode selection processes. Information gathered from discussions with various stakeholders, including local residents, employees, business owners, elected officials, community leaders, transit agency staff, board members, potential sponsors, and others, can be very valuable in guiding transit planning decisions.
- Consider the context – no transit system is an island; each one exists within a context of ecosystems and communities that are critical to supporting the lives of people and wildlife. Sustainable transit systems should be designed and built to enhance these complex and vital systems, with minimal disruption to the natural balances that have already been achieved, often over hundreds, thousands, or even millions of years. Mode selection can play an important role in this.

- Focus on value, not just money – it seems to the author to be irrational to place so much emphasis on fiscal matters, when money is merely a human construct based on the reputation of the issuer. Why is money so often valued over safety, reliability, and environmental sustainability? Without breathable air and drinkable water, many species on Earth would perish, including humans. At a minimum, performance, environmental, and social concerns should be valued to the same extent as economic concerns. The author would go further, to assert that these first three factors should be valued above economic concerns. Sustainable economics do offer several benefits, including support for maintenance and continued operation of a system, but transit systems planning should not be limited by fiscal matters initially. Economic constraints should be applied as a last step in the transit planning process.
- Don't forget about wildlife – the plants and animals present in or traveling through a transit service area should always be considered in transit planning processes to achieve optimum system safety and sustainability. Construction of new transit systems may result in trees being cut or other loss of plant life. Ideally transit projects would not only replace any trees and plants that are lost, but actually increase the service area tree canopy and landscaping, as an amenity and asset in attracting ridership. Whenever possible, native plants that thrive in the local climate with minimal maintenance should be used, creating a resilient landscape. Furthermore, crashes between transit vehicles and animals can be devastating to animals and people alike. High-speed, at-grade transit modes are associated with the greatest risk of a crash with wildlife, but potential impacts on plants and animals should be considered for slower modes as well. Aerial modes should avoid disrupting flying and nesting areas. Surface modes require safe crossings,

and should avoid sensitive habitats. Water modes should minimize pollution and hazards, such as propellers, to protect wildlife.

- Be flexible, and don't be afraid to start over – performance characteristics may change throughout the transit planning process, based on fatal flaws and contextual incompatibilities identified in any phase of the mode selection process. Modes that may be favored initially could later prove to be infeasible, while modes that might not seem appropriate at first turn out to be the most ideal fit for the project. The high-level process proposed in Chapter 6 is meant to be flexible and iterative. It is not designed to point to a single best mode for a project, but rather to help transportation planners and decision makers narrow down the field of more than 20 transit modes to those most appropriate for detailed consideration through further planning, public engagement, and detailed alternatives analysis processes. Be open to considering new and innovative modes where they make sense, but don't choose these modes for the sake of novelty alone. Often, they can be justified on their own merits given the project context, but sometimes the tried and true methods are best. Thoughtful and intentional processes, which may follow the process outlined in Chapter 6 very closely or differ substantially from it, should result in selection of the most sustainable and appropriate transit mode or modes for the service area.

7.2 Future Research Opportunities

While an overwhelming amount of data on transit modes was uncovered through the process of researching and writing this thesis, very little of the research was found to be comprehensive, or inclusive of all modes. Many opportunities exist for building upon the work that went into this thesis, but in some areas more data is desperately needed. Areas that were found to be most lacking in useful data were related to:

- transit project construction timelines and level of disruption;
- actual transit mode operating capacities;
- mode attraction among various socio-economic demographic groups;
- energy usage of transit modes that are not prevalent in the U.S.;
- mode frequencies, schedules, and wait times;
- emissions, including of pollutants other than carbon dioxide;
- surface area and land requirements;
- noise and vibrations;
- internal and external aesthetic impacts of various modes and designs;
- impacts on resources, waterways, and wildlife;
- transit mode reliability and resiliency;
- mode, route, and network accessibility;
- equity, public health, and other community benefits and drawbacks;
- extreme and typical project costs;
- willingness to pay for various modes and levels of service;
- job creation and quality; and
- economic development impacts of various modes.

The author hopes that others will join her in continuing this line of research, in support of better, more sustainable urban transit, and will happily provide access to relevant data for interested individuals.

APPENDIX A

TRANSIT MODE SELECTION CHECKLIST

Urban Transit Mode Comparison Checklist

Factors to consider when selecting modes for alternatives analyses

Performance

Space	Time	Capacity	Efficiency	Maintenance
☐ Available Space	☐ Build Time	☐ Capacity	☐ Energy Usage	☐ Maintenance Schedule
☐ Terrain	☐ Operating Hours	☐ Speed	☐ Resource Consumption	☐ Equipment Life
☐ Length	☐ Schedule	☐ Productive Capacity	☐ Adaptability	
☐ Stop Spacing	☐ Wait Times			
	☐ Travel Times			

Environmental

Air	Land	Water	Noise	Aesthetics
☐ Emissions	☐ Surface Area	☐ Quantity	☐ Audible Noise	☐ Visibility
☐ Flight Paths	☐ Exclusivity	☐ Quality	☐ Vibrations	☐ Design
☐ Air Rights	☐ Land Use	☐ Ecosystems		
	☐ Crossings			
	☐ Habitats			

Social

Safety	Reliability	Resiliency	Accessibility	Community
☐ Fatality Risk	☐ Availability	☐ Weather	☐ Information	☐ Benefits
☐ Injury Risk	☐ Delivery	☐ Incidents	☐ Stations	☐ Drawbacks
	☐ Timeliness	☐ Events	☐ Destinations	☐ Equity
	☐ Variability	☐ Congestion	☐ Disabilities	☐ Support

Economic

Cost	Revenue	Employment	Development
☐ Capital	☐ Public	☐ Connection	☐ Growth
☐ Operating	☐ Private	☐ Creation	☐ Quality
	☐ Fares		
	☐ Advertising		

APPENDIX B

TRANSIT MODE SUMMARY SHEETS

The following pages are designed to summarize the findings of this thesis for each included mode. Any of these summary sheets can be used as a quick reference for transit planners and decision makers engaged in transit mode selection. These sheets may also serve as educational handouts for distribution at public meetings. The factors and characteristics of modes described on the following pages are based on the findings from Part II of this thesis, and the author's judgement. Modes may be used differently in some cases, but these sheets summarize the typical characteristics of each mode.

The methodology used to arrive at ratings for each factor in the mode summary sheets was as follows:

- For factors that had data available in Chapter 4 or sufficient discussion in Chapter 6, ratings were assigned to each mode, for each factor in the performance, environment, social, and economic categories. Information from these chapters (Sections shown in Figure B.1) was used to rate each transit mode. Additional factors were assigned to each mode, based on the author's understanding of each technology in general. Perhaps one of the biggest challenges with this method is that each mode can be used in a variety of ways, such as by being elevated, at-grade, or underground. When multiple uses of a mode may have received different scores, an approximate average rating (the rating half way between two extreme cases) was assigned.

Category	Area	Factor	Section
Performance	Space	Space Needed	4.3.9
		Terrain Flexibility	4.3.9
		Length	4.2
		Stop Spacing	4.4.3
	Time	Build Time	6.2.2.1
		Schedule	4.3.8
		Wait Times	Estimated
		Travel Times	4.3.5
	Capacity	Capacity	4.3.1
		Speed	4.3.5
		Productive Capacity	4.3.1
	Efficiency	Energy Usage	4.3.6
		Resource Consumption	Estimated
		Adaptability	6.2.4.3
	Maintenance	Maintenance Schedule	4.3.7
		Equipment Life	6.2.5.2
Environment	Air	Emissions	4.4.1
	Land	Surface Area	4.4.3
		Exclusivity	Estimated
	Water	Quantity	Estimated
		Quality	Estimated
	Noise	Audible Noise	4.4.4
		Vibrations	6.3.4.2
	Aesthetics	Visibility	6.3.5.1
		View	6.3.5.1
Social	Safety	Fatality Risk	4.5.2
		Injury Risk	4.5.2
	Reliability	Availability	4.5.1
		Delivery	6.4.2.2
	Resiliency	Weather	4.5.4
		Congestion	Estimated
	Accessibility	Stations	6.4.4.2
		Disabilities	4.5.3
Economic	Cost	Capital	4.6.1
		Operating	4.6.2
	Revenue	Fares	4.6.3
	Employment	Creation	4.6.6
	Development	Growth	Estimated
		Quality	Estimated

Table B.1 – Sources of Information for Mode Summary Sheet Ratings

- Modes were then grouped for each factor, so that scores could be assigned a corresponding value. The scale of measurement for each factor used integers (total increasing by 1 with each added category) to represent a group, but the upper end of the scale varying between factors. The score for each area was calculated by taking an average of the ratios of each mode's score to the maximum score for each factor in the area. To generalize the findings, a relative color scale was used for each factor's scores. An example using the space area, or sub-category, of factors is shown in Figure B.2 and Figure B.3.

Section	*4.3.9*	*4.3.9*	*4.2*	*4.4.3*
Mode	**Space Needed**	**Terrain Flexibility**	**Length**	**Stop Spacing**
Aerial Tramway	Low	High	Short	Short
Bus	Medium	Medium	Medium	Very Short
Bus Rapid Transit	High	Medium	Medium	Short
Cable Car	Medium	Medium	Short	Very Short
Commuter Bus	Medium	Medium	Long	Long
Commuter Rail	Medium	Low	Long	Long
Demand Response	Medium	Medium	Medium	Medium
Ferryboat	Low	Low	Medium	Long
Funitel	Low	High	Short	Short
Gondola	Low	High	Short	Short
Heavy Rail	High	Medium	Medium	Medium
Hybrid Rail	Medium	Low	Long	Long
Inclined Plane	Medium	Medium	Short	Medium
Jitney	Medium	Medium	Medium	Medium
Light Rail	High	Medium	Medium	Short
Maglev Rail	High	Medium	Long	Medium
Monorail / Automated Guideway	Medium	Medium	Short	Medium
Publico	Medium	Medium	Medium	Medium
Streetcar Rail	Medium	Medium	Short	Very Short
Taxi	Medium	Medium	Medium	Medium
Trolleybus	Medium	Medium	Short	Very Short
Vanpool	Medium	Medium	Long	Long
Water Bus	Low	Low	Short	Short
Water Taxi	Low	Low	Medium	Medium

Figure B.2 – Space Example for Transit Mode Summary Sheet Ratings

Mode	Space Needed	Terrain Flexibility	Length	Stop Spacing	Space Score
Aerial Tramway	3	3	3	2	88%
Bus	2	2	2	1	56%
Bus Rapid Transit	1	2	2	2	54%
Cable Car	2	2	3	1	65%
Commuter Bus	2	2	1	4	67%
Commuter Rail	2	1	1	4	58%
Demand Response	2	2	2	3	69%
Ferryboat	3	1	2	4	75%
Funitel	3	3	3	2	88%
Gondola	3	3	3	2	88%
Heavy Rail	1	2	2	3	60%
Hybrid Rail	2	1	1	4	58%
Inclined Plane	2	2	3	3	77%
Jitney	2	2	2	3	69%
Light Rail	1	2	2	2	54%
Maglev Rail	1	2	1	3	52%
Monorail / Automated Guideway	2	2	3	3	77%
Publico	2	2	2	3	69%
Streetcar Rail	2	2	3	1	65%
Taxi	2	2	2	3	69%
Trolleybus	2	2	3	1	65%
Vanpool	2	2	1	4	67%
Water Bus	3	1	3	2	71%
Water Taxi	3	1	2	3	69%
Maximum	*3*	*3*	*3*	*4*	*88%*
Minimum	*1*	*1*	*1*	*1*	*52%*

Figure B.3 – Space Example for Transit Mode Summary Sheet Scores

- The modes were then grouped again, into red (worse than average), yellow (average), and green (better than average), based on the author's judgment using the red to green relative color scale as a guide, as well as natural breaks in the data. This is the final rating shown in the mode summary sheets. The process of developing these scores required estimation for 8 of the 39 included factors, and is in many ways based on the author's personal views and understanding of urban transit modes. Others may arrive at different conclusions, using the same or a similar process.
- Some factors (and areas, in the case of community) were deemed to be too context-specific (flight paths, air rights, land use, habitat, ecosystems, variability,

incidents, events, destinations, and community), operator-specific (operating hours, timeliness, and information access), or subjective (design) to be included in this analysis, but analysis of additional data could lead to more comprehensive ratings for urban transit modes.

Transit Mode: Aerial Tramway

Names	Aerial Tramway, Aerial Tram, Cable Car
Definition	An electric system of aerial cables with suspended powerless passenger vehicles. The vehicles are propelled by separate cables attached to the vehicle suspension system and powered by engines or motors at a central location not onboard the vehicle.
Image	 (Photo by: Cacophony on Wikipedia)
Common uses	Crossing difficult terrain, Transit line extension, Intermodal connector, Water crossings
Examples	Roosevelt Island Tram, Portland Aerial Tram
Strengths	Vertical flexibility, Safety, Low impact, Resiliency, Attractiveness
Weaknesses	Horizontal flexibility, Capacity

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Bus

Names	Bus, Shuttlebus, Motorbus
Definition	Rubber-tired passenger vehicles operating on fixed routes and schedules over roadways.
Image	
Common uses	Local transit service, Feeder routes, Rural and suburban transit, Circulators
Examples	Many publicly and privately operated systems
Strengths	Low startup costs, Minimal infrastructure
Weaknesses	Reliability, Resiliency, Economic development, Operating costs

Performance

Space | Time | Capacity | Efficiency | Maintenance

Environment

Air | Land | Water | Noise | Aesthetics

Social

Safety | Reliability | Resiliency | Accessibility | Community *(Varies)*

Economic

Cost | Revenue | Employment | Development

Transit Mode: Bus Rapid Transit

Names	Bus Rapid Transit, Bus Semirapid Transit, Rapid Bus, Enhanced Bus
Definition	Fixed-route bus mode in which the majority of each line operates in a separated right-of-way dedicated for public transportation us during peak periods, including features that emulate the services provided by rail (fixed-guideway) public transportation systems.
Image	 (Photo by: Mario Roberto Duran Ortiz on Wikipedia)
Common uses	Rapid transit, Trunk lines, Line extensions
Examples	LA Metro Orange and Silver Lines, Bogota Transmilenio
Strengths	Safety, Low emissions
Weaknesses	Space requirements, Water impacts, Resiliency

Performance

Space Time Capacity Efficiency Maintenance

Environment

Air Land Water Noise Aesthetics

Social

Safety Reliability Resiliency Accessibility Community *(Varies)*

Economic

Cost Revenue Employment Development

Transit Mode: Cable Car

Names	Cable Car, CABLE Liner
Definition	An electric railway with individually controlled transit vehicles attached to a moving cable located below the street surface and powered by engines or motors at a central location, not onboard the vehicle.
Image	 (Doppelmayr Seilbahnen GmbH, 2016)
Common uses	Airport connector, Light rail alternative, Shuttle, Circulator
Examples	BART to Oakland Airport, Venezia People Mover
Strengths	Safety, Short installation time, Resiliency, Low operating costs
Weaknesses	Limited vertical flexibility

Performance

Space	Time*	Capacity*	Efficiency*	Maintenance*

Environment

Air	Land	Water	Noise*	Aesthetics

Social

Safety*	Reliability*	Resiliency	Accessibility*	Community *(Varies)*

Economic

Cost*	Revenue	Employment	Development*

*Modern systems are expected to perform better than historic systems for this factor.

Transit Mode: Commuter Bus

Names	Commuter Bus, Express Bus, Regional Bus
Definition	Fixed-route bus systems that are primarily connecting outlying areas with a central city through bus service that operates with at least five miles of continuous closed-door service. This service may operate motorcoaches and feature peak scheduling, multiple-trip tickets, and limited stops in the central city.
Image	 (Photo by: RTABus on Wikipedia)
Common uses	Commuter services, Express routes, Feeder routes, Suburban routes
Examples	GRTA Xpress, Maryland Transit Administration Commuter Bus
Strengths	Safety, Speed, Low emissions, Costs
Weaknesses	Reliability, Resiliency, Wildlife impacts

Performance

Space | Time | Capacity | Efficiency | Maintenance

Environment

Air | Land | Water | Noise | Aesthetics

Social

Safety | Reliability | Resiliency | Accessibility | Community *(Varies)*

Economic

Cost | Revenue | Employment | Development

Transit Mode: Commuter Rail

Names	Commuter Rail, Suburban Rail, Regional Rail
Definition	An electric or diesel propelled railway for urban passenger train service consisting of local short distance travel operating between a central city and adjacent suburbs. Service must be operated on a regular basis by or under contract with a transit operator for the purpose of transporting passengers within urbanized areas, or between urbanized areas and outlying areas.
Image	 (Photo by: Joe Mabel on Wikipedia)
Common uses	Commuter services, Feeder lines, Suburban lines
Examples	Sound Transit Sounder, MBTA Commuter Rail Lines
Strengths	Speed, Capacity, Low emissions, Low operating costs
Weaknesses	Terrain flexibility, Noise, Wildlife impacts

Performance

Space	Time	Capacity	Efficiency	Maintenance
🔴	🟡	🟢	🟡	🟢

Environment

Air	Land	Water	Noise	Aesthetics
🟢	🔴	🟡	🔴	🟡

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*
🟡	🟢	🟡	🟡	

Economic

Cost	Revenue	Employment	Development
🟢	🟡	🟡	🟡

Transit Mode: Demand Response

Names	Demand Response, Demand Responsive Transport, Dial-a-Ride Transit, Flexible Transport Services, Paratransit
Definition	Passenger cars, vans or small buses operating in response to calls from passengers or their agents to the transit operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations.
Image	 (Photo by: Ubid20pk53 on Wikipedia)
Common uses	On-demand mobility, Paratransit, Coverage for low-demand areas
Examples	MARTA Mobility, ACCESS LYNX
Strengths	Route flexibility
Weaknesses	Capacity, Emissions, Resiliency, Costs

Performance

Space | Time | Capacity | Efficiency | Maintenance

Environment

Air | Land | Water | Noise | Aesthetics

Social

Safety | Reliability | Resiliency | Accessibility | Community *(Varies)*

Economic

Cost | Revenue | Employment | Development

Transit Mode: Ferryboat

Names	Ferryboat, Ferry
Definition	Vessels (generally steam or diesel powered) that carry passengers and / or vehicles over a body of water, typically between two points.
Image	
Common uses	Point to point services for people and their vehicles
Examples	Washington State Ferries, Staten Island Ferry
Strengths	Space requirement, Water impacts, Safety, Wildlife impacts
Weaknesses	Capacity, Emissions, Terrain flexibility, Resiliency

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Funitel

Names	Funitel
Definition	Aerial transit mode using cars that detach from the two steel cables that propel them, so that they may be slowed or stopped in stations for boarding and alighting purposes.
Image	
Common uses	Crossing difficult terrain, Transit line extension, Intermodal connector, Water crossings
Examples	Squaw Valley Funitel
Strengths	Vertical flexibility, Safety, Low impacts, Reliability, Resiliency, Attractiveness
Weaknesses	Horizontal flexibility

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Gondola

Names	Gondola, Aerial Gondola, Gondola Lift, Cable Car
Definition	Aerial transit mode using cars that detach from the single steel cable that propels them, so that they may be slowed or stopped for boarding and alighting purposes. Unlike aerial tramways, gondolas are continuously moving and available for on-demand service.
Image	
Common uses	Crossing difficult terrain, Transit line extension, Intermodal connector, Water crossings
Examples	Medellin Metrocable, London Emirates Air Line
Strengths	Vertical flexibility, Safety, Low impacts, Reliability, Resiliency, Attractiveness
Weaknesses	Horizontal flexibility

Performance

Space Time Capacity Efficiency Maintenance

Environment

Air Land Water Noise Aesthetics

Social

Safety Reliability Resiliency Accessibility Community *(Varies)*

Economic

Cost Revenue Employment Development

Transit Mode: Heavy Rail

Names	Heavy Rail, Metro, Rapid Transit, Rail Rapid Transit, Subway, Underground
Definition	An electric railway with the capacity for a heavy volume of traffic. It is characterized by high-speed and rapid-acceleration passenger rail cars operating singly or in multi-car trains on fixed rails, separate rights-of-way from which all other vehicular and foot traffic are excluded, sophisticated signaling, and high platform loading.
Image	
Common uses	Trunk lines, Urban service, Rapid transit
Examples	Bay Area Rapid Transit, New York City MTA Subway
Strengths	Speed, Capacity, Low emissions, Resiliency, Wildlife impacts
Weaknesses	Space requirements

Performance

Space | Time | Capacity | Efficiency | Maintenance

Environment

Air | Land | Water | Noise | Aesthetics

Social

Safety | Reliability | Resiliency | Accessibility | Community *(Varies)*

Economic

Cost | Revenue | Employment | Development

Transit Mode: Hybrid Rail

Names	Hybrid Rail, Commuter Rail, Light Rail Rapid Transit, Regional Rail
Definition	Rail system primarily operating routes on the National system of railroads, but not operating with the characteristics of commuter rail. This service typically operates light rail-type vehicles as diesel multiple-unit trains. These trains do not meet Federal Railroad Administration standards, and so must operate with temporal separation from freight rail traffic.
Image	 (Photo by: Greg3564 on Wikipedia)
Common uses	Commuter services, Suburban transit
Examples	Capital Metrorail, NJ Transit River Line
Strengths	Speed, Capacity, Low emissions
Weaknesses	Safety, Terrain flexibility, Revenue, Noise

Performance

Space | Time | Capacity | Efficiency | Maintenance

Environment

Air | Land | Water | Noise | Aesthetics

Social

Safety | Reliability | Resiliency | Accessibility | Community *(Varies)*

Economic

Cost | Revenue | Employment | Development

Transit Mode: Inclined Plane

Names	Inclined Plane, Funicular, Cliff Railway
Definition	A railway operating over exclusive right-of-way on steep grades (slopes) with powerless vehicles propelled by moving cables attached to the vehicles and powered by engines or motors at a central location not onboard the vehicle. The special tramway types of vehicles have passenger seats that remain horizontal while the undercarriage (truck) is angled parallel to the slope.
Image	 (Photo by: Plastikspork on Wikipedia)
Common uses	Ascending and descending steep grades
Examples	Pittsburgh Duquesne Incline, MTA Inclined Elevators
Strengths	Revenue, Attractiveness, Safety, Wildlife impacts
Weaknesses	Speed, Emissions, Costs

Performance

Space Time Capacity Efficiency Maintenance

Environment

Air Land Water Noise Aesthetics

Social

Safety Reliability Resiliency Accessibility Community *(Varies)*

Economic

Cost Revenue Employment Development

Transit Mode: Jitney

Names	Jitney, Share Taxi, Jitney Cab
Definition	Passenger cars or vans operating on fixed routes (sometimes with minor deviations) as demand warrants without fixed schedules or fixed stops.
Image	 (Photo by: Worldbook1967 on Wikipedia)
Common uses	Shuttle services, On-demand services, Downtown circulators
Examples	Georgia Bus Lines, Atlantic City Jitney, Lyft
Strengths	Low emissions, Costs, Route flexibility
Weaknesses	Capacity, Resiliency, Information availability

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Light Rail

Names	Light Rail, Light Rail Transit
Definition	Typically an electric railway with a light-volume traffic capacity compared to heavy rail. It is characterized by: passenger rail cars operating singly (or in short, usually two-car, trains) on fixed rails in shared or exclusive right-of-way; low or high platform loading; and vehicle power drawn from an overhead electric line via a trolley or a pantograph.
Image	
Common uses	Rapid transit, Trunk lines, Commuter services, Extension lines
Examples	UTA TRAX, RTD Light Rail, Houston METRORail
Strengths	Wildlife impact
Weaknesses	Space requirement

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Maglev Rail

Names	Maglev Rail
Definition	A rail transit mode that uses magnetic levitation to eliminate contact between train cars and rails when the system is in operation. High-speed systems are the most efficient use of maglev, but this technology can also be used for urban rapid transit.
Image	
Common uses	Commuter services, Airport connectors, Rapid transit, High-speed rail lines
Examples	Shanghai Maglev Rail, Linimo
Strengths	Speed, Capacity, Resiliency, Safety, Quiet, Wildlife impacts
Weaknesses	Space requirements

Performance

Space | Time | Capacity | Efficiency | Maintenance

Environment

Air | Land | Water | Noise | Aesthetics

Social

Safety | Reliability | Resiliency | Accessibility | Community *(Varies)*

Economic

Cost | Revenue | Employment | Development

Transit Mode: Monorail / Automated Guideway

Names	Monorail, Automated Guideway Transit, Automated Guided Transit
Definition	Transit modes on exclusive guideway without using steel wheels on rails. Monorail refers to rail systems operating over or suspended from a single rail. Automated guideway transit refers to computer-controlled transit systems that allow vehicles to be operated without drivers.
Image	 (Photo by: Scott Ricamore on Wikipedia)
Common uses	Airport connectors, Circulators, Shuttle services, Feeder lines
Examples	Las Vegas Monorail, Seattle Monorail, Morgantown People Mover
Strengths	Resiliency, Revenue, Noise, Wildlife impacts
Weaknesses	Emissions, Safety

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Note: Low ridership in the U.S. appears to be negatively impacting ratings for this mode.

Transit Mode: Publico

Names	Publico, Share Taxi
Definition	Passenger vans or small buses operating with fixed routes but no fixed schedules. Publicos are privately owned and operated public transit services which are market-oriented and unsubsidized, but regulated through a public service commission, state, or local government.
Image	 (Photo by: Metro Puerto Rico)
Common uses	On-demand services, Shuttle services
Examples	Puerto Rico Publicos
Strengths	Low emissions, Costs
Weaknesses	Capacity, Resiliency

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Streetcar Rail

Names	Streetcar Rail, Tram, Tramcar, Trolley, Trolleycar, Electric Street Railway, Interurban, Light Rail
Definition	Rail transit systems operating entire routes predominantly on streets in mixed traffic. This service typically operates with single-car trains powered by overhead catenaries and with frequent stops.
Image	 (Photo by: Cacophony on Wikipedia)
Common uses	Circulators, Economic development
Examples	Portland Streetcar, Kansas City Streetcar, New Orleans Streetcars
Strengths	Economic development, Wildlife impacts
Weaknesses	Speed, Reliability

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Taxi

Names	Taxi, Taxicab, Cab, Demand Response Taxi
Definition	A special form of the demand response mode operated through taxicab providers. Systems may be privately operated or partially funded with public sources.
Image	 (Photo by: N-Lange.de on Wikipedia)
Common uses	Private on-demand services
Examples	NYC Taxi, Yellow Cab, hundreds of other service examples
Strengths	Route flexibility, Low infrastructure requirements
Weaknesses	Capacity, Resiliency

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Trolleybus

Names	Trolleybus, Trackless Trolley, Trolley, Trolley Coach
Definition	Electric rubber-tired passenger vehicles, manually steered and operating singly on city streets. Vehicles are propelled by a motor drawing current through overhead wires via trolleys, from a central power source not onboard the vehicle.
Image	
Common uses	Local transit services, Feeder routes
Examples	Seattle Trolleybuses, MBTA Trolleybuses
Strengths	Better at overcoming steep terrain and quieter than bus
Weaknesses	Speed, Resiliency, Reliability

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

<u>Transit Mode: Vanpool</u>

Names	Vanpool
Definition	Vans, small buses and other vehicles operating as a ridesharing arrangement, providing transportation to a group of individuals traveling directly between their homes and a regular destination within the same geographical area.
Image	 (Photo by: UCLA Transportation on flickr)
Common uses	Commuter services, Shuttle services, Airport connections
Examples	UCLA Vanpool, King County Metro Vanpool
Strengths	Speed, Low emissions, Costs, Safety
Weaknesses	Capacity, Resiliency, Revenue, Wildlife impacts

<u>Performance</u>

Space | Time | Capacity | Efficiency | Maintenance

<u>Environment</u>

Air | Land | Water | Noise | Aesthetics

<u>Social</u>

Safety | Reliability | Resiliency | Accessibility | Community *(Varies)*

<u>Economic</u>

Cost | Revenue | Employment | Development

Transit Mode: Water Bus

Names	Water Bus, Ferry, Sightseeing Boat, Water Taxi, Hydrofoil
Definition	A waterborne transit mode that operates like a bus, on a schedule with more than two stops in a given service area. Many water bus services call themselves water taxis, and although these terms are used interchangeably they are not the same mode.
Image	
Common uses	Water crossings, Circulators, Local transit services
Examples	Long Beach Aquabus and AquaLink, Venice Vaporetto
Strengths	Space requirements, Low impacts, Costs, Revenue, Safety
Weaknesses	Capacity, Terrain flexibility, Climate flexibility

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

Transit Mode: Water Taxi

Names	Water Taxi, Water Bus, Sightseeing Boat
Definition	A waterborne transit mode that operates like a taxi, on-demand and typically with one origin and one destination per trip.
Image	 (Photo by: Fletcher6 on Wikipedia)
Common uses	On-demand transit services, Water crossings
Examples	Boston Water Taxi, Venice Water Taxis
Strengths	Space requirements, Water impacts, Safety, Reliability
Weaknesses	Capacity, Terrain flexibility, Climate flexibility

Performance

Space	Time	Capacity	Efficiency	Maintenance

Environment

Air	Land	Water	Noise	Aesthetics

Social

Safety	Reliability	Resiliency	Accessibility	Community *(Varies)*

Economic

Cost	Revenue	Employment	Development

APPENDIX C

SURVEY

Page 1: Consent Document

CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY

Georgia Institute of Technology

Project Title: Transit Mode Selection Survey

Investigators: Dr. Kari Edison Watkins, P.E., Carly Susan Queen, Alice Barbara Grossman

Protocol and Consent Title: H15220 Main 07/13/2015v1

You are being asked to be a volunteer in a research study.

Purpose:

The purpose of this study is to develop tools to help transit planning organizations select the best transit mode or modes for their projects and service areas. Goals of this survey include learning more about transit mode decision making processes from transit planning organizations, such as evaluation criteria used and staff familiarity with available transit modes. We expect to receive completed surveys from 50 or more transit planning organizations.

Exclusion/Inclusion Criteria:

Participants in this study should be affiliated with a transit planning organization, such as a current or recent employee.

Procedures:

If you decide to be in this study, your part will involve completing an approximately 10-15 minute online survey about your familiarity with various transit modes and your organization's transit mode selection processes. Should you choose to provide your name and contact information (this is optional, not required), we may contact you by phone or email with one or more follow-up questions after you have completed the online survey. You are not obligated to answer any survey or follow-up questions. Participation is completely voluntary, and should not take more than 30 minutes total, including possible follow-up questions.

Risks or Discomforts:

The risks involved with participating in this study are minimal and comparable to those involved with sending an email.

Benefits:

You may not personally benefit from participating in this survey. However, we do hope to learn from your response and use the information you provide to develop effective decision support tools to help transit planning organizations make more informed transit mode selection choices.

Compensation to You:

There is no compensation for participation.

Confidentiality:

The following procedures will be followed to keep your personal information confidential in this study:

The data collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept in locked files and only study staff will be allowed to look at them. Participants are given the option to complete this survey anonymously or provide contact information for follow-up. In either case, neither your name nor any other fact that might point to you will appear when results of this study are presented or published. Your privacy will be protected to the extent allowed by law. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records. The Office of Human Research Protections may also look over study records during required reviews. You should be aware that the survey is not being run from a 'secure' https server of the kind typically used to handle credit card transactions, so there is a small possibility that responses could be viewed by unauthorized third parties such as computer hackers. In general, the web page software will log as header lines the IP address of the machine you use to access this page, (e.g.,102.403.506.807), but otherwise no other information will be stored unless you explicitly enter it.

Costs to You:

There are no costs to you, other than your time, for being in this study.

Participant Rights:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.

- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Questions about the Study:

If you have any questions about the study, you may contact Dr. Kari Watkins at telephone (206) 250-4415 or kari.watkins@ce.gatech.edu.

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact:

Ms. Melanie Clark, Georgia Institute of Technology

Office of Research Integrity Assurance, at (404) 894-6942.

By completing the online survey, you indicate your consent to be in the study.

Page 2: Introduction

Thank you for taking the Transit Mode Selection Survey! The purpose of this survey is to better understand the processes being used by transit planning organizations to select transit modes for their projects. Your input is critical to the success of this research, so thank you in advance for completing the survey. Let's get started with a few introductory questions.

1. Please indicate your level of familiarity with each ***aerial*** transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar). ***This question is required.**

1. Please indicate your level of familiarity with each aerial transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar). *This question is required.	1	2	3	4	5
Aerial Tramway	○	○	○	○	○
Funitel	○	○	○	○	○
Gondola	○	○	○	○	○

2. Please indicate your level of familiarity with each ***rail*** transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar). ***This question is required.**

2. Please indicate your level of familiarity with each rail transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar). *This question is required.	1	2	3	4	5
Cable Car	○	○	○	○	○
Commuter Rail	○	○	○	○	○
Heavy Rail	○	○	○	○	○
Hybrid Rail	○	○	○	○	○
Inclined Plane	○	○	○	○	○
Light Rail	○	○	○	○	○
Maglev	○	○	○	○	○
Monorail / Automated Guideway	○	○	○	○	○
Streetcar Rail	○	○	○	○	○

3. Please indicate your level of familiarity with each ***rubber-tire*** transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar). ***This question is required.**

3. Please indicate your level of familiarity with each rubber-tire transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar). *This question is required.	1	2	3	4	5
Bus	○	○	○	○	○
Bus Rapid Transit	○	○	○	○	○
Commuter Bus	○	○	○	○	○
Demand Response	○	○	○	○	○
Jitney	○	○	○	○	○
Publico	○	○	○	○	○
Taxi	○	○	○	○	○
Trolleybus	○	○	○	○	○
Vanpool	○	○	○	○	○

4. Please indicate your level of familiarity with each ***water*** transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar). ***This question is required.**

4. Please indicate your level of familiarity with each water transit mode listed below, using a 1-5 scale (1 = Not Familiar and 5 = Very Familiar). *This question is required.	**1**	**2**	**3**	**4**	**5**
Ferryboat	○	○	○	○	○
Water Bus	○	○	○	○	○
Water Taxi	○	○	○	○	○

Page 3: Current Operations

This page includes a question about the modes that your organization currently offers, with definitions of each mode provided below.

5. What transit modes are currently offered by your organization? Check all that apply. *(See below for a definition of each mode.)*

- ☐ Aerial Tramway
- ☐ Bus
- ☐ Bus Rapid Transit
- ☐ Cable Car
- ☐ Commuter Bus
- ☐ Commuter Rail

- ☐ Demand Response
- ☐ Ferryboat
- ☐ Funitel
- ☐ Gondola
- ☐ Heavy Rail
- ☐ Hybrid Rail
- ☐ Inclined Plane
- ☐ Jitney
- ☐ Light Rail
- ☐ Maglev
- ☐ Monorail / Automated Guideway
- ☐ Publico
- ☐ Streetcar Rail
- ☐ Taxi
- ☐ Trolleybus
- ☐ Vanpool
- ☐ Water Bus
- ☐ Water Taxi
- ☐ Other Please enter an 'other' value for this selection.

Transit Mode Definitions (adapted from the U.S. National Transit Database):

Aerial Tramway – An electric system of aerial cables with suspended powerless passenger vehicles. The vehicles are propelled by separate cables attached to the vehicle suspension system and powered by engines or motors at a central location not onboard the vehicle.

Bus – Rubber-tired passenger vehicles operating on fixed routes and schedules over roadways.

Bus Rapid Transit – Fixed-route bus mode in which the majority of each line operates in a separated right-of-way dedicated for public transportation use during peak periods, including features that emulate the services provided by rail (fixed-guideway) public transportation systems.

Cable Car – An electric railway with individually controlled transit vehicles attached to a moving cable located below the street surface and powered by engines or motors at a central location, not onboard the vehicle.

Commuter Bus – Fixed-route bus systems that are primarily connecting outlying areas with a central city through bus service that operates with at least five miles of continuous closed-door service. This service may operate motorcoaches, and usually features peak scheduling, multiple-trip tickets, and limited stops in the central city.

Commuter Rail – An electric or diesel propelled railway for urban passenger train service consisting of local short distance travel operating between a central city and adjacent suburbs. Service must be operated on a regular basis by or under contract with a transit operator for the purpose of transporting passengers within urbanized areas, or between urbanized areas and outlying areas.

Demand Response – Passenger cars, vans or small buses operating in response to calls from passengers or their agents to the transit operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations.

Ferryboat – Vessels (generally steam or diesel powered) that carry passengers and / or vehicles over a body of water, typically between two points.

Funitel – Aerial transit mode using cars that detach from the two steel cables that propel them, so that they may be slowed or stopped for boarding and alighting purposes. Cars typically hold 20-30 passengers and can withstand higher wind speeds than gondolas or aerial tramways.

Gondola – Aerial transit mode using cars that detach from the single steel cable that propels them, so that they may be slowed or stopped for boarding and alighting purposes. Unlike aerial tramways, gondolas are continuously moving and available for on-demand service.

Heavy Rail – An electric railway with the capacity for a heavy volume of traffic. It is characterized by high-speed and rapid-acceleration passenger rail cars operating singly or in multi-car trains on fixed rails, separate rights-of-way from which all other vehicular and foot traffic are excluded, sophisticated signaling, and high platform loading.

Hybrid Rail – Rail system primarily operating routes on the National system of railroads, but not operating with the characteristics of commuter rail. This service typically operates light rail-type vehicles as diesel multiple-unit trains. These trains do not meet Federal Railroad Administration standards, and so must operate with temporal separation from freight rail traffic.

Inclined Plane – A railway operating over exclusive right-of-way on steep grades (slopes) with powerless vehicles propelled by moving cables attached to the vehicles and powered by engines or motors at a central location not onboard the vehicle. The special tramway types of vehicles have passenger seats that remain horizontal while the undercarriage (truck) is angled parallel to the slope.

Jitney – Passenger cars or vans operating on fixed routes (sometimes with minor deviations) as demand warrants without fixed schedules or fixed stops.

Light Rail – Typically an electric railway with a light-volume traffic capacity compared to heavy rail. It is characterized by: passenger rail cars operating singly (or in short, usually two-car, trains) on fixed rails in shared or exclusive right-of-way; low or high platform loading; and vehicle power drawn from an overhead electric line via a trolley or a pantograph.

Maglev – A rail transit mode that uses magnetic levitation to eliminate contact between train cars and rails when the system is in operation.

Monorail/Automated Guideway – Transit modes on exclusive guideway without using steel wheels on rails.

Publico – Passenger vans or small buses operating with fixed routes but no fixed schedules. Publicos are privately owned and operated public transit services which are market-oriented and unsubsidized, but regulated through a public service commission, state, or local government.

Streetcar Rail – Rail transit systems operating entire routes predominantly on streets in mixed traffic. This service typically operates with single-car trains powered by overhead catenaries and with frequent stops.

Taxi – A special form of the demand response mode operated through taxicab providers.

Trolleybus – Electric rubber-tired passenger vehicles, manually steered and operating singly on city streets. Vehicles are propelled by a motor drawing current through overhead wires via trolleys, from a central power source not onboard the vehicle.

Vanpool – Vans, small buses and other vehicles operating as a ridesharing arrangement, providing transportation to a group of individuals traveling directly between their homes and a regular destination within the same geographical area.

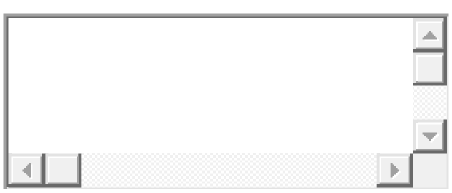
Water Bus – A waterborne transit mode that operates like a bus, on a schedule with more than two stops in a given service area.

Water Taxi – A waterborne transit mode that operates like a taxi, on-demand and typically with one origin and one destination per trip.

Page 4: Undefined Modes

This question focuses on your organization's reporting practices for modes that are not formally defined in the National Transit Database.

6. You selected one or more modes that are not defined in the National Transit Database (Gondola, Funitel, Maglev, Water Bus, and/or Water Taxi). Do you report on these modes to the Federal Transit Administration and, if so, how do you classify them? ***This question is required.**



Page 5: Consideration of Transit Expansion / Enhancement

One quick question about your organization's transit expansion and enhancement activities.

7. In the last 10 years, has your organization ***considered*** expanding or enhancing transit services? ***This question is required.**

- ◯ Yes
- ◯ No
- ◯ Unsure

Page 6: Expansion / Enhancement Studies

Questions on this page focus on your organization's experiences evaluating and selecting transit modes for expanding and/or enhancing your transit system.

8. What transit modes has your organization ***considered*** for transit expansion and/or enhancement in the last 10 years? Check all that apply.

- ☐ Aerial Tramway
- ☐ Bus
- ☐ Bus Rapid Transit
- ☐ Cable Car
- ☐ Commuter Bus
- ☐ Commuter Rail

- ☐ Demand Response
- ☐ Ferryboat
- ☐ Funitel
- ☐ Gondola
- ☐ Heavy Rail
- ☐ Hybrid Rail
- ☐ Inclined Plane
- ☐ Jitney
- ☐ Light Rail
- ☐ Maglev
- ☐ Monorail / Automated Guideway
- ☐ Publico
- ☐ Streetcar Rail
- ☐ Taxi
- ☐ Trolleybus
- ☐ Vanpool
- ☐ Water Bus
- ☐ Water Taxi
- ☐ Other Please enter an 'other' value for this selection.

9. Were any of your organization's transit enhancement / expansion studies conducted by other organizations? ***This question is required.**

- No, all of our studies were done in-house.
- Yes, some of our studies were done by contractors.
- Yes, all of our studies were done by contractors.
- Other Please enter an 'other' value for this selection.

10. Who typically defines which modes should be considered in expansion / enhancement studies? How are those modes decided upon? ***This question is required.**

11. In the last 10 years, has your organization ***expanded*** or ***enhanced*** transit services? Check all that apply. *(Expanded refers to extension of transit services to a new area or creation of a new route within an existing service area. Enhanced refers to transit upgrades on existing routes.)* ***This question is required.**

- Yes, we have expanded transit services.
- Yes, we have enhanced transit services.
- No
- Unsure

Page 7: Transit Expansion and Enhancement

Questions on this page focus on your organization's experiences expanding and/or enhancing transit services in the last 10 years. If you have not been with the organization for 10 years, please reach out to others within your organization who would have this information.

12. Please describe your organization's process for selecting transit modes to include in an alternatives analysis for transit system expansion / enhancement. ***This question is required.**

13. Please describe your organization's process for selecting final transit modes to use for transit system expansion / enhancement. ***This question is required.**

14. What transit modes has your organization ***selected*** for transit expansion and/or enhancement in the last 10 years? Check all that apply. *(Be sure to include modes that have been selected, even if they have not yet been built.)* ***This question is required.**

- ☐ Aerial Tramway
- ☐ Bus
- ☐ Bus Rapid Transit
- ☐ Cable Car
- ☐ Commuter Bus
- ☐ Commuter Rail
- ☐ Demand Response
- ☐ Ferryboat
- ☐ Funitel
- ☐ Gondola
- ☐ Heavy Rail
- ☐ Hybrid Rail
- ☐ Inclined Plane
- ☐ Jitney
- ☐ Light Rail
- ☐ Maglev
- ☐ Monorail / Automated Guideway
- ☐ Publico
- ☐ Streetcar Rail
- ☐ Taxi

- ☐ Trolleybus
- ☐ Vanpool
- ☐ Water Bus
- ☐ Water Taxi
- ☐ Other Please enter an 'other' value for this selection.

15. Why were these modes selected? ***This question is required.**

16. In the last 10 years, has your organization been involved with any mode succession activities (i.e. replacing one mode with another mode)? ***This question is required.**

- ○ Yes
- ○ No
- ○ Unsure

Page 8: Transit Mode Succession

Questions on this page focus on your organization's experiences with transit mode succession (replacing one mode with another mode). Please describe your your ***most recent*** mode succession experience below.

17. In your organization's most recent mode succession experience, what mode was being used originally? Check all that apply. *(You may check more than one more if multiple modes were replaced at one time for a particular service area.)* ***This question is required.**

- ☐ Aerial Tramway
- ☐ Bus
- ☐ Bus Rapid Transit
- ☐ Cable Car
- ☐ Commuter Bus
- ☐ Commuter Rail
- ☐ Demand Response
- ☐ Ferryboat
- ☐ Funitel
- ☐ Gondola
- ☐ Heavy Rail
- ☐ Hybrid Rail
- ☐ Inclined Plane
- ☐ Jitney
- ☐ Light Rail
- ☐ Maglev

- ☐ Monorail / Automated Guideway
- ☐ Publico
- ☐ Streetcar Rail
- ☐ Taxi
- ☐ Trolleybus
- ☐ Vanpool
- ☐ Water Bus
- ☐ Water Taxi
- ☐ Other Please enter an 'other' value for this selection.

18. In your organization's most recent mode succession experience, what mode was selected for replacing the other mode or modes? Check all that apply. *(You may check more than one more if multiple modes were used to replace an existing mode or modes at one time for a particular service area.)* ***This question is required.**

- ☐ Aerial Tramway
- ☐ Bus
- ☐ Bus Rapid Transit
- ☐ Cable Car
- ☐ Commuter Bus
- ☐ Commuter Rail

- ☐ Demand Response
- ☐ Ferryboat
- ☐ Funitel
- ☐ Gondola
- ☐ Heavy Rail
- ☐ Hybrid Rail
- ☐ Inclined Plane
- ☐ Jitney
- ☐ Light Rail
- ☐ Maglev
- ☐ Monorail / Automated Guideway
- ☐ Publico
- ☐ Streetcar Rail
- ☐ Taxi
- ☐ Trolleybus
- ☐ Vanpool
- ☐ Water Bus
- ☐ Water Taxi
- ☐ Other Please enter an 'other' value for this selection.

19. Why did you make this modal change and how did the process go? Include any challenges you faced in this process, and how you dealt with them. *(If you prefer to be interviewed over the phone to discuss this process, please indicate that here.)* ***This question is required.**

Page 9: Mode Selection Process

Questions on this page focus on your organization's current process for selecting transit modes for inclusion in alternatives analyses and/or use in project implementation.

20. What ***economic*** factors are currently considered in your organization's process for selecting transit modes for system expansion / enhancement? Check all that apply. ***This question is required.**

- ☐ Capital costs
- ☐ Operating costs
- ☐ Economic development
- ☐ Jobs access
- ☐ Job creation
- ☐ Availability of skilled workers
- ☐ Availability of funding

- ☐ Innovation
- ☐ Equipment origin
- ☐ All of the above
- ☐ None of the above
- ☐ Other Please enter an 'other' value for this selection.

21. What ***environmental*** factors are currently considered in your organization's process for selecting transit modes for system expansion / enhancement? Check all that apply.

***This question is required.**

- ☐ Emissions
- ☐ Fuel / power supply
- ☐ Noise / vibrations
- ☐ Land requirement
- ☐ Water impacts
- ☐ Resource impacts
- ☐ Wildlife impacts
- ☐ All of the above
- ☐ None of the above
- ☐ Other Please enter an 'other' value for this selection.

22. What ***social*** factors are currently considered in your organization's process for selecting transit modes for system expansion / enhancement? Check all that apply. ***This question is required.**

- ☐ Safety
- ☐ Reliability
- ☐ Resiliency
- ☐ Aesthetics
- ☐ Community views
- ☐ Political influences
- ☐ Accessibility
- ☐ All of the above
- ☐ None of the above
- ☐ Other Please enter an 'other' value for this selection.

23. What ***performance*** factors are currently considered in your organization's process for selecting transit modes for system expansion / enhancement? Check all that apply. ***This question is required.**

- ☐ Capacity
- ☐ Speed
- ☐ Schedule type

- ☐ Build time
- ☐ Energy use
- ☐ Maintenance requirements
- ☐ Spatial requirements
- ☐ All of the above
- ☐ None of the above
- ☐ Other Please enter an 'other' value for this selection. ____

24. Rate the importance of each set of factors in your organization's transit mode selection process, using a 1-5 scale (1 = Not Important and 5 = Very Important). ***This question is required.**

24. Rate the importance of each set of factors in your organization's transit mode selection process, using a 1-5 scale (1 = Not Important and 5 = Very Important). *This question is required.	**1**	**2**	**3**	**4**	**5**
Economic factors	○	○	○	○	○
Environmental factors	○	○	○	○	○
Social factors	○	○	○	○	○
Performance factors	○	○	○	○	○

25. What are the **most important factors** in your organization's transit mode selection process? ***This question is required.**

Page 10: Follow-up

If you are willing to let us contact you with follow-up questions as needed, please enter your name and contact information below. This information is completely optional, so you may choose to leave it blank and submit your response anonymously. **Be sure to click submit below so that your answer will be recorded!**

26. Please provide any additional thoughts on transit mode selection and your responses to previous survey questions.

27. What is the name of your organization? *(This information is needed for response tracking and data validation purposes; it will remain confidential and won't be associated with your response in any way.)* ***This question is required.**

28. How many years have you been with this organization? ***This question is required.**

- 0-2 years
- 3-5 years
- 6-8 years
- 9-11 years
- 12 or more years

29. Name (First and Last)

30. Job Title

31. Email Address

32. Phone Number

APPENDIX D

EXTENDED SURVEY RESULTS

The full responses, in alphabetical order, are provided for all open-ended survey questions in this appendix.

Table D.1 – Full Responses to Question 10

Question 10: Who typically defines which modes should be considered in expansion / enhancement studies? How are these modes decided upon?
A combination of Senior Management and outside consultant.
A stakeholder group consisting of the state, municipalities, MPO staff, operators, interested persons.
Agencies or the elected bodies that govern them. The mode selection in our agency is between bus, commuter bus, BRT, and demand-response / alternative service. Other agencies in the region have mandates to provide other modes, including ferries, commuter bus, commuter rail, light rail, and streetcar rail.
Agency Directors, transportation planners, Board of Commissioners and other executive offices.
Agency planning leadership defines; typically decided on the basis of expanding current operating modes
Agency staff decides based on cost and community familiarity and consistency with existng rolling stock.
Alternatives analysis process, RMRTD Staff analysis
An alternatives analysis study defines the optimal solution based on the purpose & need identified in the corridor.

Table D.1 (continued)

Analysis by consultants working with staff and the public with a recommendation to the Memphis Area Transit Authority Board for a decision.
Based on needs the study team decides on the final selection
Board of Directors
Board of Directors
Board of Directors for Chatham Area Transit
Board of Directors. Majority vote.
Board, CEO
Capacity needs, topography and other factors inform which type of expansion services will be studied. Various agency staff are involved in alternative analysis with Planning being the lead.
CCRTA planning dept. staff defines modes for consideration with approval by Board of Directors. Modes are decided upon based on agency goals and objectives.
City Administration & City Council in council with input from the City transit provider and City-County Planning
City Council
Collaboration of MPO, Transit Authority, Jurisdiction, and Consultant Expertise
Combination of in house or consultant recommendation or input from community outreach
Consultant offers choices in scenarios
County in coordination with the State DOT
Deputy Secretary
Director of Transit

Table D.1 (continued)

DOT, Transit Authority, MPO, Public: (Transportation Advisory Committee), and elected officials.
Elected official decision makers decide. Implementation is often approved by voters
Executive Director
Expansion considerations are undertaken by department level staff, with input from the public, regional boards, and Mayor/City Council members.
Expansion studies are based on existing services, adopted plans, public input, and staff research.
Federal alternatives analysis and local leaders review and discussion
For any given corridor, a project team of sponsors (agencies and jurisdictions with likely roles and impacts) is defined and a steering committee with representatives from those entities as well as members of the public, business community and other stakeholders is formed. The project sponsor works with and under the guidance of the steering committee to define and select modes.
General public, community stakeholders, local government staff, elected officials, transit staff, the MPO through planning studies
Growth in ridership and/or community demands
In addition to industry experts, local stakeholders and potential funding partners provide the greatest input regarding type. Decisions for an LPA are based upon demand and project feasibility.
In the past we have provided studies based upon community requests. We recently did a self-evaluation and created a new service plan to satisfy the direction provided by the community stake holders in our recent study.
In-house staff

Table D.1 (continued)

Internal staff, with input from consultants and public
It is a collaborative effort between all of our member entities and agencies. They are decided upon based on their estimated productivity and cost.
It's a collaborative effort involving the transit authority, the Metropolitan Planning Organization, the Florida Department of Transportation, the Pinellas Planning Council (countywide land use agency) and the area's local governments.
It's based primarily on technical analysis (capacity, throughput, cost, long-term O&M, etc.) but also looks at development opportunities as well as political considerations. This is led by us at UTA but involves our local city and county partners.
Joint decision between Transit Operator and MPO
Jointly by staff, our Board or an advisory committee, and a consultant.
Local government
Local Transit Authority
Modes considered are decided upon after study, a needs assessment and alternatives analysis.
NCTD in coordination with SANDAG (MPO) who is responsible for the design, engineering and construction of major capital investments.
Old regime considered light rail. No funding available to complete.
Operators boards give parameters, set budgets, and, then at the advice of staff from studies. Transit operations are ultimately decided by transit boards and the municipal governments from which they are comprised.

Table D.1 (continued)

Our agency operates rubber-tied transit service including fixed-route bus and demand response service. We are looking into streetcar and are involved in commuter rail planning, but we do not operate the service. Most of our planning revolves on our ability to expand bus and paratransit service.
Our Executive Director along with our Board of Director's define expansion. The decisions are made based on meetings, outreach and consultants.
Our non-profit Board of Directors
Our org as a whole.
Our organization, the Atlanta Regional Commission, does not directly decide which mode of transit should be used for expansion. This is handled by the transit agency/local municipality. They decide by a public vetting process which includes the expansion's environmental review process. This environmental review should take into consideration feasibility, equity, ridership projections, impact on the community, etc...
Policy board
Professional staff, with Board direction, defines the studies. Staff/consultant recommendations are brought back to the Board for approval.
Public involvement process encompassing local cities, county, businesses, neighborhood associations, elderly and disabled community, etc. Ultimate adoption of expansion plans by a governing board of elected officials.
Rail and transit Committee - County For BRT - elected officials
Regional Planning Agency, transit operator, state department of transportation
Ridership dictates the most probable mode to expand to. The studies confirm or adjust the proposal. The Transit Board votes on the expansion decision.

Table D.1 (continued)

Service Development
Staff from our MPO, transit agency, state DOT, other stakeholders, and the general public.
Staff/consultant based on service thresholds
Suggested by public or elected official, studied by MPO or transit agency
Technical recommendations are made by the Vice President of Capital Planning to the Board of Directors through a public planning process. Recommendations are then adopted into a cost constrained financial plan and system plan.
The agency in charge of the study is responsible for identifying alternative modes to be considered. Modes are typically identified based on purpose and need, stakeholder and public input, and consideration of the existing system.
The City of Chicago works with our MPO and the region's transit service operators to consider modes for expansion/ enhancement. (The City has not typically provided the service.)
The decisions are often collaboratively decided by the transit authority, local community, and the MPO. We are working on a trolley expansion project that also includes the National Park Service, as they currently operate the trolley system in Lowell, MA.
The DTC which operates the AGT in concert with the City of Detroit and the Regional Planning Agency.
The Metropolitan Council, the parent agency of the largest transit agency, and the MPO for the Twin City region.
The modes considered have been based on the projected future need with input from the transit operators and public

Table D.1 (continued)

The MPO defines potential rail expansion studies; the regional transit agency defines the bus-related studies.
The operator and the County.
The selected mode is typically identified via an Alternatives Analysis Study with stakeholder and public input.
The stakeholders, public and elected officials.
The study guides the mode discussion.
The transit agencies associated with our MPA. Modes evaluated are chosen by cost effectiveness and the practicality in our area.
The transit agency and its board make those decisions through the Transit Development Plan and other operations studies.
The transit agency. The modes are refined through an Alternatives Analysis study.
The two largest local transit agencies: HRT and WATA. MPO Board ultimately decides which modes will be supported.
The Worcester Regional Transit Authority (WRTA), the MBTA or private taxi companies. They are decided upon by available infrastructure, capital funds and passenger demand for service
Then counties in which we operate and which fund the service are the ones to define and decide which modes to include for consideration.
This is a combination of technical input from staff and contractors and public input.
Though a review of the existing system, modeling of anticipated demand and funding availability modes are reviewed and narrowed down.
Through an alternatives analysis process or EA/EIS

Table D.1 (continued)

Through regional policy action in 2001, BRT was identified as the high capacity mode of choice for the region. We have used this action, together with subsequent corridor specific investment decisions and operational success to continue the region's implementation of a BRT system. Decisions being made on specific corridors being studied for potential expansion/enhancement are based on a combination of technical analysis, public engagement, and formal policy decisions. The range of possible outcomes from this process include BRT, what we are terming "enhanced corridor" investments, or doing nothing (typically characterized as "no-build"). The enhanced corridor concept is not really a distinct mode, but reflects a level of transit investment intended to increase the efficiency and effectiveness of our regular bus service in a given corridor. This might include investments in queue jumps, transit signal priority, and increased station amenities. Depending on the frequency of service (15 minute or better) we might also look at longer stop spacing.
Through the stakeholder groups throughout the planning process.
Top officials. Demand.
Transit Operations and Administrative Personnel
Transit operator in consultation with MPO
Transit operators decide for their own services. It depends on the availability of local matching funds.
Transit operators define modes
Typically by request of the board or based on public interest, studies/alternative analysis are conducted.
Typically defined in-house; all decisions are political.

Table D.1 (continued)

Typically the agency that wants to expand will select the mode(s) they want to use to provide the intended service following a detailed corridor analysis. Since we are a commuter rail-only service, we only consider commuter rail.
Typically we have a study advisory board consisting of transit planners, transit operators, and government officials that help shape the parameters of the study, including what modes will be considered. The different modes are often selected based on national data that looks at service characteristics. All of our studies have a public involvement component and all recommendations are vetted through public outreach activities.
Typically, the modes is a consideration of markets served, proven technologies, cost vs. demand, and available right-of-way. The lead agency conducting the study usually establishes the modes being considered, but the regional long-range plan also discusses which modes have been considered in the region.
Usually by customer demand
Usually request consultants to provide "state-of-art" assessment and JTA staff and management decide what modes to study.
Usually through the NEPA process, MIS, AA, EIS, etc.
We are a Metropolitan Planning Organization and do not operate transit; however we do assist in funding transit projects and studies. We work closely with the Florida Department of Transportation as well as local Transit agencies and municipalities in our county and region to determine which transit modes of transit should be studied for expansion /enhancement.
We are a Public Agency with the mission of improving passenger rail service in our region.

Table D.1 (continued)

We are the contracted agency, and the operator has the final say. Ridership and cost effectiveness factors into the recommendations.
We considered many factors like projected ridership and therefore capacity needs, user experience, cost, potential for conflicts (like with trying to implement light rail on a privately-owned freight rail line), ability for mode to operate at the needed frequency, route distance, etc.
We do along with public input
We select a mode based on the needs of the corridor being studied given reasonable future budgeting assumptions. Many past studies had political beginnings, as a result we now have a pretty good deal of information about specific modes in specific corridors. Given our urban population and other factors, we are currently pursuing BRT. Transit corridor studies in the 1980s were led by the MPO, but more recent studies have been led by the City of Madison, Dane County, and more recently a consortium of the city/county/WisDOT due to the source of funding. The MPO led the most recent feasibility study of BRT and that is now the mode that is being pursued.
We typically assemble advisory committees of staff and elected officials from local governments and other organizations to lead transportation planning studies in our region. Depending on the outcome of these studies, additional actions to approve their findings may be taken by the governing bodies of our MPO, transit operators, local governments and/or state DOTs.
We use corridor studies and alternatives analyses to determine mode and alignment. Local stakeholder input is critical.

Table D.1 (continued)

We work closely with the Memphis Area Transit Authority, our Transportation Policy Board members, members of the public, and other area stakeholders to determine which modes should be considered. Typically the study itself will incorporate analyses that determine the best matched mode for a particular route.
We would generally decide with input from stakeholders involved in the project.
Who: transit agencies, study sponsors (if other than transit agencies), members of the public. How: Land use context, available connections/interface with other transit services, existing transportation networks/facilities serving affected markets, right of way condition, known or anticipated costs, ridership forecasts

Table D.2 – Full Responses to Question 12

Question 12: Please describe your organization's process for selecting transit modes to include in an alternatives analysis for transit system expansion / enhancement.
A master plan is developed (we have one now for BRT) and mode selection is generally determined by that process.
A ridership survey is completed. An alternatives analysis is completed. Further study is also completed along with additional public outreach then the recommended alternative is brought to the Board for a vote.
Agency planners, engineers, executive offices and other support staff consult with internal experts and outside consultants to discuss transit mode options.
All modes are considered in our analysis. Financial consideration and sustainability of services is a major factor on deciding which mode is selected
All modes are reviewed through the environmental process for feasibility purposes.
Alternate modes were not really a process for the Amtrak intercity service -- it was expanded in partnership between the NNEPRA (Northern New England Passenger Rail Authority), the State, and the 2 additional communities it was extended to. Rural bus and commuter bus vehicles were selected based on anticipated demand. Again, by the boards of the provider and the municipalities that are on those boards.
An alternatives analysis study or major investment study narrowed the list of viable modes to the ones that best fit the project's purpose & need.
An alternatives analysis was conducted looking at alternative modes of rapid transit services. Light rail and BRT alternatives were investigated.

Table D.2 (continued)

An extensive public outreach and technical analysis explores all reasonable alternatives once a corridor and purpose and need have been established. As described above, a steering committee of stakeholders guides the selection of transit modes.
As a Joint Powers Authority our member agencies have the sole discretion. As a Joint Powers Authority our governing body does not permit us to engage in the planning or implementation of other modes. For service that will operate within all counties a consensus has to be derived among all member agencies that will fund the service. For services that operate in a single county, that county's transportation commission has the sole discretion.
As an older region with a mature and robust transit network, most alternatives analyses in our region involve either extensions of existing rail lines or new services that would directly interface with existing lines. In both cases, some modal elements are predefined by this context, and vary only in their details. For example, if a commuter rail line is proposed for extension, so the extension be electrified (one-seat-ride) or diesel (two-seat-ride), and how would that choice impact both costs and ridership? For other projects and for non-rail concept development, additional modal options are on the table (e.g., BRT in its many forms and scales), with inclusion dependent on context and project purpose/need.
As part of our planning process we consider population and land use with regard to density and common destination. We look for corridors that are commonly traveled and then establish through standard alternatives analysis the type and mode that best fits the need.
Assessment of demand, cost and right of way availability

Table D.2 (continued)

Available rail right of way generate an alternative analysis on one corridor
BART is governed by a publicly-elected Board of Directors. The Board approves staff recommendations for analyses and selection of transit mode alternatives.
Based on services offered by transit operator. Evaluated based on anticipated ridership and cost of service.
Board Committee analysis
Broad-based process to examine modes that are appropriate for the situation. Also, previous planning has already, in some cases, decided the mode to move forward.
CCRTA staff develop goals and objectives each year in alignment with the annual budget. The Board of Directors approves the annual budget. Based on this process, a recommendation will be made by CCRTA staff and the Board of Directors to include specific transit modes in an alternatives analysis. A Title VI service equity analysis would be a part of this selection process.
Competition and price point
Consideration first given to modes currently operated. Select reasonable alternatives for the corridor. Match the appropriate mode to the demand within agency financial capacity and operating environment. Minimize transfers when and where possible. If seeking federal funding ensure compliance with federal criteria. Develop Conceptual Engineering to 2% level of design with corresponding CAPEX and O&M cost estimates. Initiate environmental review process.
Consultant reviews alternatives and costs
Demographic analysis, analysis of current service performance, current coverage, and public input identify alternatives
Density and ridership, both actual and projected

Table D.2 (continued)

Determine demand based on land use densities and destinations, analyze service thresholds for different modes and evaluate feasibility of corridors for expanded/enhanced service.
Discussion of cost/benefit
Engaged the services of n engineering design firm/ consultant.
Establish alternatives to be considered from modes identified. modes would be eliminated from consideration if fatal flaw or lack of service ability identified early
Generally an AA is conducted.
I have been here 10+ years. We did standard AA to determine a downtown circulator: to be streetcar. For example for the circulator AA we evaluated the pros and cons of BRT, streetcar, monorail (we had one for 40+ years at our Fairgrounds), BRT, and "enhanced bus."
Inclusion of expansion/enhancement plans in 6 year or strategic plans, coordination of service delivery with regional agency expanding LRT or streetcar modes, analysis of market potential, transit running way options and local jurisdiction plan coordination to expand bus, BRT, demand response modes. Availability of federal or state fund sources, e.g. Very Small Starts, was instrumental in this agencies expansion of arterial based BRT development and expansion.
It depends on the corridor, but typically we would examine bus, enhanced bus, and streetcar or light rail options.
It is left to the operator and its consultant to determine alternatives, which are limited due to lack of dedicated local matching funds.

Table D.2 (continued)

Larger projects follow a federally approved process of alternatives analysis, (in our case usually headed by one or more county). Corridors selected for these analyses must have been included in the regional policy plan. The preferred alignment and mode is then forwarded to the Met Council for adoption and implementation.
Long range transportation plans, statewide transit vision
Long Range Transportation Planning process followed by a more focused Travel Options Study and a Transit Develop Plan
Look at realistic alternatives
Looked only at existing modes of service.
LRTP, Need and Feasibility Studies, Alternative Analysis, Demographic models along with TDM.
MIS, EIS, NEPA process
Modeling, Collaborative Interest, Off-model Calculations, Public Interest, Air Quality Analysis, Cost-Benefit Assessments, MPO political Interest
MPO provides regional forum for transit expansion deliberations and covers some of the costs but ultimately city councils have to approve transit service changes in their jurisdictions.
Network plan followed by environmental review and engineering of individual projects.
No build alternative usually includes enhanced bus, and build alternatives include BRT and some kind of rail, whether light rail or commuter rail.
Planning Department initially assigned exploratory look at major corridors that would suit BRT and then it was placed in our SRTP (short range transit plan)

Table D.2 (continued)

Potential modes are included or excluded based upon their function. Aerial, water, and inclined modes are not applicable in Greenville. Higher-end modes are excluded due to cost, or need. We cannot afford or justify Mag-Lev, for example.
Public input, governmental input, costs, does it satisfy purpose and need
Public process lead by outside consultants in coordination with MPO. The process looks at cost, demand, and feasibility.
Rider demand and lack of alternative transportation were taken into consideration
Route study.
Same as previous - input from experts, stakeholders and funding agencies
See response to previous question.
Staff, consultant and public input
Staff/consultant study with significant public involvement.
Standard bus is the only option considered for expanding our fixed route system.
Study that proved ridership
Study needs analysis followed by alternatives analysis to decide the proper mode. This includes a detailed ridership, capital cost and operating cost analysis.
System-wide service planning
Taken from modes previously identified for consideration in regional planning documents by the Metropolitan Planning Organization and transit agency.
Taking in consideration the study area, and the context of the area, modes are selected, based on what works best and what could work in the area.
Team consensus

Table D.2 (continued)

The DPM was involved in a Transit Investment Study funded by FTA, the process was similar to an A/A study where all modes are considered however since this was not an A/A with all the FTA requirement the study generally focused on ridership and cost.
The Metropolitan Planning Organization (MPO) uses the priorities outlined in its current adopted Long Range Transportation Plan as a guide to making decisions regarding transit projects. The MPO also works closely with local transportation/transit agencies and municipalities, including public participation and input, to determine transit goals and modes to include in transit system expansion/ enhancement studies.
The modes are refined by examining various national data sets which show average capital costs, average operating costs, ridership thresholds, density of areas served, and results of computer modeling.
The modes are typically identified during the alternatives analysis process in response to the purpose & need and stakeholder input. There are often numerous modal options considered in response to suggestions from the public, property and business owners, real estate developers, local government staff, economic development departments, elected officials, MPO planning staff, and transit operations and planning staff
The modes selected depend on the corridor: if it is a rail corridor, rail modes suggest themselves, as well as bus, where roads are parallel. If it is not, bus is generally included. (Right-of-way for new heavy rail is not available.) Other modes (e.g., shuttles, jitneys, taxi, and demand response van) are considered depending on location, distance, and community served. Other modes may be suggested by members of a steering or stakeholder group.

Table D.2 (continued)

The modes that enter an AA would be all reasonable mode that could hypothetically address the goals and needs of the corridor and project.
The planning process with stakeholder groups and the general public.
The previously mentioned stakeholders conduct a study.
The process includes input from affected stakeholders, local communities and the public. Financial and engineering viability are also factors.
The regional transit authority studied implementing regional rail or BRT service. However, the study was shelved for the time being.
The SunTrolly operational expansions have been several new routes.
The transit modes selected for analysis were primarily based on existing modes already in service. Some emerged from studies.
There are usually several "visioning" type of studies that are done to initially establish transit corridors. Then a project gets included in the MPO's long range plan. We typically perform several studies after a project has been included in the long-range plan. These studies include land-use plans, transit feasibility studies, corridor studies, etc. in order to establish the LPA. Typically, the LPA is adopted by the local municipality, the transit agency, and the MPO.
There has been expansion of demand response and fixed route (schedule) in the last ten years. Factors such as Travel Time, Passenger per seat, Land Use, and cost are used to compare modes.
There is no fixed process in place. Guidance is provided by the Board of Directors for Chatham Area Transit
This area has a great deal of need, so we usually begin with the critical areas.
This is a SANDAG (MPO) responsibility

Table D.2 (continued)

This varies in different situations.
Through system review and the regional transportation planning process.
Transit Development Plan development vetted through public participation and evaluation of land use, population, and employment projections
Transit mode studies follow a process outlined by regional boards (bus and rail) and include considerations for residential growth, population estimates, commercial/employee centers, funding availability, and service needs.
Transit modes are generally based off proven and reasonable modes that are existing in the region (i.e. support systems already in place) or identified for expansion in the long-range plan. New technologies are occasionally considered but only if unique challenges exist. Recent new technologies include modern streetcar and diesel-multiple units as a variant on light rail expansion.
Transit modes selected for alternatives analyses are typically governed by recommendations in our region's metropolitan transportation plan and congestion management process with additional input from study advisory committee members and project consultants in response to the purpose and need statements developed for individual studies.
Transit modes that are included in the Transit Development Plan are selected for expansion/enhancement.
We are an MPO; we don't operate transit services.

Table D.2 (continued)

We develop the criteria that will be used in the selection process based on the goals for the project. We start with the universe of alternative modes and through a screening process that might involve several iterations transit modes to advance through the AA process are identified. This process was carried out in Pinellas County in 2011-12 and was overseen by a project advisory committee.
We follow the NEPA process
We have only one local transit option, so that one is the focus.
We have used a combination of technical input from staff and contractors, review of TCRP and other documents for best practices and peer comparisons, and gathered public input for this purpose.
We look at ridership trends along with customer need.
We made selections based upon research and community input from stake holder groups, Blue Ribbon Commission, polling and public outreach.
We only operate one type of service.
We selected a few modes to analyze based on several modes' operating characteristics
We started with a broad range of options, and then gradually narrowed the options through a couple of screening steps.
We typically include most transit modes that may be applicable to the study area, i.e. modes that would be serve high density areas.
We use our knowledge and that of our consultants to eliminate unrealistic modes from consideration.

Table D.2 (continued)

We use service guidelines to determine how much service an area warrants, research into market potential, and public outreach to determine the appropriate type of service for an area. As stated before, our primary choices are bus, commuter bus, BRT, and demand-response / alternative service. We attempt to provide all-day bus service to areas with market potential, but recognize that transit-dependent populations in certain, less-dense areas may not be well-served by traditional bus service. In these cases and in conjunction with the community in question, we attempt to develop alternative solutions, which are sometimes novel.
We usually start with the "universe of alternatives" at the beginning of the analysis, in which the technical staff and stakeholders determine all reasonable alternatives.
We work with our Planning Department, MPO, transit service providers, community advisory groups, and the FTA early in the AA process to select modes for consideration.
We would look at the need and feasibility. This has led us to focus on bus, commuter rail, and streetcar based on the passenger loads and available rights-of-way.
When conducting planning studies or alternatives analysis, identification of transit modes is typically based on study purpose and need, stakeholder and public input, consideration of existing system and any previous plans or studies.
When the regional planning process is done, the lead agency (typically the metropolitan planning organization) will consider/analyze several modes. Since we are a commuter rail-only service, we do not consider other modes when we look to expand or enhance service.

Table D.2 (continued)

While the CMMPO does not select specific modes, the transit authorities and private providers in the region have traditionally operated bus, taxi, demand response van, or commuter rail. CMMPO staff works closely with these agencies to select mode
Worked with City of Dallas, DART, and NCTCOG, for a one mile $20 million expansion.

Table D.3 – Full Responses to Question 13

Question 13: Please describe your organization's process for selecting final transit modes to use for transit system expansion / enhancement.
After approval of SRTP the organization searched for funding sources. Received FTA small starts grant and obtained local match.
After the corridor studies and an LPA is determined, we decide whether to pursue additional local and/or federal money. If there is momentum and funding, then we perform additional environmental and engineering studies. This solidifies mode and precise alignment.
After the study was completed the service alternatives compiled and reviewed by the original groups who provided input, our Board made the final selections for options. The recommendations to the board were a compilation of the entire process with staff recommendations presented for adoption.
Agency planners, executive offices and support staff submit proposals to Board of Commissioners for approval.
All modes that are ultimately chosen for implementation must come from an adopted plan that is fiscally constrained and has been reviewed by the public.
Alternative that achieves the best mix of high ridership and lowest costs, with public support
Alternatives analysis process

Table D.3 (continued)

As indicated previously, our selection process involves a combination of technical analysis, public engagement, and formal policy decision making. The region's BRT policy requires support by the city or cities through which a particular BRT corridor might be proposed. Thus, the modal selection (usually in the form of a Locally Preferred Alternative) is finalized through the combination of a city Council decision, a decision by LTD's board, and (assuming the presence of federal funding) the MPO.
As mentioned we initially perform a feasibility study looking for fatal flaws then roll that effort into an alternatives analysis that considers various weighting factors and provides opportunity for public input while weighing impacts and cost. Then when we feel that the effort has been robust enough we work to come to a decision or selection.
As selection for route was considered, we needed to use a mode that could operate effectively on those routes; we considered distance of the route; we considered cost of each mode; etc. (see my previous answer about criteria to select mode)
Available funding and timing considerations
BART is governed by a publicly-elected Board of Directors. The Board approves staff recommendations for analyses and selection of transit mode alternatives.
Based on public input and a range of quantitative and qualitative analyses, the steering committee defined for a corridor recommends final transit modes. Then each involved agency/jurisdiction, including cities, counties, state department of transportation, regional planning entity, and transit agency formally adopt the preferred mode.
Based on services offered by transit operator. Evaluated based on anticipated ridership and cost of service.
Based on studies.

Table D.3 (continued)

Based on the outcome of the study or alternatives analysis, the preferred mode is selected.
Board Approval along with financial planning.
Board of Directors
Board vote
Bus is the only option considered.
Community to Region Performance Measures Project Selection Process which can be found here: http://www.chcrpa.org/2040RTP.htm under the 2015 FHWA Transportation Planning Excellence Award header.
Completion of alternative analysis unless directly tied to expansion of existing service where mode is simply expanded
Consider results of route studies.
Coordinated process with WRTA, MBTA, taxi companies and private carriers to provide transit services in the Central Massachusetts region
Cost analysis, confidence in ridership projections and interest of the organization select recommendations
Cost benefit
Depends on the scale of the study. In the case of FTA major capital investment grants (New Starts, etc.), we follow the established process. In the case of other concept-development or feasibility studies, we typically develop a range of possibilities and screen down to recommended options based on an analysis that amounts to cost versus benefit as understood during the course of the study.
Discussion of cost/benefit
Driven by dollars to invest in capital and operating

Table D.3 (continued)

DTC has not had funds to actively pursue expansion. The efforts have been to maintain existing infrastructure and expand service hours.
Factors affecting selection: resource availability, geographic equity, social equity, cost effectiveness, market potential (land use factors affecting the productivity of service), the feasibility of forming a partnership with a community, availability of federal funding, capital and operating costs.
Factors such as Travel Time, Passenger per seat, Land Use, and cost are used to compare modes. Major Service changes are further analyzed by the impact on Title VI populations.
Final selection is determined by local government officials.
Final selection occurs after a study's analysis has determined the best option in terms of performance and level of financial investment.
Final: based on a mix of capital cost effectiveness, long term operating/maint costs, and community support.
Following a public process and financial analysis
From the planning document with general outlines a corridor is selected. A structured public involvement process ensues accompanied by detailed technical analyses that leads into a formal FTA alternatives analysis if federal funding is desired.
Generally a detailed study, including and operating plan and financial analysis are part of the decision making process. Ridership projections and public opinion are also considered.
Generally through the AA process with our policy Board adopting the Locally Preferred Alternative.

Table D.3 (continued)

Generally, the final transit modes selected for transit system expansion/enhancement are those that best address the purpose and need statements developed for individual planning studies. Typical factors that we consider in our region to evaluate transit modes are impacts to existing services, potential impacts to new ridership, potential economic development impacts, environmental impacts, financial feasibility and social and environmental justice impacts.
In response to stakeholder input from those noted above, the modal options are typically screened during the alternatives analysis in response to the purpose & need and evaluation criteria. The options are further evaluated and screened as necessary during development of an environmental document.
It is based on existing conditions and infrastructure, and land use goals.
It's based on an evaluation of alternatives, selecting the option that provides the most cost-effective ridership and development potential.
Match the appropriate mode to the demand within agency financial capacity and operating environment. Minimize transfers when and where possible. If seeking federal funding ensure compliance with federal criteria. Complete environmental review and preliminary engineering to a 30% level. Develop CAPEX and O&M cost estimates using DART standard and report in FTA SCC format. Conduct public and agency involvement program with 13 DART cities. Seek approval from Board to advance project to final design and construction.
MIS, EIS, NEPA process, Board of Directors decision

Table D.3 (continued)

Modal options generally are constrained to current operating modes for rubber-tired transit. Recent years have focused on development of service planning guidelines for expansion and enhancement; and on development/expansion of alternatives to fixed route bus services more appropriate to and cost effective in low density communities and/or as a complement to the fixed route bus system.
Modes are usually crossed compared based on a variety of services and/or performance characteristics that can be ranked against each other. Assuming the final mode meets with public acceptance, the selection then would typically be based on the mode that would carry the most passengers in the most frequent service time, but could be provided within a financial costs acceptable to that service area's governmental entity.
MPO provides regional forum for transit expansion deliberations and covers some of the costs but ultimately city councils have to approve transit service changes in their jurisdictions.
NEPA Process
Once a project has been identified, it is evaluated based on the most recent long range transportation plan goals, objectives and project selection criteria.
Other modes prove to be too costly.
Our studies have different scenarios to choose from and the final selection is made by elected officials.
Performance measures, including mobility, travel time, ridership potential, air emissions, land use consistency, and others.
Potential modes are analyzed in a Cost/Benefit matrix, and assessed by their practicality for implementation.

Table D.3 (continued)

Prioritization and funding availability
Public outreach, alternatives analysis
Ridership/demand and financial feasibility
ROI
Not a process, more the provider who wanted to expand researched and determined the appropriate vehicle, not so much mode.
Selection criteria are developed at the beginning of the process, and the alternatives are analyzed against each other based on the selection criteria. The project steering committee then examines the results of this analysis to determine the appropriate mode and alignment.
Selection occurs through a comprehensive alternatives analysis.
Studies
Studies select alternatives and gather public and stakeholder input before making a final decision.
Study and needs analysis followed by alternatives analysis to decide the proper mode. Following the study, the preferred modes is selected through a process of our MPO and transit board.
Surveys and Studies, public meetings, social media, etc.
TAC and TIP derived programing
TDP Development process and Board of Directors determining projects.
Team consensus

Table D.3 (continued)

Technical Advisory Committee (TAC) reviews alternatives and costs against available resources and provides recommendations to the Policy Committee. TAC is made up of primarily professional engineers. The PC is made up of engineers, managers and appointees.
That decision is typically made by the transit authority, with input from the Metropolitan Planning Organization.
The alternatives analysis process led to the decision for the selection of the mode to use.
The CCRTA Planning Department would work closely with other departments and the Board of Directors to select final transit modes for transit expansion/enhancement. In selecting final transit modes, the Title VI service equity analysis and public outreach feedback would be a part of this process.
The final mode choice also considers the viable alignments for that mode.
The final screening was based on mode and alignment and performance in a wide variety of characteristics.
the local transit operator works with the MPO and other agencies to study transit system enhancements and expansions, with implementation subject to resource availability
The operator and the County make the selection.
The planning process with stakeholder groups and the general public.
The process involves detailed study of the transportation and economic impacts of different alignments and modes. This process also includes extensive public involvement.

Table D.3 (continued)

There is no fixed process in place. Guidance is provided by the Board of Directors for Chatham Area Transit
This is a SANDAG (MPO) responsibility
This is completed through the Master Plan process and community involvement as well as facility planning studies.
This is done via stakeholder meetings, public meetings and consideration of the technical data/analysis.
This varies in different situations.
This would be based on the analysis in the AA.
Transit alternatives analysis are led by many different organizations in this region and the Metropolitan Council/Metro Transit is a typically a technical advisory (if not leading a study). Most agencies go through an alternatives analysis to get a recommended mode and alignment for consideration by the Met Council (MPO). The AA would include various technical and policy evaluation criteria to identify the preferred mode. The MPO /Transit Provider (same agency here) would consider the funding resources and assurances that there is enough revenue before including the recommendation in the long-range plan.
Transit mode expansions/enhancements are selected from phased implementation plans included in the Transit Development Plan.
Transit mode selections are made based on funding availability (local, regional, and federal participation), as well as service/public needs and land availability.
Transit projects selected for funding by the MPO are ultimately ranked and approved by the MPO Board in coordination with the Florida Department of Transportation and local transit agencies/municipalities seeking transit expansion / enhancement.

Table D.3 (continued)

We again look at the ridership trends coupled with customer needs.
We are an MPO; we don't operate transit services.
We define the goals and objectives for the project and then screen the modes to identify which alternatives are the ones that best respond to the purpose of the project.
We expanded current seasonal service to year round based on increased service demands
We have only one local transit option, so that one is the focus.
We have used the FTA AA process for large expansions.
We only operate one type of service.
We only work on commuter and intercity passenger rail.
We use a strategic planning process
We use an alternatives analysis process that includes several criteria. Most important would be cost effectiveness and community support.
When conducting planning studies or alternatives analysis, alternatives are evaluated in screened in a multi-step process that incorporates purpose and need, performance measures, stakeholder and public input, and comparative evaluation of alternatives.

Table D.4 – Full Responses to Question 15

Question 15: Why were these modes selected?
Affordable, did not require new type of vehicles or infrastructure, appropriate for the density of our area.
Answer varies
As before that is our charge as an Agency, other agencies in the region provide bus service.
As described above, modes were selected that best met study purpose and need and performed best in terms of comparative evaluation of alternatives.
As indicated above, the region in its development of the Regional Transportation Plan, and through local community land-use and transportation planning; have identified BRT as the high-capacity mode of choice in helping move the region's visions for community growth and development forward.
Available funding and shorter lead time
BART is governed by a publicly-elected Board of Directors. The Board approves staff recommendations for analyses and selection of transit mode alternatives.
Based on a detailed assessment of trip types, employment and job centers, and community wishes.
Based on demand/need.
Because they fulfilled the study goals and objectives as they relate to improving transit access, mobility and community support.
BRT was selected as a way to develop our streetcar system at a lower cost. Express bus, community shuttles and flex- service were also selected
Bus and BRT expansion are based on our ability to operate. Streetcar was selected through an alternatives analysis.

Table D.4 (continued)

Bus and commuter bus were selected because they were cost effective for new service with relatively low ridership. A hybrid commuter rail-light rail system was selected as LPA for a project that did not move forward due to the lack of local governance/funding structure. BRT is being pursued now because it is the most cost effective and would best serve the needs of the corridor given the location of the rail line and current freight service on it.
Bus--expansion of feeder routes on Virginia Peninsula was found to be necessary by HRT. Light Rail--Va. Beach city council favored this mode over BRT Vanpool--Recent local initiatives aimed at enhanced vanpool services...HRT recently decided to contract out all of their vanpool services after 29 years of in-house operation and maintenance in order to afford newer vans.
Comment about above: streetcar has been recommended by local agency but not adopted into the long-range plan yet. Status is in question.   Generally the driving factors have been cost effectiveness, increased transit access to new areas, and desire for enhanced economic development associated with rail modes.
Congested corridor needed relief.
Congestion Mitigation/Air Quality pilot study (for commuter bus). Availability of grants to fund BRT.
Cost and compatibility with our existing 25 year system.
Cost and ridership projections.
Cost benefit
Cost effectiveness. Familiarity.
Cost, flexibility, support.
Cost/benefit

Table D.4 (continued)

Current modes offered or community request.
Decision based upon the analysis and available funding.
Each case is different, but local preference, cost, economic impact, and ridership are always factors.
Each was responsive to the needs in the corridor as defined by technical analysis, public input, and steering committee guidance as well as transit board guidance.
Ease of transition and funding opportunity
Effectiveness, Public Appeal, Efficiency, Convenience
Enhanced existing systems
Existing system in place, ability to implement, finding availability
Existing system is heavy rail.
Expansion of existing mode.
Factors included cost, logistical concerns, and input from stakeholders and the general public.
Financial Constraints
Financial savings and more service for the customer.
Fixed route transit offers the best service and cost effective qualities for our community.
Followed above process. Projects met the identified criteria and were agreed to through the public planning process.
For the reasons articulated two questions prior.

Table D.4 (continued)

Generally, the final transit modes selected for transit system expansion/enhancement are those that best address the purpose and need statements developed for individual planning studies. Typical factors that we consider in our region to evaluate transit modes are impacts to existing services, potential impacts to new ridership, potential economic development impacts, environmental impacts, financial feasibility and social and environmental justice impacts.
Good fit with market needs.
Good technical solutions for the various corridors
Greenville is experiencing growth, but the current transit systems need "filling-out" before new modes are introduced.
Identified by study participants as mode alternatives
In an effort to operate more efficiently and effectively we received our first CNG bus in May 2015 with plans to order and receive more in the future.
In most cases study analysis determined them to be the most feasible. In a limited number of cases stakeholder organizations specifically sought to implement them.
Increased demand.
Indianapolis recently gave the local bus company some extra operating funding and they improved frequency on the most popular routes and added a new crosstown route.
It is consistent with what we already operate.
It is what we do
It varies depending on the factors involved. (Available financing, infrastructure requirements, capacity needs.)

Table D.4 (continued)

KC Metro is the operating agency for regional LRT and local city streetcar services; implementation or expansion of rail lines in these modes has resulted in significant restructuring/enhancement of fixed route bus services. Otherwise, expansion/enhancement is focused on the rubber-tired bus modes this agency has historically operated.
Meets demand and is financially feasible
Metra is a single mode (commuter rail) agency. If another mode had been selected, it would be left to another implementer in the region to implement.
Modes currently offered.
Most appropriate transportation enhancement for the corridor.
Most consistent with purpose and need, also align with existing capability or mode currently operating
Most feasible mode
Opportunity
Overhead already in place, just an addition
Political reasons for bus rapid system and actual transportation needs for expanding the bus fixed route services.
Potential demand and project feasibility.
Public input, governmental input, costs
Quick impact with flexible outcomes
Recommend by the study
Ridership trends and need.
Scaled to anticipate demand.

Table D.4 (continued)

See previous comment. Also, in some cases, political influence led to a certain mode being selected. In a recent example, a funding partner was only willing to fund LRT and not BRT.
Selection was based on our strategic planning process and availability of funding.
Some were enhancements to existing modes that were unable to meet demand. Expansions to other modes were selected as a result of the planning and technical process described above.
They are mostly expansions of the current system.
The Detroit CBD has had population and employment growth and convention business growth. These factors have facilitated a need for additional hours of service.
The only service we provide.
The represent expansions of existing service; new services are a challenge due to limited right of way and high real estate (takings) prices.
Their suitability to the area or service needed (boats on water, demand response for ADA service, etc.), passenger capacity, community enthusiasm.
There was need and financing available. They were publicly supported and politically endorsed.
These modes are within our service operation
These modes were already the predominant mode in the area already and the infrastructure was in place.
These modes were selected based on current operating levels (i.e., these are existing services) and projected needs in the future (population growth, student needs, commercial development, etc.).

Table D.4 (continued)

These modes were selected based on the outcome of a regional transportation long-range plan.
These modes were selected because they address need and because they are relatively cost effective.
These were and are the modes in operation
They already existed
They are the only modes operating in our region.
They best met the purpose and need of the study corridor.
They could be funded by FTA, State and local sources
They had the highest ridership
They performed well in our urban environment and were considered desirable by the community to the point where they were willing to fund the operation of these modes.
They satisfy the service requirements for existing or future service.
They were appropriate for the application
They were best to serve the markets requiring service and public involvement in the Long Range Transportation Planning process strongly favored these modes.
They were deemed most productive from a ridership or development perspective within the particular service corridors.
They were found to be the most appropriate based on planning studies, alternatives analyses, environmental documents, transit operations plans, and financing.
They were identified as being the most feasible from a cost and need perspective. In addition, the institutional structure for implementing these measures and for operating the service is already in place.

Table D.4 (continued)

They were selected because they were though to enhance our transit system and spur economic development.
To increase transit capacity (bus to rail)
To meet demand
User demand by local municipalities and transit agencies.
Various corridors had attributes that caused the selection of the mode for that corridor. Land use goals and existing infrastructure played a part.
We have a mandate to provide rubber-tire service. BRT was selected to provide high-quality transit on heavily-used corridors. Trolleybus expansion helps reduce fuel costs and CO2 emissions (helps us meet environmental sustainability goals). Employer commute services help meet state environmental goals and manage congestion.
We have only one local transit option, so that one is the focus.
We only provide commuter rail, so when we expand we will only be expanding commuter rail.
WRTA operates existing bus fleet and demand for transit could be accommodated with existing bus

Table D.5 – Full Responses to Question 19

Question 19: Why did you make this modal change and how did the process go? Include any challenges you faced in this process, and how you dealt with them.
A 15 year persistent approach with continuous promotion, education, and new/improved facilities.
Attractiveness to riders to reduce travel times - also, offered amenities such as Wi-Fi, electrical outlets, and improved wheelchair stations.
BRT is the only mode with good cost effectiveness and can serve bus lines carrying between 8,000 and 20,000 daily trips. Rail is too expensive. Ferries are terrible from a greenhouse gas perspective.
Capacity, projected economic development.
Challenges in integrating bus networks with new rail lines are primarily in changing travel patterns for current riders. These riders maintain significant resistance to change, especially if the benefit of new rail services are directly benefitting other or new riders and not themselves. I'd be happy to talk to a phone based interviewer about the complexities this agency has faced.
Change was anticipated as part of our agency System Planning efforts. First Plan adopted in 1983 and revised in 1989; 1995; and 2006 to reflect changing regional demographics and to fulfill bond and voter obligations. Followed AA process described above to confirm mode and develop engineering, cost estimates and environmental clearance. The technical aspects of the projects went well. Experienced some difficulties with explosive growth and ROW acquisition. Economic climate created bigger issues relative to escalation of material costs.

Table D.5 (continued)

Change was made to provide greater capacity challenges were in securing funding and construction - addressed through persistence, mitigation
Commuter bus was originally set-up as a demonstration project for commuter rail. Challenges with commuter rail have been cost and rail delays associated with increased freight demand.   Replacing bus with bus rapid transit was a challenge of finding funding for non-rail transit modes expansions in already heavily used corridors. Challenge with replacing bus with light rail were very technical and corridor-specific.
Commuter rail was supported by a large and consistent commuting pattern. The rail option was intended to reduce congestion on a major interstate highway
Corridor congestion and community desire for enhanced level of service.
Cost/benefit in the long term
Demand Response change was made to improve efficiency and participate in urban/rural coordination requirement. Vanpool change was made in response to employment needs in a rural community. Successful tweak in service.
Evolution of transit to higher capacity modes within key commute corridors.
Fulfill legal or other commitments
Basically, our approach to the implementation of a BRT system has been to have that mode replace the existing bus service on a given corridor. Typically, our regular service in the area of the new BRT corridor is reconfigured to provide connectivity between BRT stations on the corridor and surrounding areas.

Table D.5 (continued)

We recently upgraded transit service on the Sahara Avenue corridor from regular fixed route bus to BRT. The project was funded through the TIGER program and included the conversion of a 6-lane arterial to one with dedicated curbside bus/bike lanes, less frequent stops, pedestrian facilities, landscaping, more robust passenger shelters, system branding, and some route restructuring. Overall a great success with faster service and increase in boardings from 6,700 per day to over 10,000 per day.
Lots of challenges with patrons who used to have a one-seat ride and then had to transfer. We tried to promote the fact that commuter rail had more trips per day than the old express bus. Difficult issue.
Project A: Long sordid story stretching over ten years. See 12/18/2014 Bloomberg news feature "Washington State Spurned Money that Could have Fixed this Deadly Bridge" for thumbnail sketch. Otherwise call. Project B: Overcrowding, unreliable service. Upgrade to BRT opposed in many quarters; compromises made; project lives. Call for details.
Slightly more modern cars chosen for our expansion.
The biking community wanted a bike/bus option. The addition of bike racks has been well received. One problem was/is the length added to a bus that could not be accommodated in the bus barn.
The corridor continued to grow with population and jobs as well as congestion. The mobility benefits and development benefits of light rail were preferred by steering committee and stakeholders as well as involved jurisdictions/agencies over continuing bus service or pursuing another mode like bus rapid transit.
There were a number of vanpools originating and ending at similar places. A commuter service was put in along those routes.

Table D.5 (continued)

This change occurred because another agency with a mandate to build light rail did so. Our agency removed duplicative service and restructured service to take advantage of the expanded capacity provided by the light rail line. The process (which is ongoing as other light rail segments open) can be contentious, but we seek consensus with the affected communities. Many do not like to see bus service cut, particularly when they have to walk farther to reach light rail. We seek to demonstrate how reinvesting service hours in different ways leads to a better overall system that serves the entire community better. As a result of having to reduce service, we have also replaced fixed-route and demand-response services with alternatives, typically smaller, demand-responsive community shuttles.
We assisted SEPTA with an evaluation of alternative future vehicle technologies for two historic trackless trolley (now bus) routes, including consideration for trackless trolley restoration, bus continuation, and electric bus replacement/piloting. One challenge was the rapidly evolving nature of electric bus technology, and the resulting difficulty in assessing costs/details with certainty. The outcome was that the study's recommendations were a bit more nuanced/conditional than they might otherwise have been. Some other "mode replacement" work has involved development of BRT or "enhanced bus" concepts that would replace or overlay fixed route bus operations.
We took high performing bus lines and replaced them with higher capacity transit modes.

Table D.6 – Full Responses to Question 25

Question 25: What are the most important factors in your organization's transit mode selection process?
Ability to meet the corridor's purpose & need, costs, and compatibility with other transit modes
Access to jobs.
Affordability, local preference, operating costs.
Affordibility and sustainability. Also, projected ridership performance.
All four.
Appropriate technology to meet business needs
As a private non-profit, we must pay all costs out of the revenues generated, which makes the economics of what we choose paramount!
Available funding
Capacity needs and available funding.
Capacity needs, physical restrictions, and cost.
Capacity to meet demand
Capital and operating costs
Capital and operating cost and political acceptability.
Capital and operating costs
Capital and operating costs, availability of funding, jobs access, fuel/power supply, land requirements, safety, reliability, community views, capacity, speed, schedule type, maintenance requirements, and spatial requirements
Capital and operating costs.
Capital costs, land use context, ridership projections.
Capital costs, operating costs, capacity, cost effectiveness

Table D.6 (continued)

Community benefits and economic factors
Community demand and Service
Community support, financial support, and ridership/technical numbers.
Compatibility with existing rolling stock.
Compatibility with purpose and need of project and existing system.
Competition for funding with other parts of the agency.
Cost
Cost
Cost / effectiveness
Cost and feasibility
Cost and financing
Cost and productivity
Cost and public benefit are probably the most important factors.
Cost and Public Need
Cost effectiveness & resource availability
Cost effectiveness and community support.
Cost, demand, long-term sustainability of service, public interest and support
Cost, feasibility, and how appropriate the mode is given the built environment constraints
Cost, reliability, ease of operation.
Cost, ridership, economic benefits.
Cost-effectiveness; ridership; supporting future economic development potential; technical readiness (i.e. first to complete study is prioritized), and politically regional balance of investments.

Table D.6 (continued)

Customer accessibility
Demand
Demand / need
Demand, cost, capacity.
Depends if it is a legal commitment or not. If not, then the level of demand and the inability of the current mode to serve that demand.
Does it safely and effectively provide benefit to our customers; Capital cost and operating expense; Sustainability;
Ease of use, cost / price (capital and operational), accessibility.
Economic and performance
Economic and performance factors.
Economic and Safety
Economic and Social factors
Economic and social. Providing a reliable and safe service while taking advantage of potential economic development opportunities
Economic development potential, regional access and cost.
Economic development; community acceptance; results predicted - increase of mode share and resulting reduction in congestion
Economic factor
Economic factors
Economic factors
Economic factors Social factors
Economic factors.
Economic impact

Table D.6 (continued)

Economic viability of the expansion.
Economic, Performance, Safety
Economics
Economics and social
Efficiency, fuel, and personnel costs
Environmental
Environmental Factors
Environmental impacts Performance factors Funding
Environmental justice aspects, accessibility by disabled and low-income persons.
Equity
Existing infrastructure/available fleet, capital and operating dollars available to the region.
Financial and performance
Financial resources
Fundamentally, the key is funding. Second is community support. The technical details are critical too but can be worked out.
Funding and usage
Funding availability
Funding availability, feasibility of implementation, user demand, and local needs/wants.
Funding, Environment, Performance.
Funding.

Table D.6 (continued)

Given the multiple agencies involved in making decision on transit mode, each of these factors are important to at least one of the decision making bodies. We tend to conduct our analysis and public engagement in what approximates a triple bottom line type of framework.
In terms of ranking: performance, economic, environmental, social
Increased economic development along light rail lines.
Jobs access / ladders of opportunity
Land use goals
Level of service, maintenance costs (buses past usable service life)
Local government approval in the included cities. Funding.
Many factors are considered along with public involvement.
Match money
Money & support (public & political)
O&M costs, economic development support, social benefit
Often depends on the study corridor and stakeholder input, some communities have different top priorities.
Operation and capital cost, political views
Performance
Performance and economic.
Performance was one major driver. Our current service does not run very late into the evening, limited weekend ours or reach enough jobs. Our on-time performance and efficiency is exemplary however we need to provide service for today's needs. Currently, the service design is based upon the needs of our riders 20 years ago and really hasn't been updated. We are working to change that now.

Table D.6 (continued)

Political influences, operating cost, estimated ridership
Potential demand
Project cost and available funding
Public and MPO member input influence priorities
Ridership and economic development potential
Ridership growth, operational/capital costs
Ridership, cost-effectiveness, support for future growth vision of communities and the region
Ridership, market share
Ridership, reliability, economic sustainability
Social and Performance
Social and performance
Sustainability of services. Transportation needs and accessibility to jobs.
That the mode selected fulfills the needs of the project. In other words the project is useful to people.
The customers' transportation needs.
There is not one factor
There is so much overlap among economic, environmental, social, and performance factors that all could be considered most important. Of course, economic factors are a primary concern because if a project is not cost affordable it simply cannot be implemented.
This really depends on the specific study / project, but operations costs and funding availability are always a deciding factor
TOD around the stations and access to jobs.

Table D.6 (continued)

Transit funding here is very limited, so being a cost-effective system is the most important factor.
Travel time, economic development
Use and connections
Utilization
We are a MPO so we do not make the selection for mode choice since we do not operate transit.
We are an MPO and in large part, do not select transit
We are not a service provider however we do rank transit projects in our regional transportation plan.
We do not provide modes of transportation just fund them. So in funding we want to make sure that the selection process is proper for the region.

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