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REDUCING US TRANSIT COSTS: AN EMPIRICAL REVIEW AND COMPARATIVE CASE STUDY OF PORTLAND, MANCHESTER RAIL SYSTEMS

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Reducing US Transit Costs: An Empirical Review and Comparative Case Study of Portland, Manchester Rail Systems

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Disclaimer

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Executive Summary

The cost to build and operate transportation infrastructure, including mass transit, in the United States is consistently higher than it is elsewhere in the developed world. As America's population becomes increasing urban, addressing this issue will become increasingly important. This study seeks to understand why this cost discrepancy exists, and what to do about it, through a review of existing cost data (using operations costs from the US and International governments, and capital cost data from prior studies) and a comparative case study analysis. Two light rail systems, MAX (in Portland, Oregon) and Metrolink (in Manchester, UK), share many design and operations characteristics, and recently completed two similar capital projects. While MAX's operations and capital costs are lower than the national average, they remain above comparable costs for Metrolink. This similarity in specifications, combined with a divergence in cost, provides an opportunity to understand why US transit is comparatively expensive.

This study develops a set of hypotheses for high US transit costs based on prior literature, published data, and a comparison of these two systems. These hypotheses are then evaluated against the two case studies. For those which appear promising, the study seeks to find corroborating information from other sources to confirm or reject these hypotheses. Based on this analysis, this study provides a series of recommendations for policy makers, engineers, and transit agencies. In regards to capital costs, these recommendations include (1) reducing abuse and misuse of the environmental review process, (2) clarifying project governance structures to ensure a confluence between project authority and project responsibility, (3) developing comprehensive design standards, (4) avoidance of overdesign, and (5) developing a public database of unit costs for transit projects. In regards to operations costs, these recommendations include (1) embracing modern updates to rolling stock design, (2) embracing franchise contracting, (3) increasing transit speed, (4) catering transit fares to match passenger's ability to pay, (5) reforms to equipment procurement regulations, (6) adjusting train lengths based on demand, (7) cleaning trains during the day time to the extent possible, (8) avoiding mixed capital and operations contracts, and (9) considering automation as a means to further reduce operations costs while improving service reliability and frequency.

The issue of reducing US infrastructure costs, particularly transit operations, maintenance, and construction cost, should be of paramount importance to policy makers, engineers, and the public. This study is one of several discussing the issue, and the recommendations above merit additional study, scrutiny, and analysis. This study seeks to provide a roadmap regarding where to focus in the effort to achieve better returns on investment for transit infrastructure.

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List of Abbreviations

Term	Meaning
AASHTO	American Association of State Highway Transportation Officials
ADA	Americans with Disabilities Act
APTA	American Public Transit Association
AREMA	American Railway Engineering and Maintenance of Way Association
ASME	American Society of Mechanical Engineers
ATS	Automatic Train Stops
BART	Bay Area Rapid Transit Authority (of San Francisco)
BRT	Bus Rapid Transit
CC	City Center
CR	Commuter Rail
DB	Design Build
DBB	Design Bid Build
DBE	Disadvantages Business Enterprise
DBFOM	Design Build Finance Operate Maintain
DBM	Design Build Maintain
DBO	Design Build Operate
DBOM	Design Build Operate Maintain
DC	Direct Current, District of Columbia
DOT	Department of Transportation
DSL	Department of State Lands (of Oregon)
EA	Environmental Assessment
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ERTMS	European Rail Traffic Management System
EU	European Union
FHWA	Federal Highway Administration
FOIA	Freedom of Information Act
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GAO	Government Accountability Office
GBP	Great British Pound
GC/CM	General Contractor / Construction Manager
GP	Genera Purpose (i.e. normal traffic lanes)
HDI	Human Development Index
HVAC	Heating, Ventilation, and Air Conditioning
IIJA	Infrastructure Investment and Jobs Act
JNR	Japan National Rail
JR	Japan Rail
Kph	Kilometers per Hour

kWh	Kilowatt-Hours
LRT	Light Rail Transit
LRV	Light Rail Vehicle
LTA	Land Transport Authority (of Singapore)
MARTA	Metropolitan Atlanta Rapid Transit Authority
MAX	Metropolitan Area Express (TriMET LRT System)
Molit	South Korea Ministry of Land, Infrastructure, and Transportation
Mph	Miles per Hour
MTA	Metropolitan Transportation Authority (of New York)
MTR	Mass Transportation Railway (in Hong Kong)
NACTO	National Association of City Transport Officials
NEPA	National Environmental Policy Act
NJ Transit	New Jersey Transit
NYC	New York City
O&M	Operations and Maintenance
OCS	Overhead Catenary System
ODOT	Oregon Department of Transportation
ORR	Office of Rail Regulation, Office of Rail and Road (UK)
PM/CM	Project Management / Construction Management
PPP	Purchasing Power Parity
REM	Reseau Express Metropolitan
ROW	Right of Way
RTD	Rapid Transit District (of Denver)
SCC	Schedule Cost Categories (FTA, FRA Classification)
SMRT	Singapore Mass Rapid Transit
ST	Sound Transit (in Seattle)
TCP	Transit Cost Project (NYU Marron Institute)
TCRP	Transit Cooperative Research Program
TfGM	Transport for Greater Manchester
TfL	Transport for London
TRB	Transportation Research Board
TriMET	Tri County Metropolitan Transportation District of Oregon
TWAO	Transport and Works Act Order
UK	United Kingdom
UPRR	Union Pacific Railroad
US	United States
USD	United States Dollar
V	Volts
VTA	Valley Transportation Authority
WMATA	Washington Metropolitan Area Transportation Authority

Section 1: Introduction

In 2021, the United States (US) Congress passed the Infrastructure Investment and Jobs Act (IIJA), which included the federal government's highest ever direct investment in rail and mass transit (WH, 2023). Multiple cities across the US have also passed their own local ballot measures in support of expanded rail transit, including Seattle, Los Angeles, Denver, Austin, Atlanta, and Phoenix (Brey, 2023a; Schneider, 2023; Wanek-Libman, 2019). Each of these examples show strong national support for expanded mass transit in the US, and a willingness to fund it. In part, policymakers and the public are responding to geographic shifts in the US. Its population is becoming increasingly urban (UMich, 2022), while also clustering into several "megaregions" around the country (Posner, 2018). As population densities in these cities and regions continue to increase, the need to build and operate efficient mass transit is increasing accordingly. However, without proper cost controls, much of this new investment could fail to generate a return. As examples: Austin, Philadelphia, and Atlanta recently rolled back transit expansion plans due to escalating costs (Brey, 2023a; Schneider, 2023).

For reasons which are not entirely clear, the cost to build, operate, and maintain transportation infrastructure (including transit) in the United States is consistently higher than corresponding costs almost anywhere else in the world. This cost discrepancy exists not only in relation to developing nations (where labor & materials are cheaper and environmental regulations are less rigorous) but also in relation to many industrialized nations, particularly in Europe or Asia with high land values, tough environmental regulations, high labor costs, and high rates of unionization. For example, while farebox recovery rates and per passenger mile costs for US urban rail transit systems in this study were found to be 32% and $0.98 respectively (FTA, 2023b), comparable metrics in cities across the UK, EU, Canada, & east Asia were found to be 87% and $0.31 respectively where data could be obtained (Table 3). In regards to capital costs, 7 of the 10 most expensive at grade and tunneled rail projects analyzed in this study on a per mile basis were American, while none of the corresponding cheapest projects were found to be American (Table 5). And prior analysis has found a "US Capital Cost Premium" that ranges from 48%-57% when compared to other developed countries even after excluding capital projects in New York City (NYC). Once NYC projects are included, this "US Capital Cost Premium" increases to 263% (Lewis, 2022).

The high cost to build and operate transportation facilities in the US has not translated into better outcomes. For example, the US saw 11.4 traffic fatalities per 100,000 Americans in 2020. Associated numbers in Canada, New Zealand, Finland, Spain, & Israel were 4.6, 6.3, 4.0, 3.3, & 2.9 respectively. And while the US fatality rate is increasing, associated fatality rates elsewhere continue to decrease (Rodriguez & Ferenchak, 2023; TC, 2020; Zipper, 2022). In regards to rail, the US saw 0.95 fatalities per million train miles in 2012. The European Union (EU), United Kingdom (UK) and India saw 0.16, 0.02 and 0.41 fatalities per million train miles the same year. In regards to overall accidents, the discrepancy is worse. The US saw 10 accidents per million train miles in 2012, while the EU, UK, and India saw just 0.32, 0.08, and 0.34 accidents per million train miles the same year (Evans, 2020; FRA, 2023; IR, 2015; ORR, 2023). While safety is one of many ways to measure the success of a transportation system, it's clear the US isn't spending more to get higher quality facilities.

It is imperative that US transit investments be spent as efficiently as equivalent investments elsewhere in the world. Otherwise, the country may not see results in the form of better transit facilities and more efficient transit operations. While there have been several studies evaluating this discrepancy at a policy level vis-à-vis capital costs, limited prior research has been done to understand this discrepancy from an engineering standpoint or at an operations level. This study aims to fill this research gap.

No two transit systems are the same, so it can be difficult to determine the specific factors which do or don't improve the cost effectiveness of transit. However, Portland's Metropolitan Area Express (MAX) and Manchester's Metrolink system share many common attributes – including ridership, total track length, total number of stations, rolling stock, platform lengths, average speed, & Overhead Catenary Systems (OCS). The cities they service are also similar in their climate, total size, and median incomes. Two recent project extensions, Portland's Orange Line and Manchester's Airport Line, also share many design similarities like their length, design criteria for stations and OCS facilities, number of stations, and at grade percentage. Despite these similarities, the associated operations and capital costs of these two systems & projects diverge significantly. While MAX has a farebox recovery rate of approximately 32%, Metrolink's equivalent recovery rate is around 96% (see Table 7). Likewise, the per mile cost of the two new capital projects on both lines differed by a factor of 2.4 to 1 (see Table 8). The similarity of these two systems, combined with their divergent costs, provide an opportunity to better understand why it costs more money to operate and build transit in the United States than it does elsewhere.

In section 2 of this paper, a literature review and data review is used to understand what factors contribute to transit cost. This includes a review of past studies conducted on the issue, past claims made regarding transit costs, analysis of the Federal Transit Administration (FTA)'s national transit database (FTA, 2023b) and global farebox recovery data, analysis of global transit capital cost data previously gathered by the Eno Center (Aevaz, 2020) and Transit Cost project (TCP) (Goldwyn, 2020), and a review of the FTA's Standard Cost Categories (SCC) database of capital costs (FTA, 2017). Then, section 3 compares the two transit systems (as well as their recent capital projects) noted above, predominantly using expert interviews and field visits. Section 4 includes a resulting hypothesis list and evaluates it against the two transit systems in question. For those hypotheses which appear promising, section 4 also outlines corroborating information where available to either confirm or contradict each hypothesis in question. Finally, section 5 outlines recommendations based on the sections above and section 6 concludes the study.

Section 2: Analysis of Existing Transit Costs

2.1 Research Methodology

Several research steps were taken to understand the current landscape regarding transit operating and capital costs, and the factors which contribute to them. This includes a literature review and a data review pertaining to operations and capital costs.

To gather prior literature pertaining to the issue of transit costs, several steps were taken. These include searches of online databases of academic publications (including Google Scholar) for phrases like "transit" and "transit cost," as well as discussions with staff at the NYU's Marron Center of Urban Management & C2SMART Center, as well as other experts noted in Table 1.

In regards to section 2.3 (which covers operating costs), most data was obtained from the FTA national transit database (FTA, 2023b). Average values were taken over three years (2017, 2018, and 2019). Data from 2022 was not available at the time of this analysis. Data from 2020 and 2021 were impacted by the COVID-19 pandemic – with many values in associated datasets marked as either "questionable" or "waived."

All rail systems classified by the FTA as "Light Rail," "Heavy Rail," "Commuter Rail," and "Hybrid Rail," were analyzed. Systems which exclusively provide peak service were removed from analysis as these services can be more complicated and expensive to operate on a per passenger basis (Stangas, 2023). Several smaller systems (with less than 8 vehicles in the entire agency) were also removed. Puerto Rico's Tren Urbano system's farebox recovery dropped from 54% in 2017 to 8% in 2018, while its hourly cost per car increased from approximately $600/hr to $800/hr during the same period. These impacts can be understood as consequences of Hurricane Maria, and this line was removed from analysis accordingly.

The remaining lines were then reclassified into "Urban," "Regional," and "Special" categories. The urban category includes all light rail & heavy rail systems, and two commuter rail systems – Caltrain and Denver's Regional Transit District (RTD) commuter rail lines. These lines were classified as "Urban," as their route lengths and coverage areas are similar to those of other light or heavy rail systems in the same metro areas. All remaining commuter rail lines were classified as "regional," while all hybrid rail lines were classified as "special." Only the 38 Urban systems were shown in figure 1. While information from the other lines has been included in figures and tables below.

Some operating cost data for transit systems abroad was also gathered to provide a basis for comparison. This information was derived through expert interviews (see Table 3), and well as online searches and conversations with staff at the NYU Marron Center.

Finally, to evaluate global transit capital costs (in section 2.4), two datasets were used – one from the Eno Center, and another from the Transit Cost Project. Each contains cost/mile data for hundreds of projects around the world scaled for 2021 US Dollars (USD) based on inflation and Purchasing Power Parity (PPP), along with a breakdown of basic project elements such as mode, percent elevated/tunneled, opening date & construction timeline, etc. While TCP data was more extensive, the Eno center's dataset provided more in depth information. So when duplicates were identified between these datasets, TCP information was removed. The resulting dataset included 430 capital projects.

Two common explanations for international infrastructure cost differentials are as follows. First, countries with a lower standard of living have lower labor and materials costs, and the public in those countries are generally willing to sustain greater level of construction impacts as well as lower design standards for new facilities. Second, countries without democratic processes, property rights, or a free press are generally able to build new projects more cost effectively as they don't have to contend with political opposition, fare market property acquisition, or community input. For this reason, the resulting dataset was filtered further to only include countries with a Human Development Index (HDI) of at least 0.820 (matching those of the United States) (UNDP, 2023) and a Freedom House Freedom Index of at least 35 (In the "Free" or "Partially Free" category) (FH, 2023). To further analyze the relationship between cost of living and construction costs, information from Mercer's Cost of Living Ranking (Parakatil, 2022) was added to the dataset based on the city project was located in.

This data was filtered further to only include projects slated for completion between 1990 and 2030, and any projects where the % at grade, elevated, and tunneled were unknown were removed. Projects in Hong Kong were also removed as Hong Kong builds projects based on a "Rail + Property" model and it could not be determined if Hong Kong's capital costs therefore include capital costs associated with property development (Goldwyn, 2023). The resulting filtered dataset includes 293 capital projects, 55 of which are within the US (Appendix C).

To facilitate the research conducted in section 2, several expert sources were consulted or interviewed. The list of expert sources pertaining to section 2 are below in Table 1.

Table 1: Expert sources & interviews pertaining to section 2 (existing transit cost analysis)

Name	Tittle or Background	Date	Topic
Alice Saunders	Senior Analyst, Imperial College London Transport Strategy Centre	7/31/2023, Emails & TRB Presentation	Post COVID Ridership Recovery. Safety & security issues on rail transit.
Anne Aagaard	Ragneskabschef, Copenhagen Metro	Emails, 6/2023	Copenhagen metro operating expenses
Colleen Fee	TransLink Information Access Manager	Emails, 6/2023	Data provision
Elif Ensari	Transit Cost Project Research Scholar	Emails, 6/2023	Turkish unit prices & environmental review process
Eric Goldwyn	Assistant Professor, New York University (NYU) Marron Institute	3/14/2023	Transit Cost Project
Jasmine Howard	General Council, Transport for London	Emails, 8/2023	UK environmental permitting, implications for TfL Congestion Charge
Leigh Lumsden	FTA National Transit Database (NTD) Program Support Contractor	Emails, 6/2023	FTA operating cost accounting
Lisa Gavin	FTA Office of Project Management	6/9/2023	FTA SCC cost database
Marco Chitti	University of Montreal Postdoctoral Fellow	7/13/2023	Italian unit prices and associated contracting system.
Paul Stangas	Rail Engineer & NJ Transit Positive Train Control (PTC) Senior Director	3/13/2023	Rolling stock & rail operations
Ryan Taylor	Project Engineer, Hatch LTK	3/14/2023	Rolling stock & rail operations

2.2 Literature Review

Several previous studies have been conducted evaluating why US transit capital costs are as high as they are, and some (not all) findings from these studies can also apply to operating costs. These include studies conducted by the NYU Marron Center's Transit Cost Project (TCP) (Goldwyn, 2020), the Eno Center (Aevaz, 2020), the Transit Cooperative Research Program (TCRP) (TCRP, 2006) and Sound Transit (ST, 2023). These studies noted several findings.

According to the Eno Center and contrary to conventional wisdom, transit mode has little impact on cost. Instead, grade plays a greater role, and US capital costs deviate from global costs to a greater degree when building tunnels or elevated guideways than they do when building at grade transit (Aevaz, 2020). US subway stations appear uniquely expensive to build. The Transit Cost project attributes this high-cost discrepancy, in part, to a tendency to over-size and over-design US transit facilities. Beyond this, the transit cost project attributes America's high transit capital costs to a lack of transparency regarding project cost estimates, offloading of project risks by transit agencies to private contractors (who price their bids accordingly), Disadvantaged Business Enterprise (DBE) Requirements, overstaffing on projects (particularly in regards to management) overuse of design consultants without sufficient in house capabilities, and resistance to adopting international best practices (Goldwyn et al., 2023). The last two of these findings were corroborated by research from the Eno Center (Lewis, 2022). Several other findings by the TCP were corroborated by TCRP's own research, attributing high US transit costs to unusually slow construction timelines and design changes made late in the design or construction process, partly due to micromanagement from politicians or other interest groups (TCRP, 2006). This is partly corroborated by Sound Transit, which noted that project delays, often caused by environmental approvals, scope changes, or property acquisition, can cost millions of dollars per day (ST, 2023). Because of this, the TCP recommends that transit agency boards be structured to keep elected officials at arm's length from design and planning details (Goldwyn et al., 2023), but the Eno Center says that governance structure is not an indicator of project cost (Lewis, 2022).

Related to the issue of transit infrastructure costs is the issue of cost overruns in construction. Studies of transportation infrastructure projects have found that cost overruns of 50% or more are common (Skamris & Flyvbjerg, 1997), and the situation has not improved in the past 70 years (Flyvbjerg et al., 2003). While cost overruns are common globally, they appear to be more prevalent in developing nations than in developed ones (Flyvbjerg et al., 2003). This is a significant issue, but the factors that lead to overruns are not necessarily the same as the factors that contribute to high overall transit capital costs, and sometimes steps taken to reduce cost overruns simply increase overall project costs (Goldwyn et al., 2023). This study focuses on the issue of total cost rather than the issue of cost overruns.

In regard to transit operations, unit costs have increased considerably above the rate of inflation on both a vehicle mile and passenger mile basis in the US (Sarriera et al., 2018). One likely cause of this cost inflation is Baumol's Cost Disease (Sarriera & Salvucci, 2016). Many urban areas in developed countries have high rates of worker productivity and therefore have high wages & living costs. This put pressure on transit operators to raise wages to competitive rates, even though associated worker productivity rates may not be as high, to a level which transit agencies may not be able to afford (Sarriera & Salvucci, 2016). However, the entirety of cost escalation in transit operations cannot be attributed to this issue (Sarriera et al., 2018). Some possible solutions to this issue include franchising (discussed further below), and automation (Sarriera et al., 2018). Other possible ways to increase efficiency in transit service is use short turning to better cater service frequency to demand (Tirachini et al., 2011), and using new fare payment methods and station designs to reduce dwell times (Tirachini, 2013).

Additional prior research pertains to the analysis of transit user costs, i.e. cost incurred by passengers as opposed to transit agencies (Horcher, 2021; Tirachini et al., 2010). As noted above, this is a significant issue, but costs incurred by passengers are not the same as costs incurred by transit operators. This study therefore focuses on costs incurred by transit agencies specifically, of which there are several factors.

2.2.1. Methods of Fare Payment

The means by which fares are collected can influence the efficiency of a transit system. For example, it's estimated that processing cash fare payments can cost transit agencies as much as 20% of total fare revenue (Klein, 2023). This has helped push transit agencies to adopt digital forms of fare payment, but the associated procurement costs for these digital fare payment systems vary significantly. In Portland, the HOP payment system (unveiled in 2016) cost $35 million to implement (Tucker, 2017). In Seattle, the "ORCA Next Generation" system (unveiled in 2021) cost $125 million (Giordano, 2017). In New York City, the OMNY systems (launched in 2019) cost $772 million (Nessen, 2022). In Boston, the new fare payment system (which has yet to be implemented) has already cost $935 million so far (Cawley, 2023). These are significant discrepancies that point to a lack of sufficient cost control. On top of this, transit agencies which adopt digital methods of fare payment must pay interchange fees, but efforts have been made in some states (like California) to negotiate fee reductions with relevant banks (Klein, 2023).

Another issue pertaining to fare payment which can impact transit operating costs is fare integration. A study from Haifa, Israel found that fare integration lead to a 7% increase in overall transit ridership, and a 25% increase in single ticket purchases (Sharaby & Shiftan, 2012) – which suggests that a simplified fare payment model across transit modes and agencies can generate new ridership, revenue, and increase farebox recovery accordingly.

2.2.2. Alternative Sources of Revenue

Many transit systems around the world have developed alternative revenue streams to fund transit (Raine, 2021). These revenue sources include property development (as is true in London, Hong Kong, and Copenhagen) (Eno, 2022a; ESCAP, 2014; Pitcher, 2023), retail (London and Manchester)(ML, 2013; Sommers, 2023), and advertising (London and Singapore) (Feng et al., 2020; ML, 2020). However, these transit systems cover the bulk of their operating costs through fares alone, using alternative sources primarily to finance capital expenditure (see Table 3).

2.2.3. Infrastructure Maintenance, and Associated Political Involvement

As mentioned above, one likely cause for high transit capital costs is attributed to political micromanagement (Goldwyn et al., 2023). This issue can apply to maintenance as well (Rosenthal, 2017). Neglecting infrastructure maintenance leads to the deterioration of infrastructure over a long time, but the effects aren't seen immediately. For this reason, maintenance budgets have often been reduced by elected representatives to fund other priorities (Fitzsimmons, 2018), as those representatives expect to be out of office by the time the public sees the consequences of poor maintenance. In London, this issue was addressed by a proposal to ring-fence maintenance funding for the London Underground, allowing maintenance staff to more effectively "fix before failure," rather than in a reactive manner (Byford, 2023). Similar legislation for the New York MTA was passed into law in 2019 (Albany, 2019).

2.2.4. Peak vs. All Day Transit Service

It has been claimed that many US public transit agencies overly cater their service to traditional 9 to 5 commuters, and under serve other markets (Spieler, 2021). The pandemic has further highlighted this issue. In New York City, ridership recovery in outer residential boroughs has outstripped that in major business centers (DiNapoli, 2023). Nationally, transit ridership for transit services which cater to rush hour commuters has lagged behind services which run all day (APTA, 2023). This is particularly true when it comes to commuter rail services (Blumgart, 2021). All day transit service can often be cheaper to provide on a per passenger basis (Cervero, 1981; Stangas, 2023) as it involves less deadheading and less complicated staff scheduling, so an overemphasis on service 9 to 5 commuters could lead to less efficiency in transit operations on a per passenger basis.

2.2.5. Facility Design Standards

Unlike in many other developed countries, clear & consistent engineering design guidance is often lacking in the US for transit projects. This lack of clear standardized engineering guidance can create confusion or unnecessary customization in facility design – increasing capital, construction, maintenance, and procurement costs (GAO, 2010; Lewis, 2022; TCRP, 2006). It can also lead transit agencies to pursue unproven new technologies in lieu of technologies which have already been tested and proven elsewhere (TVO, 2023). While some limited publications do exist on light rail (TCRP, 2012), other forms of urban rail (Pulido et al., 2018), and Bus Rapid Transit (BRT) (ITDP, 2016) design, there are no national design standards for new transit facilities. This forces transit agencies to develop their own design standards, often relying on guidance from the American Railway Engineering & Maintenance of Way Association (AREMA) (AREMA, 2018). However, AREMA design standards are developed by the private rail industry and geared towards freight rail. Even in regards to roadway design, guidance from the two main industry groups which provide design guidance, the American Association of State Highway Transportation Officials (AASHTO) (AASHTO, 2018) and National Association of City Transportation Officials (NACTO) (NACTO, 2023), can often conflict. By contrast, a single national organization in the Netherlands provides design guidance for all transportation projects (CROW, 2023), while the UK's Office of Rail Regulation (ORR) has published national design standards for light rail projects (ORR, 2006).

2.2.6. Rail Car Weight and FRA Compliance

Historically, US transit agencies which shared track with freight trains or operated adjacent to freight traffic have been unable to procure vehicles which are widely used in Europe and Asia. This is due to unique Federal Railroad Administration (FRA) buff strength regulations, which required that US railcars be able to withstand 800,000lbs of lateral load without any deformation in a collision (Edmondson & Scribner, 2013; Hicks, 2023a). This regulation was justified on the basis of rail safety. However (per section 1), the US rail network is less safe than many countries which do not have the same regulatory requirements. This regulation increased the weight of US railcars, in part by leading to steel car bodies instead of aluminum, which in turn increases energy cost as well as maintenance costs for track (Pulido et al., 2018). If agencies wanted to procure lighter rolling stock (usually with aluminum car bodies), they had to ensure temporal separation between passenger and freight traffic (Stangas, 2023). In 2018, the FRA modified these regulations to more closely align with international industry standards (FR, 2018). And American Public Transit Association (APTA) and American Society of Mechanical Engineering (ASME) design standards now reflect this change (APTA, 2022; ASME, 2020). However, few transit agencies have subsequently procured modern railcars to international design standards despite suggestions to do so from rolling stock manufacturers (Taylor, 2023).

2.2.7. Privatized Transit Operations

In many European and Asian countries, transit operations are partially or fully privatized. The associated business models vary by country, but generally involve a greater role for private enterprise than exists in the United States.

2.2.7.1 – Franchised / Tendered Operations. Transport for London (TFL, 2015), Singapore Land Transport Authority, The Netherlands, Melbourne, Copenhagen

Under this model, private companies bid for operations contracts to run buses or trains for a state-owned transit agency, while route planning and fare collection are still managed by the public agency. In London, both public and private companies bid for bus route operations contracts, and it is estimated that this bidding model has reduced operations expenditure by 16% to 20% (Kennedy, 1996). Part of these savings have come from reduced wages (Kennedy, 2007). In the Netherlands, a similar business model was introduced in 2000, and both farebox recovery rates and customer satisfaction rates have increased in the bus network since the franchise operations model was introduced (Van-De-Velde & Eerdmans, 2016). Melbourne introduced a similar franchise model in 1999 which has largely been viewed as a success, despite minor modifications, as it lead to a reduction in operations cost and an increase in ridership (Currie, 2021). In Singapore, the Land Transport Authority (LTA) introduced a similar business model in 2015 for its bus network (Tan, 2015). Parts of Singapore's rail network also operates under a similar framework (Feng et al., 2020). The Copenhagen Metro (Aagaard, 2023) also operates under this model, as does Manchester (Shock, 2023)

2.2.7.1.1 – UK National Rail.

The UK national rail network operates under a slightly modified model. Unlike the examples above, private operators maintain their own brand identify, set some (not all) of their own fares, and directly receive a portion of fare revenue. This system has been criticized for increasing Operations and Maintenance (O&M) costs (Economist, 2020). And proposals have been made to modify the system (Comfort, 2021).

2.2.7.2 – Open Competition. EU Rail Network

In accordance with EU regulations (EC, 2011; EU, 2012), all member states are required to allow multiple operators to provide both passenger and freight service across their rail networks regardless of track ownership. This is facilitated by another EU requirement to provide structural separation between agencies which handle "infrastructure management," (i.e. track construction & maintenance) and those which provide "service provisions," (i.e. operate trains). This is also facilitated by the introduction of a standardized railroad signaling system called the European Rail Traffic Management System (ERTMS) (Tomczak, 2023). Some EU member states have accommodated these requirements by having separate state agencies provide infrastructure management and service provision, while others have continued to provide both services through one state agency. However, in both models, private companies have been allowed to provide competing service on state-owned tracks (Alexandersson, 2009; Nikitinas, 2015) .

2.2.7.3 – Traditional Privatization. (Singapore, Japan)

In some cases, existing transit agencies have been privatized as single entities. In Singapore, the SMRT (Singapore's state-owned rail operator) was listed on the Singapore Stock exchange in July 2000. While retail sales and operational profits increased, the Singapore Mass Rapid Transit system (SMRT) faced significant performance issues between 2011 and 2017, and was eventually re nationalized (Feng et al., 2020). In Japan, the Japan National Railways (JNR) a state-owned railway company was divided geographically and listed on the stock market as a series of regional Japan Rail (JR) companies. Unlike in Europe, no separation exists between infrastructure management and service provision. While profitability has increased, the number of cross-regional services has declined, and any train which crosses regions must also change operators. While each JR corporation maintains a monopoly of rail service along its own tracks, Japan has a dense network of privately owned railways which compete with the JRs (Kim & Huang, 2019; Mizutani & Nakamura, 2004). Another factor which contributes to the success of this business model is the privatization of Japan's highway network. Unlike in the US, Japanese highways are funded almost entirely through tolls (Himmel, 2014; Shimbun, 2021). This allows rail companies to compete on a level playing field without subsidizing a major source of competition.

2.2.7.2.3 – US Application (Brightline) (Bojnansky, 2023)

A recent successful example of privately owned and operated transit service in the United States is Brightline. The line runs from Miami to Orlando and has plans to expand further to Tampa. It began to turn an operational profit in March 2023 (Brennan, 2023), although it's unclear if this is purely due to higher fares or if it has lower operating costs than other US commuter railroads. Most of the existing line runs on tracks owned by a class II freight railroad, the Florida East Coast Railway (HSRA, 2023). Brightline owns stations and tracks outside this area, and has received some limited financial support from TriRail, a public commuter railroad, for access to its Miami Central station (TriRail, 2023).

2.2.8. Environmental Documentation and Permitting Requirements

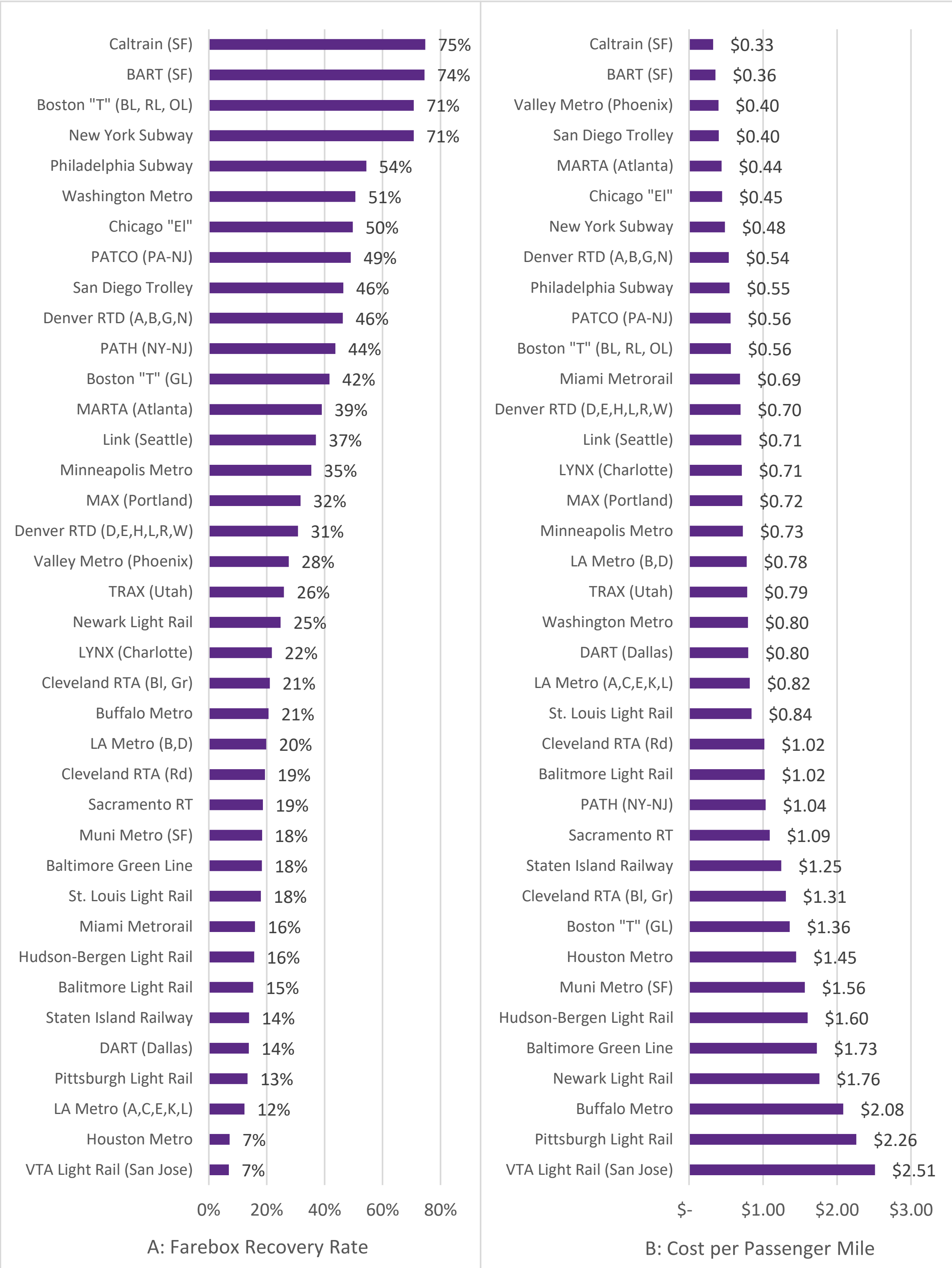
In accordance with the National Environmental Policy Act (and associated equivalent legislation at the state / local level), agencies building a new transportation facility must go through an environmental disclosure process. This either involves the publication of an Environmental Impact Statement (EIS), a shorter Environmental Assessment (EA), or a Categorical Exclusion specifying why documentation is not necessary. As part of this disclosure process, agencies must identify how impacts will be mitigated if necessary in accordance with other environmental legislation. Following this process and (if required) an associated public comment period, the appropriate regulatory agencies (usually the FTA, FRA, or FHWA in regards to transportation projects) issues a Record of Decision permitting the agencies to advance the project. (CEQ, 2023; EPA, 2022; FTA, 2020; ODOT, 2011; OR, 2023). Some have argued that this process slows down the delivery of new transit projects, increases their costs, and at times is misused by political opponents to block projects entirely through legal action (Clemente, 2020; Demsas, 2021). According to AASHTO and the Brookings institute, NEPA regulations have played a role in cost escalation for US highway projects as well (AASHTO, 2019; Brooks & Liscow, 2021). However, others have argued that this is a crucial step to make sure the public are appropriately consulted in project delivery and potential environmental impacts are properly addressed (DeGood, 2018; Pepper, 2015).

2.3 Operating Cost Data Review

Operations costs for urban rail transit systems in the US vary significantly. Figure 1 shows their farebox recovery rates, hourly operating costs (by car and by train), and costs per passenger mile. Each of these metrics measure the operations costs of transit systems differently. The hourly costs strictly look at the cost to run rail vehicles irrespective of ridership, fare, or distance travelled. The cost per passenger mile takes into account ridership and network distance but omits fare, while farebox recovery takes into account all these factors. The FTA further splits transit operating costs into 4 categories: Vehicle Operations (on average, 37.5% of total), Vehicle Maintenance (20.8%), Facility Maintenance (19.4%), and General Administration (22.3%).

While the FTA calculates farebox recovery purely using direct fare revenue, US transit agencies report other forms of direct revenue to the FTA as well (including advertising, concessions, and park & ride revenue), although this is reported by agency, not by mode. The transit agencies which provide urban rail service in Figure 1 receive approximately 4.5% extra advertising revenue, 0.3% extra concession revenue, and 1.3% extra park and ride fee revenue when compared to fare revenue.

Portland's MAX Light Rail system ranks above average on all of these metrics compared to other rail transit systems in the United States. Of the 38 transit systems analyzed in Figure 1, MAX ranks 16th in farebox recovery, 11th in cost per car service hour, 10th in cost per train service hour, and 16th in cost per passenger mile.


Caltrain (SF) 75%
BART (SF) 74%
Boston "T" (BL, RL, OL) 71%
New York Subway 71%
Philadelphia Subway 54%
Washington Metro 51%
Chicago "El" 50%
PATCO (PA-NJ) 49%
San Diego Trolley 46%
Denver RTD (A,B,G,N) 46%
PATH (NY-NJ) 44%
Boston "T" (GL) 42%
MARTA (Atlanta) 39%
Link (Seattle) 37%
Minneapolis Metro 35%
MAX (Portland) 32%
Denver RTD (D,E,H,L,R,W) 31%
Valley Metro (Phoenix) 28%
TRAX (Utah) 26%
Newark Light Rail 25%
LYNX (Charlotte) 22%
Cleveland RTA (Bl, Gr) 21%
Buffalo Metro 21%
LA Metro (B,D) 20%
Cleveland RTA (Rd) 19%
Sacramento RT 19%
Muni Metro (SF) 18%
Baltimore Green Line 18%
St. Louis Light Rail 18%
Miami Metrorail 16%
Hudson-Bergen Light Rail 16%
Balitmore Light Rail 15%
Staten Island Railway 14%
DART (Dallas) 14%
Pittsburgh Light Rail 13%
LA Metro (A,C,E,K,L) 12%
Houston Metro 7%
VTA Light Rail (San Jose) 7%
0% 20% 40% 60% 80%
A: Farebox Recovery Rate
Caltrain (SF) $0.33
BART (SF) $0.36
Valley Metro (Phoenix) $0.40
San Diego Trolley $0.40
MARTA (Atlanta) $0.44
Chicago "El" $0.45
New York Subway $0.48
Denver RTD (A,B,G,N) $0.54
Philadelphia Subway $0.55
PATCO (PA-NJ) $0.56
Boston "T" (BL, RL, OL) $0.56
Miami Metrorail $0.69
Denver RTD (D,E,H,L,R,W) $0.70
Link (Seattle) $0.71
LYNX (Charlotte) $0.71
MAX (Portland) $0.72
Minneapolis Metro $0.73
LA Metro (B,D) $0.78
TRAX (Utah) $0.79
Washington Metro $0.80
DART (Dallas) $0.80
LA Metro (A,C,E,K,L) $0.82
St. Louis Light Rail $0.84
Cleveland RTA (Rd) $1.02
Balitmore Light Rail $1.02
PATH (NY-NJ) $1.04
Sacramento RT $1.09
Staten Island Railway $1.25
Cleveland RTA (Bl, Gr) $1.31
Boston "T" (GL) $1.36
Houston Metro $1.45
Muni Metro (SF) $1.56
Hudson-Bergen Light Rail $1.60
Baltimore Green Line $1.73
Newark Light Rail $1.76
Buffalo Metro $2.08
Pittsburgh Light Rail $2.26
VTA Light Rail (San Jose) $2.51
$- $1.00 $2.00 $3.00
B: Cost per Passenger Mile

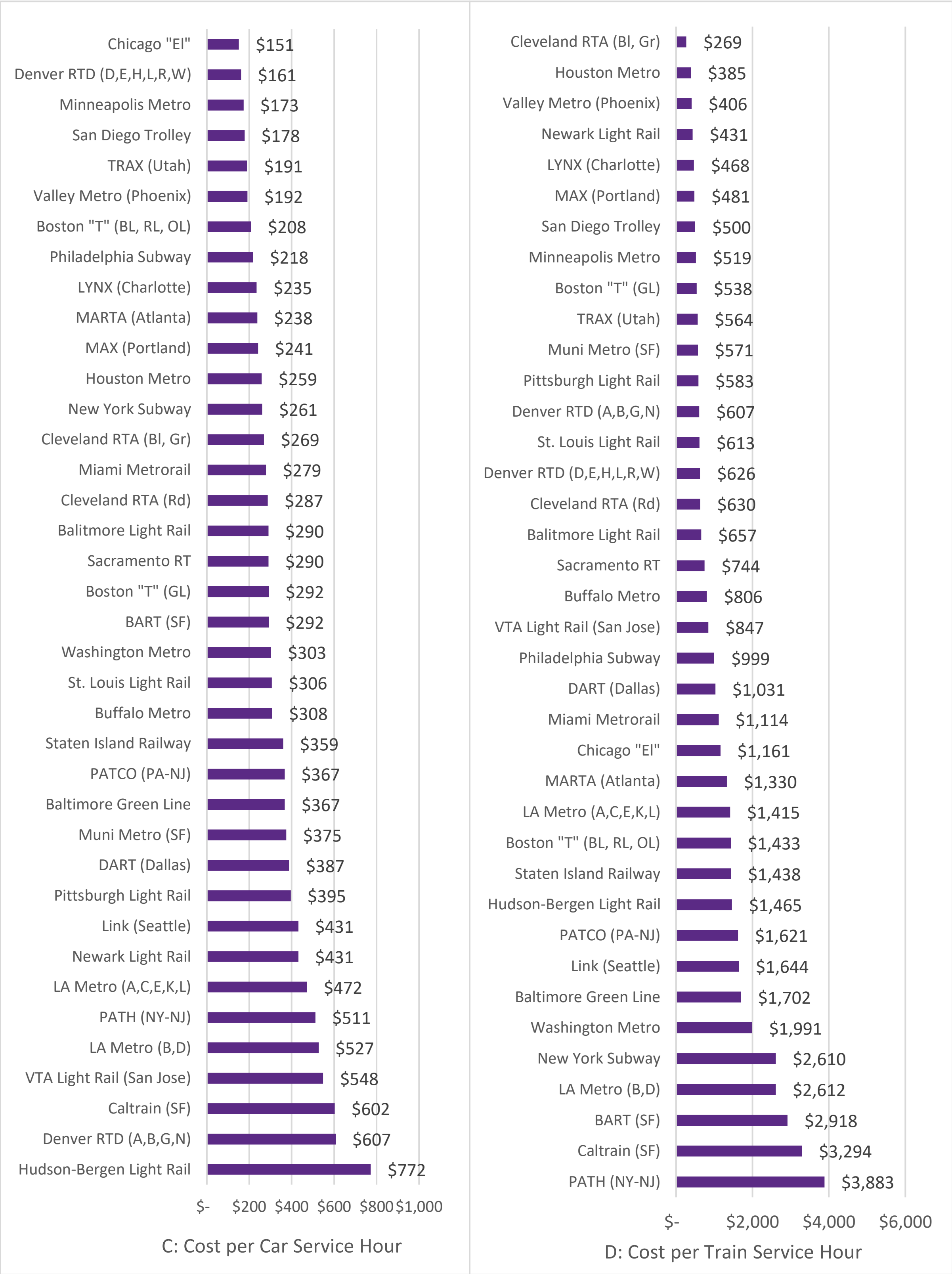


Figure 1: US Urban Transit Operating Costs, Average: 2017-2019: (a) farebox recovery, (b) cost per passenger mile, (c) cost per car service hour, and (d) cost per train service hour. (FTA, 2023b)

2.3.1. Comparing Modes of Rail Transit

As noted above, Figure 1 shows a breakdown of operating costs for urban transit systems in the US. Table 2 compares these costs to other forms of transit in the FTA's national transit database (see Appendix B for a full table of associated data).

Several findings can be obtained from the data. Firstly, it appears that light rail is no cheaper to operate than heavy rail. In fact, the average light rail system costs more to operate across 3 out of 4 metrics analyzed. That being said, the opposite can't be stated either as the range in operating costs between light and heavy rail systems overlaps significantly. This is partially why these systems were reclassified using the methodology described above.

Secondly, it appears that Hybrid/Special Systems, chosen to reduce capital costs, are significantly more expensive than any other mode to operate. Examples of these transit systems include "WES" in Portland, "eBART" in San Francisco, the River Line in New Jersey, and Capital Metro in Austin. These "Hybrid Rail" systems (as categorized by the FTA) were intended to reduce capital costs. While that might be the case (BART estimates the use of eBART technology cut capital costs for their Antioch extension by 40% (BART, 2018)), they are consistently more expensive to operate. This is true even when comparing two systems that are in the same city and run by the same agency. For example, eBART costs nearly twice as much to operate per car hour than regular BART service. In Portland, WES costs nearly 4 times as much per car hour to operate as traditional MAX service, and has a farebox recovery rate of just 6% (compared to 32% for MAX). Each of the Hybrid/Special rail systems noted above also use diesel propulsion. While the use of diesel propulsion can lead to lower capital costs, diesel trains are more expensive to maintain than their electric counterparts (Gattuso & Restuccia, 2013).

Thirdly, it appears that while BRT and streetcar systems are cheaper to operate on a per hour basis than other forms of rail transit, this does not translate into better metrics for cost/passenger mile or farebox recovery. So while BRT and streetcar lines may be cheaper facilities, they are not more cost effective to operate than traditional rail transit.

Table 2: Operating Costs of US Transit Systems by Mode (FTA, 2023b)

Transit Mode	*Farebox Recovery*	*Cost / Car Service Hour*	*Cost / Passenger Mile*
	FTA Mode Classifications (Format: Avg / Min-Max)		
Heavy Rail	42% / 14%-74%	$312 / $151-$527	$0.76 / $0.36-$1.73
Light Rail	23% / 7%-46%	$327 / $161-$772	$1.17 / $0.40-$2.51
Commuter Rail	39% / 6%-75%	$653 / $251-$1352	$0.76 / $0.32-$2.46
Hybrid Rail	15% / 6%-50%	$815 / $457-$1418	$1.27 / $0.87-$2.02
	Project Classifications (Format: Avg / Min-Max)		
Urban Systems	32% / 7%-75%	$336 / $151-$772	$0.98 / $0.33-$2.51
Regional Systems	35% / 6%-60%	$659 / $251-$1352	$0.80 / $0.32-$2.46
Special Systems	15% / 6%-50%	$815 / $457-$1418	$1.27 / $0.87-$2.02
	Comparison to Other Modes (Format: Avg / Min-Max)		
BRT Systems[1]	25% / 0%-70%	$150 / $76-260	$1.28 / $0.80-$3.97
Streetcars	9% / 0%-31%	$286 / $84-$627	$6.15 / $1.33-$23.80

[1] FTA BRT definition - 50% of route in peak hour bus lanes, defined branding, signal priority, dedicated stations (Lumsden, 2023).

2.3.2. Global Operating Cost Comparison

International transit operating cost data does not appear to be as readily available as data reported to the FTA. However, Table 3 shows farebox recovery rates for various transit systems around the world where data could be obtained. It appears that, contrary to popular belief in the US, many transit systems around the world rely heavily on fare revenue for operations and maintenance expenditure.

Unless otherwise noted, farebox recovery values specified in this table are shown according to FTA assumptions. This means the farebox recovery value factors in fare revenue (but not other forms of revenue like real estate or advertising), against operations and maintenance expenditure (but not paratransit, asset depreciation, or debt financing for past capital projects). However, unlike values noted above, many of the farebox recovery values below are consolidated farebox recovery rates across all fixed modes in specific cities.

Table 3: Global transit operating cost comparison

	Transit System	Farebox Recovery	Year	Cost/ Pass. Mile (USD)	Source
USA	Urban Rail Average (Reference)	32%	2017-2019	$0.98	Table 2
	Regional Rail Average (Reference)	35%	2017-2019	$0.80	Table 2
	Heavy Rail Average (Reference)	42%	2017-2019	$0.76	Table 2
	Light Rail Average (Reference)	23%	2017-2019	$1.17	Table 2
	Portland MAX (Reference)	32%	2017-2019	$0.72	Figure 1
UK	London Underground	133%	2018		(TfL, 2019)
		117%	2023[3]		(TfL, 2023)
	London - Docklands Light Railway	135%	2018		(TfL, 2019)
	London Elizabeth Line	99%	2023[3]		(TfL, 2023)
	London Buses	78%	2018		(TfL, 2019)
		44%	2023[3]		(TfL, 2023)
	Manchester Metrolink	96%	2016 - 2019	$0.32	Table 7
Canada	Vancouver Translink (Bus, Skytrain[1], Seabus, Commuter Rail (CR))	59%	2018 - 2019	$0.37	(TransLink, 2023)
	Toronto (TTC Bus & Subway)	71%	2009 - 2013	$0.37	(TransLink, 2014)
	Montreal (Bus & Metro)	55%	2009 - 2013	$0.36	(TransLink, 2014)
	Calgary (Bus & Light Rail)	53%	2009 - 2013	$0.24	(TransLink, 2014)
	Ottawa (Bus & O-Train)	51%	2009 - 2013	$0.37	(TransLink, 2014)
	Edmonton (Bus & Light Rail)	44%	2009 - 2013	$0.49	(TransLink, 2014)
Asia	Hong Kong MTR (Incl. Fares/Ops Only)	107%	2021		(MTR, 2012)
	Hong Kong MTR (Incl. Fares/Property)[2]	121%	2021		(MTR, 2012)
	Singapore (MRT & Bus)	97%	2013		(WorldBank, 2013)
	Japan (Metro Rail)	88%[2], 153%	1990	$0.18	(Mizutani & Shotji, 1997)
	Japan (Regional / Commuter Rail)	108%[2], 141%	1990	$0.08	(Mizutani & Shotji, 1997)
Europe	Vienna U-Bahn	49%	2008		(Hale, 2008)
	Copenhagen Metro (Incl. Fares/Ops Only)[1]	95%	2018 - 2019		(Olsen, 2019)
		75%	2021		(Olsen, 2021)
	Copenhagen Metro (Incl. All Op. Income/Expenses)[1,2]	127%	2018 - 2019		(Olsen, 2019)
	Swiss National Transit System	50%	2022		(I. Griffiths, 2023; SBA, 2022)
	Irish National Transit System	65%	2019		(MVIW, 2021)
	Danish National Transit System	50%	2019		(MVIW, 2021)

[1] Fully driverless system (Aagaard, 2023; Fee, 2023)

[2] Includes asset depreciation / debt financing

[3] Budgeted as of March 2023 (TfL, 2023)

2.3.3. Labor & Operating Costs

Labor is a significant component of total operating costs for most transit agencies. The average US transit agency spends approximately 60%-70% of its total operating expenditure on labor (APTA, 2021; Walker, 2011). Between 2017 and 2019, 40% of these labor expenses were spent on vehicle operations (like drivers and other operators), 21% on vehicle maintenance, 25% on facility maintenance, and 14% was spent on general administration (FTA, 2023b).

As mentioned in section 2.2, escalating labor costs in urban centers coupled without equivalent escalations in labor productivity for transit (i.e. Baumol's Cost Disease), is cited as a key factor in creating high US transit operating costs (Sarriera & Salvucci, 2016; Sarriera et al., 2018). However, an analysis of FTA data shows the picture is more nuanced . It's not clear that either wage rates or unionization have as much impact on operating costs as one might presume. As shown in Table 4, correlation coefficients between wage rates and operational efficiency range between 0.12 and 0.46, showing limited correlation. When narrowing down this analysis to low floor light rail systems which operate 1-3 car trains (similar to MAX), these coefficient's increase. However, while MAX pays above average wages for this group of systems ($33.7 for MAX vs. $31.7 average) it performs better than average in terms of farebox recovery (32% vs. 24%), cost per car service hour ($241 vs. $322), cost per train service hour ($481 vs. $607), and cost per passenger mile ($0.72 vs. $1.11).

Another way to look at this issue is to compare the Newark & Hudson-Bergen light rail lines in New Jersey. Both are owned by NJ transit, both are in northern New Jersey, and both use similar rolling stock. However the Newark line is run using unionized labor directly by NJ transit while the Hudson-Bergen line is run by a Design Build Operate Maintain (DBOM) contractor with non-unionized staff (Stangas, 2023). The unionized Newark line operates at a per car service hour cost that is 44% lower than that of the Hudson-Bergen line, and its per train service hour cost that is 70% lower. While the Hudson-Bergen line's DBOM contractor doesn't report labor rates to the FTA, it can be assumed that their non-unionized operators earn lower wages than Newark's operators.

It does appear, however, that staff numbers (as opposed to wages) impact operating costs to a greater degree. US transit agencies rely on very different total staff numbers to provide the same service – while some agencies provide a car service hour with less than 2 staff hours, others provide the same car service hour with over 5 staff hours. And this variation appears to be the case regardless of average train length or mode. For example, the New York City (NYC) subway and SF BART are both 10-car heavy rail systems, but the NYC subway needs 2.7 staff hours per car service hour while BART requires just 1.8. Likewise, Chicago's El and New Jersey's PATH are both 8-car heavy rail systems, but the El requires just 1.9 staff labor hours/car service hour while PATH requires 2.9. In both these cases, the transit system which requires more staff hours per service hour has higher operating costs. And as shown in Table 4, associated correlation coefficients for a transit systems' staff hour per service hour range between 0.55

and 0.85 for 3 out of 4 efficiency metrics analyzed. This suggests a strong correlation between this metric and operational efficiency.

MAX's required staff hours per car service hour (2.45) is lower than the average for 1-3 car low floor light rail systems (3.30). All systems in this category with costs per car service hour than MAX require more staff hours per service hour to operate.

2.3.3.1 – Operating Speed & Labor.

Because labor is paid by the hour, it has been said that one way to increase transit efficiency is to increase average transit speeds, as this would mean that each hour of labor which move passengers a longer distance, or move more passengers (Chitti, 2023; Walker, 2011). However, as noted above, only about 40% of total O&M labor costs are spent on vehicle operations labor. As seen in Table 4, some limited correlation exists between average speed operating efficacy (correlation coefficient range between 0.4 and 0.6 across 3 out of 4 efficiency metrics in Table 4).

2.3.3.2 – Rolling Stock Utilization & Economies of Scale.

A larger transit system could theoretically be able to reduce associated operations costs on a per service hour or per passenger mile basis due to economies of scale (J. Griffiths, 2023). There are several ways in which this could be measured, shown in Table 4). When looking at all US urban transit systems, it appears that larger size leads to improved farebox recovery, but it does not necessarily lead to reduced costs across other efficiency metrics. This is likely because larger US transit systems are located in cities with higher population densities, higher incomes, lower rates of car ownership, and therefore more willingness to pay for transit.

Another related issue is the extent to which each transit agency utilizes its infrastructure. The number of weekly service hours run per railcar in US transit systems varies from 37 to 124. Also looking at Table 4, there is a moderate correlation between this metric and operating cost as well.

Table 4: Pearson's correlation coefficients - operations vs. efficiency metrics (FTA, 2023b)

	Operations Metrics	*Efficiency Metrics*			
		Cost / Car Service Hour	Cost / Train Service hour	Farebox Recovery	Cost / Passenger Mile
	All Urban Rail Systems (per Figure 1)				
Labor	Wage Rates	0.458	0.377	0.116	0.191
	Staff Hours per Car service hour	0.549	-0.175	-0.621	0.574
	Staff Hours per Train Service Hour	0.115	0.834	0.555	-0.391
Operations	Average Speed[b]	0.088	0.463	0.488	-0.604
	Percent of Hours Spent on Deadheading	0.268	0.345	0.204	-0.061
	Avg. Car service hours before Mechanical Failure	0.030	0.545	0.436	-0.204
	Avg. Train Service Hours before Mechanical Failure	0.066	0.043	-0.090	0.131
	Energy Efficiency (mi/kWh)	-0.369	0.240	0.511	-0.479
	Avg. weekly service hours per car	-0.465	-0.471	-0.286	-0.166
Ridership	Passengers per car hour	0.406	0.475	0.403	-0.210
	Passengers per train hour	-0.506	-0.331	0.678	-0.102
	Avg. passenger trip length	0.062	0.323	0.419	-0.574
System Size	Avg. number of cars / train	-0.148	0.783	0.726	-0.486
	Total train service hours	-0.219	0.208	0.416	-0.210
	Total track mileage	-0.167	0.376	0.512	-0.339
	Total number of railcars	-0.152	0.347	0.453	-0.228
	Max. trains in operation	-0.180	0.253	0.432	-0.197
	Systems similar to MAX (Low floor light rail systems operating 1-3 car trains)[a]				
Labor	Wage Rates	0.945	0.502	-0.515	0.850
	Staff Hours per Car service hour	0.760	0.140	-0.775	0.849
	Staff Hours per Train Service Hour	-0.385	0.150	0.171	-0.245
Operations	Average Speed[b]	-0.405	-0.046	0.473	-0.399
	Percent of Hours Spent on Deadheading	0.491	0.200	-0.185	0.635
	Avg. Car service hours before Mechanical Failure	-0.141	-0.173	-0.422	0.105
	Avg. Train Service Hours before Mechanical Failure	-0.031	-0.166	-0.542	0.237
	Energy Efficiency (mi/kWh)	-0.672	-0.468	0.308	-0.435
	Avg. weekly service hours per car	-0.762	-0.672	0.378	-0.622
Ridership	Passengers per car hour	0.582	0.499	0.042	0.120
	Passengers per train hour	-0.688	-0.628	0.552	-0.343
	Avg. passenger trip length	-0.523	-0.200	0.417	-0.456
System Size	Avg. number of cars / train	-0.525	-0.073	0.651	-0.687
	Total train service hours	-0.305	-0.269	0.142	-0.162
	Total track mileage	-0.320	-0.113	0.311	-0.236
	Total number of railcars	-0.389	-0.108	0.480	-0.371
	Max. trains in operation	-0.178	-0.166	0.136	-0.085

a: List of systems included: LYNX (Charlotte), Houston Metro, Minneapolis Metro, Hudson-Bergen Light Rail, Newark Light Rail, Valley Metro (Phoenix), MAX (Portland), TRAX (Utah), San Diego Trolley, VTA Light Rail (San Jose)
b: Calculation of average speed as reported to the FTA includes layover time (Lumsden, 2023)

2.3.3.3 – Automation

Another possible way to reduce transit operating costs is automation. Of the international systems noted in Table 3, two are fully automated – Vancouver's Skytrain and Copenhagen's Metro. In regards to the Skytrain, just 35% of Translink's rail operating costs between 2017 and 2019 were due to labor (compared to 60%-70% elsewhere). On a per service hour basis, Translink spent USD $151 / hour to run its system from 2017 to 2019, lower than all US transit systems except Chicago (note that these numbers include both Skytrain and the West Coast Express, a peak hour commuter rail service – meaning that the actual performance metrics for Skytrain alone are likely to be better). Per passenger, Skytrain spends USD $1 on operations and maintenance, less than any US urban rail system (Fee, 2023; TransLink, 2014, 2023). It does this while running very high service frequencies (ex: every 3-5 minutes from 5am to 1am on the Expo line, 7 days a week), and superior service reliability (93%-95% of trains within 2min of schedule). Copenhagen's metro runs similarly high service frequencies while turning an operational profit (Aagaard, 2023; Olsen, 2019, 2021). This suggests that automation can result in an approximately 30% reduction in total O&M cost while improving service frequency and reliability.

2.3.4. COVID-19 and Farebox Recovery

All information noted above uses pre COVID-19 data. While the COVID-19 pandemic was a global phenomenon, its associated reduction in transit ridership appears to be a national phenomenon. When comparing 2019 and 2023 ridership on Manchester's Metrolink for the first 4 months of the year, Metrolink has recovered 85% weekday, 87% Saturday, and 94% of Sunday pre pandemic ridership. And Transport for Greater Manchester (TfGM) is raising more fare revenue now than it was pre pandemic as a larger proportion of is passengers are buying single tickets (Sommers, 2023). By contrast, Portland MAX's April 2023 average weekday ridership was 61,680, just 51% of its equivalent number in April 2019 (121,230) (TriMET, 2023j).

Nationally, US transit ridership has recovered to roughly 65% of pre pandemic levels (APTA, 2023; Saunders, 2023). By contrast, ridership in Europe and Asia has recovered fully from the pandemic, and ridership in Latin America has recovered to a greater extent than in North America (Saunders, 2023). Ridership levels in France, Germany, Austria, and Switzerland are all above pre pandemic levels (I. Griffiths, 2023; Luman, 2022), despite EU regulations requiring employers to permit work from home (Hoek, 2021). This issue merits separate study. For the purposes of this report, the issue has been avoided by using pre pandemic data exclusively.

2.4 Capital Cost Data Review

2.4.1. Data Snapshot

Table 5 shows the cheapest / most expensive at grade, elevated, and tunneled transit projects in the global dataset. Only projects in cities which had a Mercer Cost of Living Ranking (Parakatil, 2022) were included below in order to provide a better comparison across metro areas. Despite the factors noted above, capital costs for US rail transit projects are consistently higher than those elsewhere in the world. Unless otherwise noted, all costs below are in 2021 USD. A full dataset of all projects analyzed is in Appendix C.

Table 5: Cheapest and most expensive rail projects per mile, categorized by grade.

Country / State	City / Region	Agency / Line	Project	% At Grade	Cost/Living Ranking	Cost/Mile ($million, 2021)
Most expensive at grade rail projects (at least 80% at grade)						
MA	Boston	MTA	Green Line Extension[1]	86%	30	$ 605.18
Australia	Sydney	Transport for NSW	Sydney Light Rail L2 and L3 Extension[2]	100%	58	$ 323.81
CA	Los Angeles	LA Metro	Expo Line Phase 2[2]	85%	17	$ 248.38
TX	Houston	Metro	Green Line[2]	100%	85	$ 245.94
NJ	New York	NJ Transit	Hudson-Bergen light rail[2]	87%	7	$ 236.94
France	Paris	RATP	Tram 11[2]	100%	35	$ 223.30
TX	Houston	Metro	Red Line Extension[2]	84%	85	$ 196.25
France	Paris	RATP	Line 8 to Pointe-du-Lac[2]	100%	35	$ 173.38
TX	Houston	Metro	Purple Line[2]	100%	85	$ 164.73
CA	Los Angeles	LA Metro	Expo Line Phase 1[2]	96%	17	$ 162.55
Cheapest at grade rail projects (at least 80% at grade)						
S. Korea	Seoul		GTX A[1]	100%	14	$ 45.08
Italy	Rome		Rome Tram Line 8 extension[2]	100%	57	$ 44.38
Italy	Milan	M1	M2 (Famagosta-Assago)[2]	100%	48	$ 42.32
France	Paris	RATP	Tram 2 – Initial[2]	89%	35	$ 36.36
France	Paris	RATP	Tram 1 - Extension to Noisy-le-Sec[2]	100%	35	$ 34.77
Australia	Adelaide		Glenelg Tram[2]	100%	102	$ 34.21
Germany	Berlin	BVG	Adlershof II extension[2]	100%	46	$ 32.59
Germany	Munich	MVG	Tram 16 Extension to St. Emmeram[2]	100%	33	$ 27.42
Germany	Berlin	BVG	Tramway Adlershof-Schöneweide[2]	100%	46	$ 26.83
Germany	Munich	MVG	Tram 25/19 Extension to Berg am Laim[2]	100%	33	$ 23.84
Country / State	**City / Region**	**Agency / Line**	**Project**	**% Elev.**	**Cost/Living Ranking**	**Cost/Mile ($million, 2021)**
Elevated rail projects (at least 50% elevated)						

PA	Pittsburgh	Port Authority	North Shore Connector[2]	57%	82	$ 618.60
HI	Honolulu	HART	Skyline Segment 1[1]	100%	20	$ 616.97
Japan	Tokyo	Tokyo Tama Intercity	Tama Monorail first phase[2]	98%	9	$ 317.56
FL	Miami	Miami-Dade Transit	AirportLink metrorail[2]	100%	32	$ 294.85
WA	Seattle	Sound Transit	Angle Lake Extension[2]	100%	45	$ 257.18
Canada	Vancouver	Translink	Skytrain Evergreen Line[2]	50%	108	$ 218.52
CA	San Francisco	BART	Coliseum-Oakland International Airport Line[2]	83%	19	$ 202.70
Austria	Vienna	Wiener Linien	Line 2 extension[2]	100%	21	$ 202.05
Denmark	Copenhagen	Copenhagen Metro	M1 and M2 Lines (initial segment, manc Ext.)[2]	52%	11	$ 194.77
Canada	Vancouver	TransLink	Millennium Line – Initial[2]	88%	108	$ 152.08
S. Korea	Yongin		EverLine[2]	100%	14	$ 113.51
S. Korea	Uijeongbu		U-Line LRT[2]	100%	14	$ 96.78
S. Korea	Busan		Busan-Gimhae LRT[2]	100%	34	$ 93.57
Country / State	**City / Region**	**Agency / Line**	**Project**	**% Tunnel**	**Cost/Living Ranking**	**Cost/Mile ($million, 2021)**
Most expensive tunneled rail projects (at least 80% tunneled, 50 most expensive cities)						
NY	New York	MTA	East Side Access[1]	100%	7	$7,226.57
NY	New York	MTA	Second Avenue Phase 2[1]	100%	7	$4,300.36
NY	New York	MTA	Second Avenue Phase 1[2]	100%	7	$3,915.85
NY	New York	MTA	7 Extension [2]	100%	7	$3,349.12
NY	New York	Amtrak	Gateway[1]	100%	7	$2,884.06
Singapore	Singapore	SMRT	Circle Line Stage 6[1]	100%	8	$2,204.53
CA	San Francisco	VTA (& BART)	BART to San Jose[1]	83%	19	$1,525.20
CA	Los Angeles	LA Metro	Purple Line Phase 3[1]	100%	17	$1,379.14
United Kingdom	London	TFL	Elizabeth Line (Central and Southeast Sections)[2]	90%	15	$1,318.18
Japan	Tokyo	Yokohama Minatomirai	Minatomirai Line[2]	100%	9	$1,278.06
Cheapest tunneled rail projects (at least 80% tunneled, 50 most expensive cities)						
S. Korea	Seoul		2020s program[1]	100%	14	$ 180.24
Italy	Milan	Milan Metro	M1 (Sesto FS - Monza Bettola)[1]	100%	48	$ 179.98
S. Korea	Seoul		Sillim Light Metro[1]	100%	14	$ 178.48
S. Korea	Seoul	Seoul Subway	Jinjeop Line[1]	100%	14	$ 163.14
Norway	Oslo	Sporveien T-banen	Loren[2]	100%	27	$ 162.71
S. Korea	Seoul		Ui Light Metro[1]	100%	14	$ 149.64
S. Korea	Seoul		Gimpo Goldline[2]	100%	14	$ 149.25
Italy	Milan	Milan Metro	M1 (Molino Dorino-Rho MilanoFiera)[1]	100%	48	$ 135.74
S. Korea	Seoul	Seoul Subway	Line 9 Phase 1[2]	100%	14	$ 118.45
Norway	Oslo	Sporveien T-banen	Ring Line[2]	80%	27	$ 76.97

Footnotes
[1] Data from Transit Cost Project (Goldwyn et al., 2023)
[2] Data from Eno Center (Eno, 2020)

2.4.1.1 – At Grade Projects.

Of the 10 most expensive at grade projects in the database, 7 are American. By contrast, none of the cheapest at grade transit projects are American. If one doesn't account for the Mercer Cost/Living ranking, one US rail project would be in the 10 cheapest projects list – the Blue line in Salt Lake City. However it is safe to assume that the cost of labor & materials in Salt Lake City is significantly lower than in Berlin, Munich, Paris, or Seoul.

2.4.1.2 – Predominantly Elevated Projects.

Not as many transit projects in Appendix C are elevated. Table 5 shows all projects that are at least 50% elevated and in cities that have a Mercer Cost of Living ranking. Once again, the US projects hover at the top of the list. The project in Pittsburgh is only 57% elevated and 43% tunneled, so its high cost can be partially attributed to this. However, the Copenhagen Metro is 48% tunneled with 1/3rd the per mile cost.

2.4.1.3 – Underground Projects.

For these projects, an additional filter was added – only projects in cities that are among the 50 most expensive are noted. This is because most of the top 10 most expensive tunneled rail projects are in very expensive US cities, and therefore an additional filter was added to provide a closer global comparison. Just as above, of the 10 most expensive tunneled transit projects globally, 7 are American. None of the 10 cheapest tunneled rail projects are American, which is still the case if looking at cities that aren't among the world's 50 most expensive. As others have previously noted (Aevaz, 2020) - transit tunnels in New York City (especially those delivered by the MTA) appear to be uniquely expensive. Additional discussion regarding the causes of these uniquely high New York City capital costs have previously been published by the Marron Institute's Transit Cost Project (Goldwyn et al., 2023)

The 7th most expensive project on the list is San Jose's Bay Area Rapid Transit (BART) extension (being delivered by the Valley Transportation Authority (VTA)). One possible contributor to high costs for BART & VTA has been a reluctance to inconvenience neighbors during construction. When evaluating design options for their Downtown San Jose tunnel, VTA chose the most expensive design option as it believed the construction impacts from 3 cut/cover train stations would be too severe (Luczak, 2022; VTA, 2022). And this issue is not unique to BART or VTA (Goldwyn et al., 2023).

2.4.2. Unit Costs & FTA Standard Cost Categories

Unlike in relation to operating costs, where all US transit agencies report detailed metrics to the FTA, capital cost data for transit projects is not as comprehensive. While the TCP and Eno Center have created databases of total cost per mile for rail transit projects, they do not have an associated breakdown of unit costs. Unlike many State Departments of Transportation (DOT)s in the US which publish unit bids online, unit bid libraries for transit agencies and municipal DOTs in the US are usually not made public. On top of this, different agencies quantify bid items differently from each other (preventing an "apples-to-apples" cross agency comparison). In 2005, the FTA implemented "standard cost categories" (SCC) to provide a uniform means of evaluation for projects receiving FTA grant funding. These SCCs are consistent with SCCs that must be followed for FRA grant applications (FRA, 2016). Since 2005, the FTA has developed a database of costs following these SCCs, but this database only includes projects which have received FTA funding. Also, except for a few projects which have undergone "Before & After" studies, most of the cost information in this dataset does not reflect "as built" costs and quantities (FTA, 2023a). And the SCCs themselves reflect a level of detail needed at a preliminary engineering stage rather than for final design or construction (FTA, 2017). While the use of these SCCs can serve as a starting point for the standardization of US transit cost estimates, more needs to be done. Both the Government Accountability Office (GAO) (GAO, 2019) and TCRP (TCRP, 2006) have noted the need to provide a central, accessible source where unit costs can be obtained for project estimates. And the Transit Cost Project noted the need to develop a "culture of transparency" around the issue of cost estimating, which currently does not exist (Goldwyn et al., 2023).

Several other countries around the world have taken steps to develop more comprehensive and publicly available unit cost libraries, including Italy, France, & Turkey (Chitti, 2023; Ensari, 2023; Goldwyn et al., 2023). In Italy, these libraries are developed at a regional level based on projects delivered by all government agencies and private developers in the particular region. A resulting list of maximum unit prices for all bid items is published annually by a commission made up of representatives for contractors, designers, and public/private stakeholders. This list includes expected percentages for each unit price that would be spent on labor, construction materials, and construction equipment (RL, 2023). Before capital projects are put out to bid, engineering estimates are released publicly based on these maximum unit prices and if all bids are above this maximum total engineering estimate the agency is not legally allowed to advance the project (Chitti, 2023). This allows for more rigorous cost control, and also simplifies any possible disputes between contractors and owners when issues arise in construction which necessitate design changes. To control the cost of professional services, a similar standardized set of unit prices have been developed based on each associated design deliverable (Chitti, 2023). This process is facilitated by the fact that construction contracts are usually priced by units, while engineering contracts are priced lump sum (this is the opposite of the US). As seen in Table 5, Italian projects show up repeatedly on the lower end of the cost spectrum. On top of this, some research has been conducted to determine pan European planning level cost estimates for rail projects across the European Union (Gattuso & Restuccia, 2013), which can also aid in cost control.

2.4.3. Limitations of evaluating capital costs per mile

All projects in Table 4 have been ranked based on "per mile" costs. This is how both the Transit Cost Project and Eno Center have evaluated transit capital costs. However, as noted by Christoff Spieler, if one overlays rail transit network maps in many US cities over maps of population density, it often appears that transit lines are actively avoiding major urban population centers. This is because transit planners in those areas intended to build in the "easiest" places (I.e. along existing rail or freeway Right-of-Way (ROW)). While these may have been the most cost effective places to build transit on a "per mile" basis, they are not the most cost effective places to build on a "per passenger" basis (Spieler, 2021). However, due to data availability, this paper uses "per mile" capital costs as its main basis for evaluation.

2.4.4. Design Build Contracting

It has been claimed that Design Build (DB) contracting, where a single team both designs and constructs a particular facility (as opposed to traditional Design Bid Build (DBB), where designers and contractors are parts of separate teams), can result in reduced construction costs. However, evidence for this claim is limited. A study conducted by FHWA determined that DB contracting lead to an average cost reduction of just 2.6% for transportation projects in the United States. A similar study in Arizona determined an average cost reduction of 4%, while a study by the Washington State DOT determined a cost increase of 23% (FHWA, 2006). In part, this lack of cost reduction is because most DB contracts are lump sum contracts, which limits cost transparency (Goldwyn et al., 2023). While each of these studies found reductions in constructing timelines as a result of DB contracting, this does not appear to have resulted in reduced financial cost. Furthermore, some of the most expensive transit projects in Table 5 above were delivered using DB contracting, including the Second Ave Subway phase 1 (Goldwyn et al., 2023) and Honolulu Skyline (PR, 2009).

Another means of project delivery, Design Build Operate (DBO) or Design Build Operate Maintain (DBOM) contracts, have also been touted as a means of reducing project cost. However, some transit lines delivered in this manner have unusually high operating costs. As mentioned in section 2.3.3, NJ Transit Newark and Hudson-Bergen LRT lines have similar rolling stock and are both in northern New Jersey. However, the Hudson-Bergen line, which is operated by a DBOM contractor, costs 44% more per service hour to operate. Likewise, Denver's A, B, G, and N lines, which were delivered using a Design Build Finance Operate Maintain (DBFOM) contract (FHWA, 2016), cost more and 4 times as much to operate per service hour as compared to Denver's other rail lines. While neither operator provides sufficiently detailed data to the FTA to confirm, it appears these DBOM/DBFOM contractors are attempting to inflate their operating costs to compensate for capital expenses.

2.5 Comparison to Other Modes of Transportation Infrastructure

While the IIJA included the federal government's largest ever investment in rail and transit, these funding levels are still lower than funding for other forms of transportation infrastructure (WH, 2023). In the preceding three decades, federal funding for transit & rail amounted to approximately $14 billion / year, our of an average annual transportation spend of approximately $90 billion / year (Musick, 2022). This information is relevant for two reasons, outlined below.

First, the issue of high US capital & operating costs for transportation projects is not restricted to transit. The problem also extends to road construction & operations. While there does not appear to be a comprehensive database which compares per mile capital costs for roadway projects around the world, there is other information which show that per mile capital costs of highways in the US (FHWA, 2019) remain higher than those in the European Union (ECA, 2013). Average cost overruns on North American roadway projects are higher than they are in Europe as well (Cantarelli et al., 2012). And these costs have increased over time. Between 1960 and 1990, per mile capital costs for highways in the United States quadrupled, which is a significantly higher increase in cost than the associated increase in labor and materials cost during this time period (Brooks & Liscow, 2021). Given that the issue of high US transportation capital costs is not restricted to transit, the causes of this problem are likely also not restricted to transit.

Second, another issue of note is the high level of public subsidy for roads in the US. The percentage of US highway operations & maintenance costs that are financed through "user fees" (i.e. tolls, gas taxes, vehicle registration fees, etc.) range between 12% and 69% by state (Bliss, 2017). This is not the case in every advanced economy. In Spain, Germany, France, the UK, or Switzerland, the total money raised through highway user fees exceeds highway expenditure (Jaffe, 2013). In Japan, approximately 100% of expressway funding comes from toll revenue alone (Shimbun, 2021). Because transit and road networks effectively compete with each other for patronage, it should be understood that highway subsidies play a role in reducing farebox recovery for transit. This disproportionate subsidy for highways played a key role in driving many US railroads to bankruptcy in the 1970s (AAR, 2023). However, the discrepancy in farebox recovery between US and global transit systems cannot be fully explained through differences in ridership or fare revenue (see Table 7).

Section 3: Case Study Review

3.1 Research Methodology

The analysis of each transit system, and candidate capital project, noted below was based primarily on expert interviews and field observations. Table 6 has a list of those interviewed along with their titles and interview topics. Field visits were performed in May 2023. Along with this, documents were provided by TfGM, TriMET, and the Greater Manchester Council, Manchester's municipal governing body, through Freedom of Information Act (FOIA) requests (Also noted in Table 6). Some operations data for Metrolink was obtained from the United Kingdom's Office for Rail and Road (ORR, 2023).

Table 6: Expert sources & interviews pertaining to section 3 (case study review)

Name	Tittle or Background	Date	Topic
Anthony Moore	Greater Manchester Council Information, Delivery, and Support Team Lead	Emails, 7/2023	Planning Permission for Metrolink Airport Line
Carole Mason	Health & Safety Manager, Keolis Amey Metrolink	Emails, 7/2023	TfGM Safety Statistics
Daniel Maquire & Kimberly Akimoto	TriMet Legal Services	Emails, 4/2023-6/2023	Freedom of Information Act (FOIA) Request, TriMet Document Needs
John Griffiths	Trimet Rail Operations Planning Manager	7/6/2013	TriMet Operations Practices
Lucas Johnson	TriMet Vehicle Engineering Manager	Emails 7/2023	MAX Rolling Stock
Paige Schlupp	Project Director, MAX Red Line Extension & Reliability Improvement Project	5/1/2023	TriMet Agency Governance, Orange Line project
Peter Sommers	Engineering Manager, Transport for Greater Manchester (TfGM)	4/23-6-23 (multiple)	TfGM Agency Governance and Document Needs
Richard Perry & Paul Dean	Metrolink Finance Manager, TfGM Client Commercial Manager	5/31/2023	Metrolink Operations
Tom Kelly & Richard David	Airport Line Project Mgr., TfGM Commercial Lead	5/30/2023	Metrolink Airport Line

3.2 Portland MAX Light Rail

Metropolitan Area Express (MAX), Portland's Modern Light Rail Transit (LRT) system, is one of the first postwar LRT systems built in the US, initially opening in 1986 (TriMET, 2023f), serving Portland's Metropolitan area. A map of the network, along with other rail services in Portland, is shown on Figure 2. Within Downtown Portland, the system operates at grade predominantly on two corridors. An east/west corridor operates entirely in dedicated lanes, and a North/South corridor operates predominantly in Portland's "Transit Mall," a combination of bus lanes and rail ROW where buses and trains weave across each other and stop on alternating blocks. Outside Downtown, the system runs predominantly along freeway ROW, in highway medians, on disused private railroads, or near live private railroads.

TriMET, the agency which owns MAX, is governed by a board of directors who are all appointed by the Governor of Oregon. TriMET has the power to levy an employer payroll tax to finance operations/construction (TriMET, 2023g). All operations and maintenance staff who run MAX are TriMET employees (J. Griffiths, 2023). Within Downtown Portland, MAX trains operate using line of sight signaling. Outside Downtown, MAX uses a traditional fixed block signal system with Automatic Train Stops (ATS) if operators miss a signal or speed in advance of an interlocking (TriMET, 2023i). While almost all MAX Light Rail Vehicles (LRV)s have low floors, MAX does not provide level boarding at stations, instead opting for a slight step of several inches. Therefore, MAX trains are equipped with automatic wheelchair ramps, the maintenance of which was cited by TriMET staff as contributing to increased maintenance expense (J. Griffiths, 2023). As TriMET does not own traffic signals at roadway intersections, it must coordinate accordingly with the Oregon Department of Transportation and local municipalities (J. Griffiths, 2023).

Pre-COVID, most lines provided 15-minute headways except for the blue line (which ran 6-7 minute service) and the orange line (which provided 10 minute service during peak periods). Pre COVID service frequencies maxed out at 22 trains/hour (approx. every 2 minutes 40 seconds) (J. Griffiths, 2023). While MAX never mixes with General Purpose (GP) traffic, small sections of the network share tracks with the Portland Streetcar, and TriMET buses. MAX acts as both a local and regional rail service in Portland's Metropolitan area. And only about 1/3rd of trips on MAX are made up of commuters (TriMET, 2018b). MAX fares are lower than those in many US transit systems, and all fares are fully transferrable to all other modes of transit in Portland's metropolitan area. MAX is more efficient than the average US transit system across multiple metrics (See Figure 1).

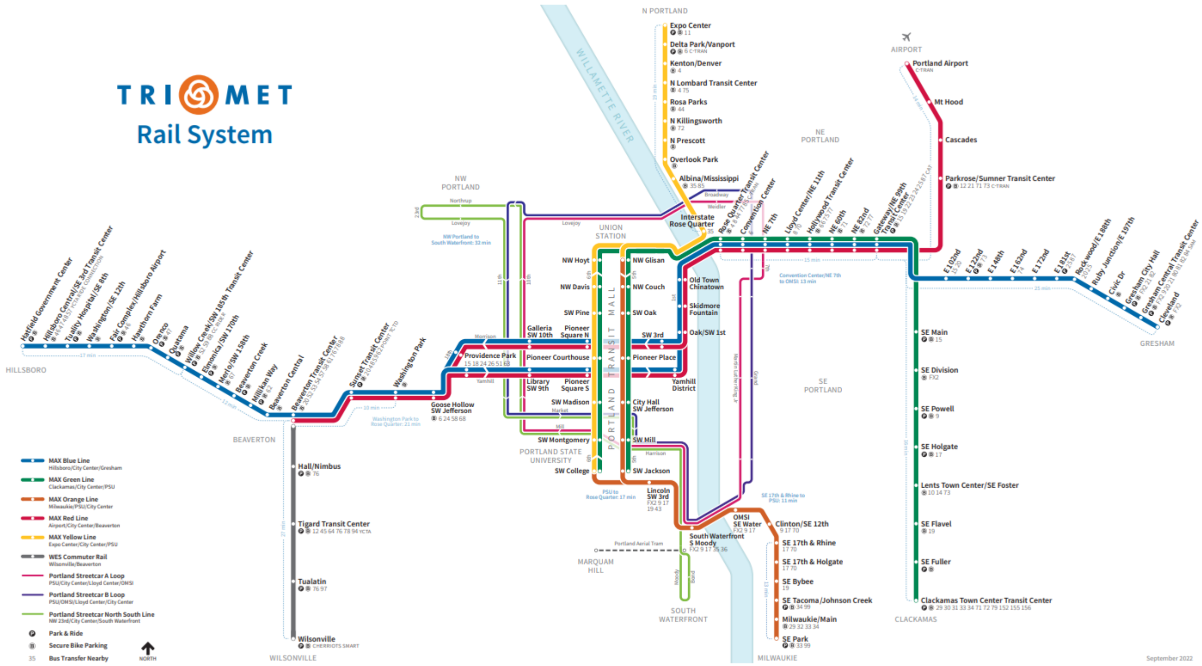


Figure 2: MAX Rail Map (Include Portland Streetcar, WES Commuter Rail) (TriMET, 2023e)

3.2.1. Candidate Capital Project – MAX Orange Line

The orange line, also called the Portland-Milwaukie Light Rail project, is the most recent expansion of MAX. A map of the line is shown in Figure 3. The project was delivered using a General Contractor / Construction Manager (GC/CM) contract and was constructed in 3 segments with 3 separate contractors – the Tillicum River Crossing (a new bridge for transit, pedestrians, and bicycles), along with separate segments west/east of the river (Akimoto, 2023; Schlupp, 2023). The line connects southwest Portland and Milwaukie, OR to Downtown Portland on the 5th/6th Ave transit mall.

A significant portion of the route runs along tracks owned by Union Pacific (UPRR). However, UPRR imposed a 25' clearance requirement forcing TriMET to acquire significant portions of land and build multiple elevated viaducts to avoid geometric constraints. Local jurisdictions also mandated the imposition of quiet zones along the freight Railroad (RR) as a condition for construction of the orange line, which required TriMET to update and refresh all active traffic control devices (I.e. gates & flashers) and make other upgrades to roadway channelization along the entire corridor for both itself and Union Pacific (Schlupp, 2023).

In some cases, TriMET also had to reconfigure and reconstruct UPRR tracks. The project also included a new bike trail in Milwaukie as well as a new river crossing (noted above, the Tillicum Crossing), which facilitated expansion of TriMET's "FX2" BRT line and the Portland Streetcar. TriMET attributes its high relative cost to design difficulties resulting from interagency cooperation, and the resulting need to add additional elements to the project (Schlupp, 2023). During a review of TriMET's costs with TfGM staff, TfGM staff concurred with this assessment (Kelly, 2023). However (as shown in Table 8), per mile costs for the Orange Line remain above those for the Airport Line even after one removed all elevated guideways, signals, or active warning elements. Despite these difficulties, the project opened in 2015, on schedule, and approximately $48million under its original budget (Wanek-Libman, 2015).

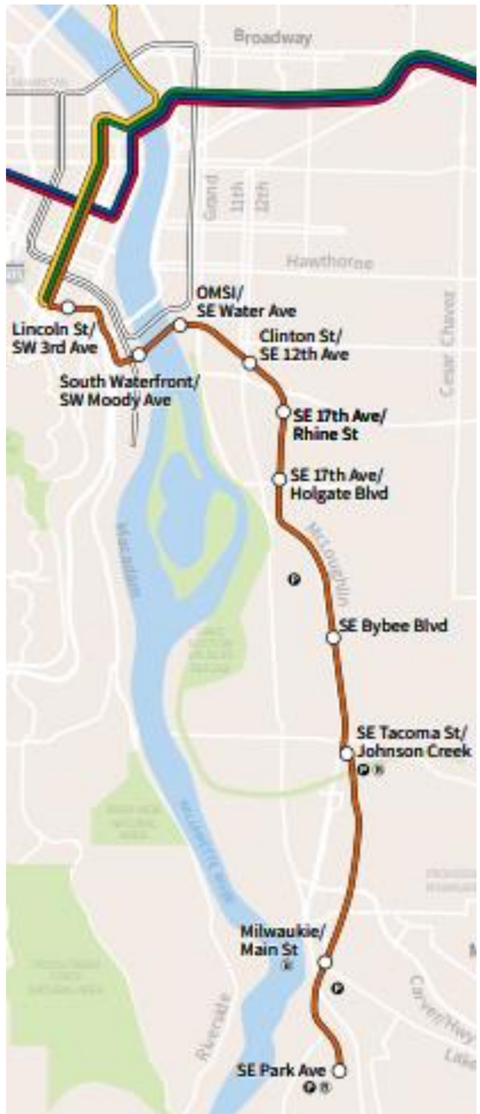


Figure 3: MAX Orange Line project alignment (TriMET, 2023f)

3.3 Manchester Metrolink

Metrolink is a modern LRT system (first opened in 1992) which augments the UK's national rail network within Manchester's metropolitan area (RT, 2018). See Figures 4 and 5 for schematic and geographic maps of the system. Within the city center, the system operates at grade like a streetcar – partly in dedicated lanes, partly through pedestrian plazas, and partly in GP travel lanes. The bulk of the system outside the city center runs on disused sections of the UK's national rail network, while a few of its newer lines run in roadway medians, along existing freeways or in GP lanes outside the City Center as well.

Unlike most light rail systems, Metrolink is universally made up of high floor LRVs with level boarding at all stations, which was done to provide compatibility with the UK's national rail network and to simplify modifications needed to disused national rail trackway (Sommers, 2023). TfGM, the agency which owns the system, reports to the Greater Manchester Combined Authority (GMCA) which in turn reports to Manchester's Mayor. While TfGM owns the system, it has never operated it. It relies on private franchisees for operations and maintenance (Sommers, 2023).

The system operates adjacent to the UK's national rail network (alongside freight & commuter trains) in 3 locations. And in one of those locations, TfGM trains are dispatched/controlled by the UK national rail dispatcher, Network Rail (Kelly, 2023; Perry, 2023). While the initial system used line of sight signaling in the city center and traditional fixed block signaling outside, UK regulators required the entire system to be adjusted to line of sight signaling (except for the segment that's dispatched by Network Rail) to avoid potential confusion (Sommers, 2023).

Currently, the system operates up to 90 second headways in grade separated segments, and 2-minute headways in segments with roadway crossings, although each individual line alone runs 12-minute headways. Like in Portland, most passengers do not use the system for commuting purposes. Fares on the systems have consistently been higher than other UK LRT systems. However, a significant number of concessions are provided to those who are low income, students, children, seniors, or those in job training programs. TfGM staff credit high base fares and simple signaling as key factors in the system's high farebox recovery (Sommers, 2023).

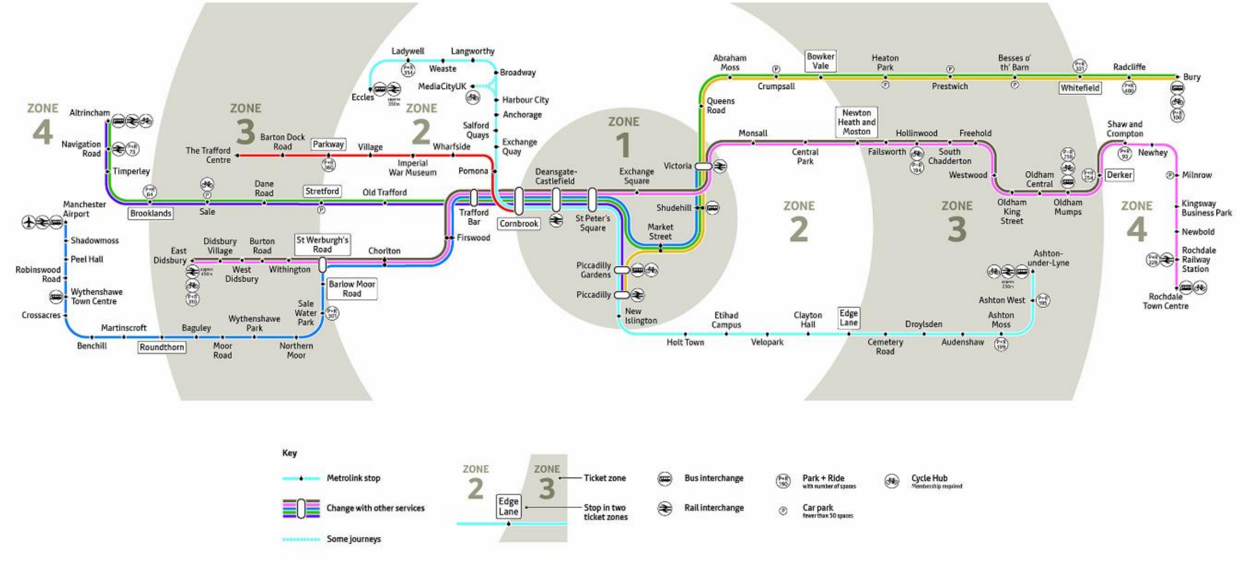


Figure 4: Metrolink schematic map (TfGM, 2023c)

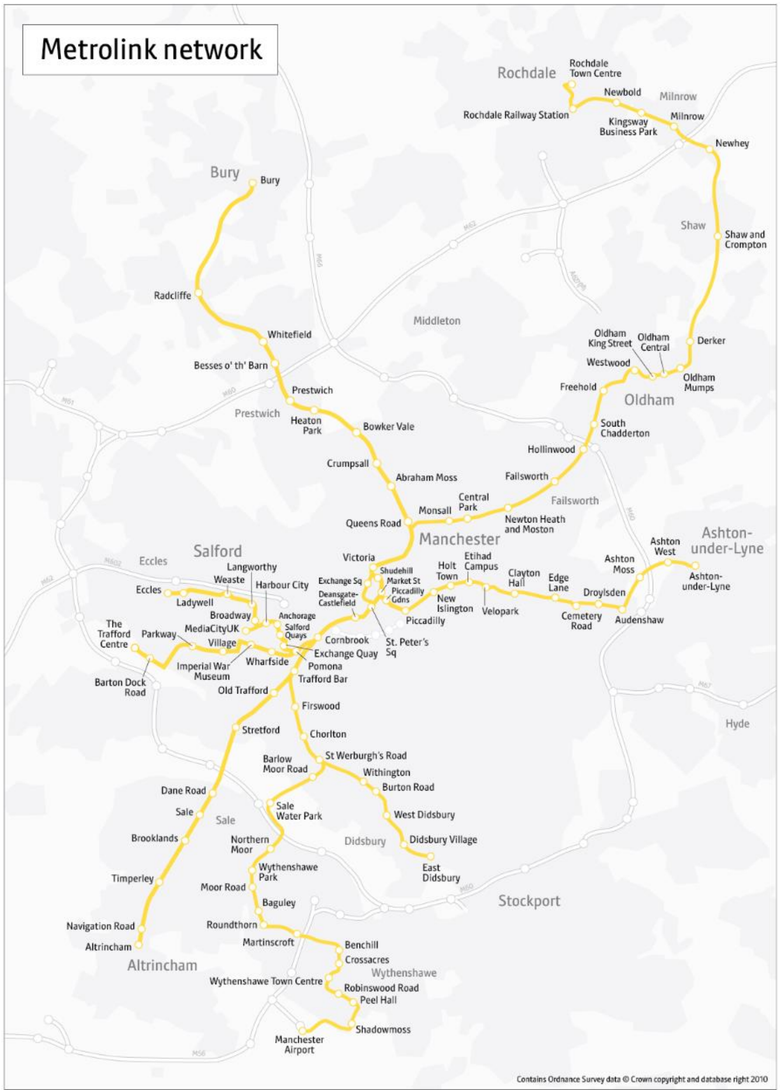


Figure 5: Metrolink geographic map (doesn't included mainline railroads) (TfGM, 2023c)

3.3.1. Candidate Capital Project – Metrolink Airport Line

Metrolink's current network was delivered in 3 phases. The third phase, which included the Airport Line, was delivered entirely by a single DB contractor although the contract was amended at later stages to give TfGM more control over design (Kelly, 2023). Because Manchester Airport already has a connection to the UK's national rail network, the goal of the Airport Line project was not to connect Manchester Airport to Manchester City Center, but rather to connect low-income residential neighborhoods to both (as can be seen in Figure 6). The overwhelming majority of the line was constructed at grade, with a small tunnel near the airport and a few elevated segments above freeways or other geographic constraints.

Despite the use of a DB contract, TfGM was responsible for property acquisition. However, property acquisition needs were limited as TfGM owns Manchester’s major roads network and operates traffic signals in the metro area. The project opened to service in November 2014, over a year ahead of schedule (Pidd, 2014). Project staff credit the project’s low cost and quick turnaround to limited political interference (Pidd, 2014), increased institutional knowledge from earlier system expansions, and cooperative / supportive local municipalities (Kelly, 2023). Beyond this, the UK has no Make in Britain regulatory requirements, nor does it have any DBE requirements (Sommers, 2023).

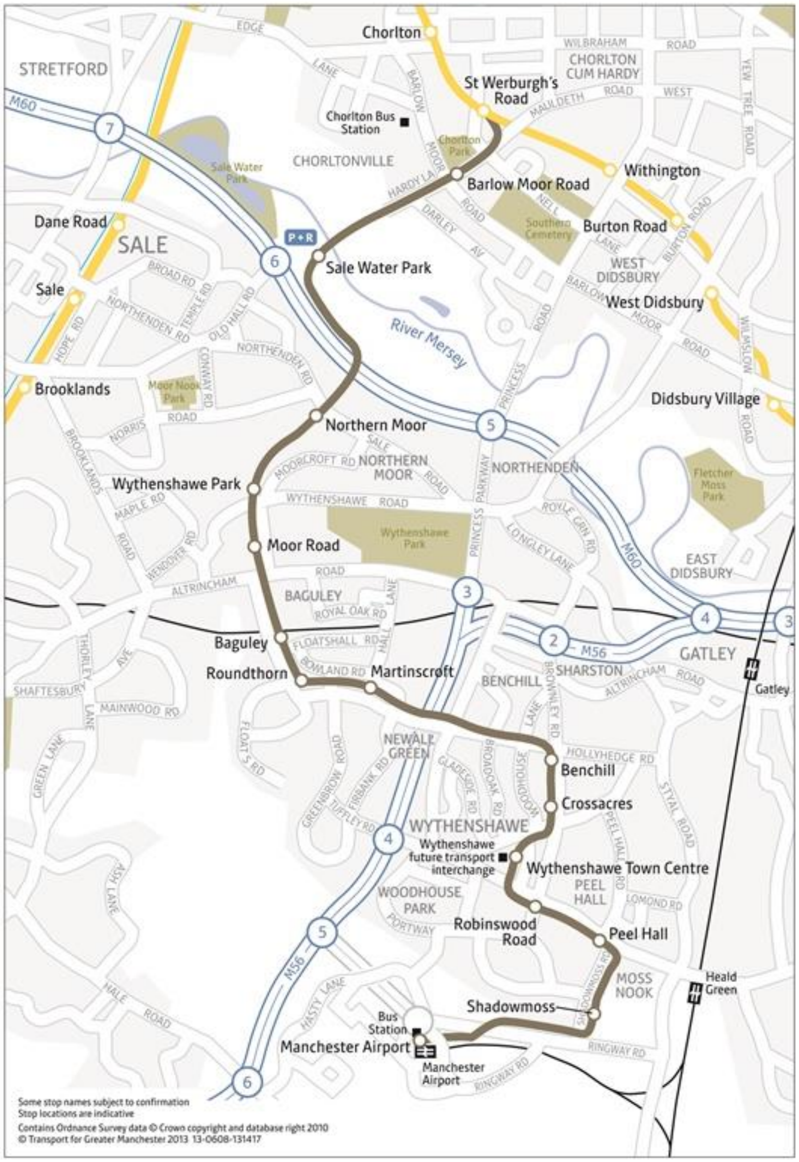


Figure 6: Airport line project alignment, also shows UK national rail connection (RTM, 2014)

3.4 System Comparison

Tables 7 & 8 provide a detailed comparison of system attributes for MAX and Metrolink, as well as for the MAX Orange Line & Metrolink Airport Line projects. As mentioned in section 2, these systems and projects are similar in many ways. Additional discussion pertaining to these attributes and differences is in section 4.

Table 7: MAX and Metrolink system comparison

System Attributes	Portland MAX	Manchester Metrolink
Metro Area Information		
Metro Population	2.51 million, 2021 (Census, 2021)	2.87 million, 2021 (Varbes, 2023)
Core City Population	635,067 (2022) (Census, 2022)	586,100 (2021) (MCC, 2023)
Per Capita Income (2021)	City: $47,289 (Census, 2022) Metro: $44,343 (Census, 2021)	Metro: £36,338 ($55,224) (Varbes, 2023)
Climate	"Cool Temperate Dry" Climate[11] 36" Annual Rainfall	"Cool Temperate Wet" Climate[11] 41" Annual Rainfall
Power Costs	$0.06 - $0.16 / Kilowatt-Hours (kWh)[12]	£0.10 - £0.37 ($0.15 - $0.56) / kWh[12]
Ridership & Fare Structure		
Annual Ridership	38.9 million (2019)[2]	44.3 million (2019)[5]
Weekday Ridership	120,900 (2019)[13]	128,400 (2019)[7]
Total Fare Revenue	$49.5 million (2017)[13] $48.3 million (2018)[13] $45.6 million (2019)[13]	£60.055 million ($81.7 million) (2016)[6] £64.868 million ($83.7 million) (2017)[6] £72.850 million ($99.1 million) (2018)[6] £73.253 million ($93.8 million) (2019)[6]
Advertising Revenue	$3.64 million, 3% surplus over fares (2017-2019 average)[2]	£0.468 million ($0.711 million), 0.72% surplus over fares (2017)[6] £0.474 million ($0.720 million), 0.65% surplus over fares (2017)[8] £0.429 million ($0.652 million), 0.59% surplus over fares (2017)[8]
Fares & Discounts	$2.50 (Flat Fare) • $5.00 (Day Pass) • 50% Discount for seniors, disabled, low income • Employer subsidies • Non profit employee discounts (J. Griffiths, 2023; TriMET, 2023a, 2023b, 2023c)	£1.40 - £4.60 ($2.1-$7.00) (Zone Based) • Free off peak* travel for seniors/disabled • 50% off for youth (under 16) and students • Discount on off peak*, weekend, & family passes • Employer Subsidies * Off Peak defined as any travel after 9:30am, and any weekend travel (Perry, 2023; TfGM, 2020, 2023d)
Fare Revenue / Trip	$1.22 (2017-2019 Avg)[2]	£1.43 (2019), $1.83 [7]
Fare Evasion Rates	14.5% (2016) (Altstadt, 2018) 16.6% (2018) (Altstadt, 2018) 18.2% (2019) (Garcia, 2022)	3.2% (2018)[7] 5.2% (2019)[7] 8.1% (2020)[7]
Primary Purpose of Passenger Trip (2018 Data)	41% - Recreation 26% - Work 9% - Airport Access 5% - Shopping 4% - School 3% - Medical Appointments 3% - Friend/Family Visits 8% - Personal Business 1% - Other (TriMET, 2018b)	50% - Recreation 47% - Commuting 3% - Business (Metrolink, 2020)
System History		
Opening Year – First line	1986 – MAX Blue Eastside (Gresham to City Center) [10]	1992 – Altrincham to City Center[7]

Opening Year – Most recent extension	2014 – MAX Orange Line (Milwaukee to City Center) [10]	2020 – Trafford Park Line[7]
Rolling Stock		
Car Length	95.4' (29 meters)[3]	28.4 meters (93.2')[4]
Max # of Cars/Train	2[9]	2[9]
# of Operators/Train	1[9]	1[9]
# of Cars/Train in Operation	2 (At all times)[9]	1 – 2, dependent on demand [9]
No. of Railcars	145 (2016)[10]	120 (2016-2021)[5] 137 (2022)[5]
Material	Steel Car Body[3]	Aluminum & Steel mixed Car Body[4]
Rolling Stock Weight (by car)	45.8 metric tons (empty)[3] 50.5 US Short Tones (empty)	39.2 metric tons (empty)[4] 43.2 US Short Tones (empty)
Propulsion	750 Volt (V) Direct Curent (DC) Overhead Catenary[3] Single contact water – Downtown[10] Dual-wire catenary – other areas[10]	750V DC Overhead Catenary[4] Single contact wire – everywhere[9]
Signal System	Fixed block signal system with Automatic Train Stops (ATS) (grade separated segments). Line of sight signalling with signal pre-emption (median & street running segments)[10]	Line of sight signalling (almost all locations)[7] ATS style safety system planned[7] Fixed block signalling – 1.3 miles on commuter rail trackway. [7]
Labor & Operations		
Driver Wage	$27/hour (min), $36/hour (max) $56k-$75k/year (TriMET, 2023d)	Approx. £30k Annually (Approx. $46k Annually)[7]
Use of Union vs. Non Union Staff	Unionized operators & maintenance staff – Amalgamated Transit Union (TriMET, 2022b)	Unionized Operations & Maintenance Staff[7] – Unite Union (BBC, 2021)
Operating Agency	TriMet (Publicly Owned)[14] (TriMET, 2023d)	Keolis Amey (Franchisee – 10 year contract starting in 2017) (Ferrovial, 2023; Keolis, 2019) RATP Dev (Franchisee – 2007-2017) (RTM, 2016)
Speed & Service		
Approx Frequency & Service Levels	Post COVID: 15 minutes on each line [1,9] (4 lines across 6 branches) Pre COVID: extra service on Blue (6-7 minute frequency), extra peak service on orange (10 minute frequency). No plans for restoration. [14]	Post COVID: 12 minutes on each line [1,9] (9 lines across 8 branches) Pre COVID: Extra peak service from MediaCity to Ashton, extra early morning service on Airport line. Future plans: Trafford Park line extension through City Center, MediaCity to Etihad peak service restoration. [7]
Approx. Service Hours	4am – midnight [1, 14] Pre COVID: 3:30am – 1:30am [14]	6am – midnight [1, 7] Pre COVID: Friday/Saturday night service until 1am. (2024 plans for restoration)[7]
Max Operational Speed	55mph, or adjacent roadway speed limit[3]	80kph (50mph), or adjacent roadway speed limit, or line of sight restrictions[4,7]
Average Speed (City Center)	7.6mph[1]	6.8mph[1]
Average Speed (Outside City Center)	21.8mph[1]	17.0mph[1]
Average Speed (System-wide)	19.9mph (as measured using schedules and system lengths) [1]	16.6mph, as measured using schedules and line lengths

	14.2mph (as reported to the FTA, including layover)[2]			
Maximum Service Frequency	22 Trains / Hour [14]		40 Trains/Hour (Grade separated) [1,7] 30 Trains/Hour (City Center)[1,7]	
System Bottlenecks	Steel Bridge, Gateway Transit Center		St. Peter's Square, Deansgate - Castlefield	
On Time Performance	84% (7/22) (TriMET, 2023h) 80.6% (12/22) *Measured as under 5 mins late		88.1% (7/22) (TfGM, 2023a) 89.7% (12/22) *Measured as under 2 mins late	
Safety Statistics (2022 Average)	1.78 Collisions per 100,000 Miles[10]		0.77 Collisions per 100,000 Miles[7]	
		Track & Layout		
Track Length	59.7 miles[10]		64 miles[5]	
No. of Stations	97 station[10]		93 stations (2016-2018)[5] 99 stations (2019-2022)[5]	
Track Gauge	4' 8.5" (Standard Gauge)[3]		4' 8.5" (Standard Gauge)[4]	
System Configuration	City Center – Street Running[9] Outside – Grade Separated[9]		City Center – Street Running[9] Outside – Grade Separated[9]	
Branches	6 total[1]		8 total [1]	
Length	Total[1]	%	Total[1]	%
At grade (Total)	50.4 Miles[1] (3.3 Miles in City Center (CC))	85% (6% in CC)	56 Miles[1] (2.3 Miles in City Center)	91% (4% in CC)
At grade: In Road (median or adjacent)	14.8 Miles[1] (1.7 Miles in CC)	25% (44% of CC)	8.1 Miles[1] (0.75 Miles in City Center)	13% (33% of CC)
At grade: Exclusive ROW (incl freeway / railroad ROW)	33.7 Miles[1] 0.2 Miles in CC)	57% (6% of CC)	40.5 Miles[1] (1.1 Miles in City Center)	65% (48% of CC)
At grade: In Road (mixed traffic)	1.8 Miles*[1] (1.4 Miles in CC)	3% (37% of CC)	7.7 Miles**[1] (0.43 Miles in City Center)	12% (19% of CC)
	*MAX mixes with buses only[1,9]		**Metrolink mixes with GP traffic[1,9]	
At grade: Ballast Track	44.0 Miles[1]	74% (87% of at grade total)	32.7 Miles[1]	53% (58% of at grade total)
At grade: Slab / Embedded Track	6.5 Miles[1]	11% (13% of at grade total)	22.8 Miles[1]	37% (41% of at grade total)
Elevated (Total)	5.4 Miles[1]	9%	3.9 Miles[1]	6%
Elevated – Rail Only	4.6 Miles[1]	8%	3.9 Miles[1]	6%
Elevated – Rail + Bus	0.8 Miles[1]	1%	0 Miles[1]	0%
Tunnel	3.4 Miles[1]	6%	1.8 Miles[1]	3%
Single Track Segments	1.4 Miles[1] *	2%	0.89 Miles [1] **	1%
	*double tracking in progress[14]		** 4 terminus segments[1]	
No. of At Grade Crossings	48 at grade crossings with active traffic control devices (I.e. gates & flashers) [10]		2 grade crossings with active traffic control devices (all other crossings treated as traditional intersections with roadway signaling & preemption where applicable)[7,9]	
Platform Length	200' [1]		200' [1]	
		Cost Effectiveness		
Farebox Recovery	32% (2017-2019 average)[2]		101% (2016)[6] 93% (2017)[6] 97% (2018)[6] 93% (2019)[6]	

Cost / Passenger Mile	$0.72 (2017-2019 average)[2]	£0.24 ($0.33) (2016) [5,6] £0.24 ($0.31) (2017) [5,6] £0.26 ($0.33) (2018) [5,6] £0.25 ($0.32) (2019) [5,6]

System Comparison Footnotes

[1] Measured from aerial imagery and Google Maps
[2] FTA National Transit Database (FTA, 2023b; Lumsden, 2023)
[3] Fact Sheet from Siemens (Siemens, 2018), along with other corroborating sources (J. Griffiths, 2023; RT, 2019)
[4] Fact Sheet from Bombardier (Bombardier, 2007), along with other corroborating sources (RT, 2014b; Sommers, 2023)
[5] UK Department of Transportation & Office for National Statistics (UK, 2022)
[6] Transport for Greater Manchester account statements: (TfGM, 2023b)
[7] TfGM – Staff Interviews and Document / Data Provision (Kelly, 2023; Mason, 2023; Perry, 2023; Sommers, 2023)
[8] Unused
[9] Field observations
[10] TriMET fact sheets and system information (TriMET, 2018a, 2023f, 2023h, 2023i)
[11] Based on an analysis of global climates: (Sayre, 2020)
[12] Ranges based on residential, business, and industrial rates noted online for Portland (EL, 2023) and Manchester (BEIS, 2022; BEP, 2023; Isgin, 2022).
[13] TriMET ridership and revenue statistics (TriMET, 2022a)
[14] TriMET staff interviews and document provision (Akimoto, 2023; J. Griffiths, 2023; Johnson, 2023; Schlupp, 2023)

Table 8: MAX Orange Line / Metrolink Trafford Park Line Project Comparison

Project Attributes	**MAX Orange Line**		**Metrolink Airport Extension**	
Project Components				
Opening Date	September 2015[6]		November 2014[5]	
	Total / East Segment	%	Total	%
Total Length	7.3 Miles[6] / 6 Miles[1]	100%	14.5km (9 Miles)[5]	100%
At grade length (Total)	5.4 Mile[1] / 4.9 Miles	73% / 82%	8.3 Miles[1]	93%
At grade – In Roadway (median alignment)	1.2 Miles[1] / 0.9 Miles	15% / 15%	0.4 Miles[1]	4%
At grade – In Roadway (mixed traffic)	0.5 Miles[1] / 0.3 Miles	5% / 5%	2.6 Miles[1]	29%
At grade – Exclusive ROW	3.7 Miles[1] / 3.7 Miles	51% / 62%	5.3 Miles[1]	60%
At grade – Ballast Track	4.6 Miles[1] / 4.6 Miles	63% / 77%	2.1 Miles[1]	24%
At grade – Slab/Embedded Track	0.7 Miles[1] / 0.3 Miles (All embedded)	10% / 5%	6.1 Miles[1] (Mostly slab track)	69%
Elevated (Total)	2 Miles[1] / 1.1 Miles	27% / 19%	0.6 Miles[1]	6%
Elevated – Rail Only	1.1 Miles[1] / 1.1 Miles	15% / 19%	0.6 Miles[1]	6%
Elevated – Rail + Bus	0.9 Miles[1] / 0 Miles	12% / 0%	0 Miles[1]	0%
Tunnel	0 Miles	0%	0.1 Miles[1]	1%
No. of Stations	10[6]		15[5]	
No. of Grade Crossings	11[1] – With Active Traffic Control		21[1] – No Active Traffic Control Devices (Treated as intersections)	
No. of Intersections	12[1]		12[1]	

No. of Railcars Procured	18[3]	10[4]
Other Project Components	2 Park & Rides (719 spaces)[6] "Tillicum Crossing" – LRT, Streetcar, and Bus Bridge (1720' long) Rail yard expansion	1 Park & Ride (300 Spaces)[5]
Design Specifications		
Platform Length	200' [1]	200' [1]
Platform Height	Low Floor Platforms[2]	High Floor Platforms[2]
Average Operating Speed	18.5mph[1]	15.0mph[1]
Proposed Frequency	15 Minutes, 10 minutes peak[1]	12 Minutes[5]
Delivery Method		
Contracting Method	GC/CM (General Contractor / Construction Manager)[3]	"Bespoke" contract – initially Design Build Maintain, subsequently modified into contract resembling Progressive Design Build, with maintenance obligations transferred to a franchise operator in 2017 [4, 8]
Contractor	Stacy/Whitbeck, Kiewit[3]	MPact Thales (Joint Venture of Laing O'Rourke, VolkerRail, Thales)[5]
Project Cost		
Total Cost	$1.44 billion (Total) [3] $1.18 billion (Total, minus financing) [3]	£398 million ($605 million)[4]
Construction Cost (Structures, Civil/Site work, Systems elements)	$596 million (Total) [3] $303 million ("Like for Like" Comparison for full project - After removing elevated guideways, yard expansion, block signals & active warning) [3] $227 million (East Segment Alone) [3]	£130 million ($198 million)[4] 33% of Total Cost
Land Costs	$238 million (total) [3] $190 million (East Segment) [3]	$0 [4, 7]
Vehicle Procurement	**Initial 2012 Order**: $73.8 million + $6.4 million[a] (18 LRVs) [9] $4.1 +.0.4 million[a] per LRV [9] **Subsequent Order in 2019**: $130.2 million + $16.9 million[a] (26 LRVs) [9] $5.0 million + $0.7 million[a] per LRV [9]	£25 million / $38 million** (10 LRVs) [4] £2.5 million / $3.8 million** per LRV
	[a] additional cost for parts, warranties, contingencies	[b] unclear if cost includes parts, warranties, contingencies.
Final Design, PM/CM	$160 million[3]	£68 million ($104 million)[4]
% Cost Breakdown	Construction: 41% Property: 17% Rolling Stock: 6% Design & Project Management / Construction Management (PM/CM) Costs: 11% Other: 25%	Construction: 33% Property: 0% Rolling Stock: 10% Design & PM/CM Costs: 26% Other: 31%
Cost per Mile	**Full Project** Total: $162 million[3] Construction (total): $82 million[3] Construction ("like for like"): $42 mil. Property: $33 million[3]	Total: £44.2 million ($67 million) [4] Construction: £14.4 million ($22 million) [4]

	East Segment Construction: $38 million[3] Property: $32 million[3]	

Capital Project Comparison Footnotes
[1] Measured from aerial imagery and Google Maps
[2] Field Observations
[3] TriMET – Staff interviews and document provision (Akimoto, 2023; J. Griffiths, 2023; Johnson, 2023; Schlupp, 2023)
[4] TfGM – Staff Interviews and Document / Data Provision (Kelly, 2023; Perry, 2023; Sommers, 2023)
[5] Online publications pertaining to Metrolink Airport Line (Barrow, 2014; TfGM, 2012)
[6] TriMET fact sheets on light rail project histories (TriMET, 2023f)
[7] Two partial fee takes from private property owners were completed before the project, and were not included in project costs (Sommers, 2023).
[8] (Ferrovial, 2023; Keolis, 2019)
[9] (Johnson, 2023; Kelsey, 2019; McFarlane, 2012)

3.5 Sources and Assumptions of Cost Comparison

3.5.1. Operating Costs Assumptions

Operating cost data for Portland's MAX system were retrieved from the FTA's national transit database(FTA, 2023b), and matches the assumptions noted in section 2. In regards to Metrolink, all of the functions that the FTA includes when calculating operating costs are performed by a single private franchisee – currently Keolis Amey. This includes vehicle & control center operations, security, vehicle maintenance, facilities maintenance, and other administration expenses. For this reason, farebox recovery was calculated by comparing the total compensation given to Keolis Amey in each year of service against total fares collected by TfGM in the same time period, and then reviewing / confirming associated assumptions with TfGM staff) (TfGM, 2023b; UK, 2022). However, a few differences remain and are listed below.

(a) Keolis Amey occasionally provides taxis to those with disabilities who need to access stations which have been made inaccessible due to construction or out of service elevators. This expense is accounted for separately by the FTA, but Metrolink staff noted that the cost incurred on Keolis Amey for work of this kind is negligible (Shock, 2023).
(b) Keolis Amey turns a profit through their operations contract with TfGM. The size of this profit margin is unknown, but Metrolink's overall cost/passenger mile is still below that of TriMet's MAX system (Perry, 2023).
(c) While TfGM pays Keolis Amey to provide some security, the transit operator occasionally works with Manchester Police to deter "anti social" behavior on Metrolink. TfGM does not compensate Manchester Police for this work (Sommers, 2023).

To determine total costs per passenger mile for Metrolink, statistics regarding total passenger miles traveled were obtained from the UK's office for national statistics (UK, 2022).

3.5.2. Capital Costs Sources & Cost Breakdown

Capital costs for the MAX Orange Line were based on several data sources. These include the preliminary engineering estimate developed by TriMet for its Full Funding Grant Agreement with the FTA (FTA, 2011), which provided an overview of all project costs. Of the three project segments of the Orange Line, the east segment is more similar in design specifications to Manchester's Airport Line. More detailed information for this segment was obtained from contractor invoices (Stanton, 2012), and TriMET's final ROW acquisition report (TriMET, 2017b). TriMET staff confirmed that their contractor directly performed UPRR track reconfiguration and signal work as well, meaning the contractor invoices covered all construction work relating to the TriMET East Segment (Schlupp, 2023) As some of these cost estimates were prepared before project completion, there were some inconsistencies between them (for example, property acquisition costs increased between the time of the grant application and project completion. However, the total project cost for this $1.49 billion project only changed by $48 million, (approx. 3.2%) between grant application and completion (Wanek-Libman, 2015).

For Metrolink, total capital expenditure was determined based on reports from multiple online publications (Cox, 2014; Pidd, 2014; RTM, 2014). Due to the use of a single DBM contract for multiple Metrolink contracts and TfGM staff turnover, TfGM staff were unable to confirm this number (Kelly, 2023), but were able to provide more detailed information pertaining to construction and property acquisition costs. A "basis of cost" invoice was provided by the DBM contractor (MPT, 2010) which covered construction costs. Property acquisition and rolling stock costs were provided by TfGM separately (Sommers, 2023).

3.5.3. Currency & Present Value Conversion

Currency conversions between USD ($) and GBP (£) is based on data from the Wall Street Journal (WSJ, 2023). In most cases, a conversion rate of £1 = $1.52 was used based on average values between March 1st, 2006 and May 2nd, 2023. In circumstances where conversion can be specified to a specific year (for example, average operating costs), average conversions for the year in question were used instead. (£1 = $1.36 for 2016, £1 = $1.29 for 2017, £1 = $1.36 for 2018, £1 = $1.28 for 2019). Because the Max Orange Line opened just 10 months after Metrolink's airport extension, no present value adjustments were made to address inflation.

Section 4: Hypotheses & Evaluation

Based on the literature review and data review, a list of hypotheses was developed pertaining to the issue of high US transit costs. Each of these hypotheses were evaluated against the two case studies above. For those which seemed to be true according to the case study analysis, an attempt was made to find corroborating information (in data, prior study, or examples elsewhere) which reinforce the conclusion. A full table evaluating these hypotheses is in Appendix A, and an abridged version is in Table 9. Where applicable, additional information explaining and evaluating each hypothesis is below Table 9.

Table 9: Hypothesis list & evaluation table (full table in Appendix A)

#	Cost Discrepancy Hypotheses	Hypothesis Source	Case Study Based Evaluation	Evaluation (Corroboration from Other Sources)
1	Privatization - Franchised/Tendered Operation	Section 2.2.7	True	Yes
2	Privatization - Open Competition	Section 2.2.7	Not Applicable	
3	Privatization - Traditional	Section 2.2.7	False	
4	Privatization - Overuse of private design consultants	Section 2.2	False	
5	Rolling Stock - Crash Readiness Requirements on Mixed Passenger / Freight Rail	Section 2.2.6	True	Yes
6	Rolling Stock - Material & Weight	Section 2.2.6	True	Yes
7	Rolling Stock - Floor Height (High floor trains have lower centers of gravity)	(Stangas, 2023; Taylor, 2023)	True	No
8	Rolling Stock – Passenger door control for temperature control	(Stangas, 2023; Taylor, 2023)	True	Yes
9	Rolling Stock - Incremental Procurement vs. Bulk Procurement	Personal Observation	No Difference	
10	Rolling Stock - Timeline for Vehicle Replacement	(Taylor, 2023)	True	Yes
11	Rolling Stock - Multiple units vs. Locomotives vs. Train Sets	(Stangas, 2023; Taylor, 2023)	No Difference	
12	Rolling Stock - Standardization	Section 2.2.5	True	Unclear
13	Rolling Stock - Diesel vs. Electric Traction	(Gattuso, 2013; Stangas, 2023)	No Difference	
14	Rolling Stock - Adjusting Train Lengths for Demand	(Uher, 1984).	True	Yes
15	Rolling Stock - Door design	(Coxon et al., 2010)	No Difference	
16	Construction Methods - Standardized, Publicly Available Unit Costs	Section 2.4.2	Inconclusive	Yes
17	Construction Methods - Publishing Engineers Estimates Before Bid	Section 2.4.2	No Difference	Yes
18	Construction Methods - Precast vs. cast in place elevated span & station construction	(Hallmark et al., 2012)	Not Applicable	
19	Construction Methods - Cut & Cover vs. Tunnel Boring	(Goldwyn et al., 2023)	Not Applicable	
20	Construction Methods - Maintenance of Traffic During Construction	(Goldwyn, 2023)(Chitti, 2023)	Inconclusive	
21	Construction Methods - Noise mitigation location	(FRA, 2022)	Not Applicable	
22	Construction Methods - Use of DB Delivery Method (Instead of DBB)	Section 2.4.4	Inconclusive	No
23	Construction Methods - Use of GC/CM Delivery Method (Instead of DBB)	Section 2.4.4	False	Unclear

24	Construction Methods - Over transference of risk to contractors	Goldwyn et al., 2023; Chitti, 2023; Sommers, 2023	Inconclusive	
25	Construction Methods - Competition During Bidding Process	Personal Observation	Inconclusive	
26	Economies of Scale - Building Large numbers of projects in succession	(Goldwyn et al., 2023)	True	Unclear
27	Fare Payment - Fare Evasion Rates	Section 3.4	True	Yes
28	Fare Payment - Use of Fare Gates / Turnstyles	Section 2.2.1	No Difference	
29	Fare Payment - System Procurement	Section 2.2.1	Inconclusive	
30	Fare Payment - Flat vs. Distance/Time based Fares	Field Observation	True	Yes
31	Fare Payment - Fare Integration (CR, LRT, Metro, Bus, etc.)	Section 2.2.1	False	
32	Daily Operations - End of Line vs. Overnight Cleaning	(Stangas, 2023)	True	Yes
33	Daily Operations - Unnecessary Speed Restrictions	(Finnegan, 2018; PR, 2019; Taylor, 2023; Duke, 2022)	True	Yes
34	Daily Operations - Delayed passenger boarding	Personal Observation	Not Applicable	
35	Railroad Signaling complexity	(Stangas, 2023)	True	Unclear
36	Agency balkanization - Sharing resources & land across agencies	(Chitti, 2023; Goldwyn, 2020; Goldwyn et al., 2023).	True	Yes
37	Agency Balkanization - Unclear/overlapping jurisdictional authority	(Goldwyn et al., 2023; TVO, 2023).	True	Yes
38	Agency Balkanization - Catering projects to grants between agencies	Personal Observation	Inconclusive	No
39	Agency Balkanization - Regional limits in transit service	Personal Observation	No Difference	
40	Route Planning - Regularity of network redesigns	(Spieler, 2018)	Not Applicable	
41	Route Planning - Trunk-Branch vs. Trunk-Feeder route network	(TCRP, 2013)	No Difference	
42	Route Planning - Peak vs. All Day Service Pattern	Section 2.2.4	No Difference	
43	Route Planning - Short Turning, Catering Service Frequency to Demand	Tirachini, 2011	Inconclusive	
44	Route Planning - Brand Complexity & Overlap	Personal Observation	Not Applicable	
45	Overdesign - clearance requirements for track / shoulders on roadway	Personal Observation	True	Yes
46	Overdesign - overhead catenary design requirements	Field Observation	True	Unclear
47	Overdesign - oversized stations	(Goldwyn et al., 2023)	True	Yes
48	Overdesign - Unclear or overlapping design guidance	Section 2.2.5	True	Yes
49	Civil / Structural Design - Asphalt vs. Concrete Paving	Field Observation	True	No
50	Civil / Structural Design - Tunneling vs. Elevated Guideway	Personal Observation	Not Applicable	
51	Civil / Structural Design - Fencing & Trespassing Protection	Field Observation, (Stangas, 2023)	Inconclusive	Unclear
52	Civil / Structural Design - Ballast Track vs. Slab Track	Field Observation	True	Yes
53	Civil / Structural Design - Standardization of stations	(Goldwyn et al., 2023)	No Difference	
54	Metric units in design & operations calculations	Personal Observation	True	Unclear
55	Planning - Appropriate guidance regarding the purpose of each mode	Section 2.2.5	Not Applicable	
56	Planning - Environmental Documentation Requirements	Section 2.2.8	True	Yes
57	Planning - Yard / Depot Location	Field Observation	True	No

58	Planning - Segregation of Modes by Street	Field Observation	No Difference	
59	Additional Revenue Streams - Advertising	Section 2.2.2	False	
60	Additional Revenue Streams - Property development & sale/rent	Section 2.2.2	Inconclusive	
61	Additional Revenue Streams - Retail revenue	Section 2.2.2	Inconclusive	
62	Labor/Union Rules - Division of Labor	(Goldwyn et al., 2023)	Inconclusive	
63	Labor/Union Rules - Health Insurance Incorporation into Labor Cost	Personal Observation	True	Unclear
64	Labor/Union Rules - Number of Staff on Construction Projects (Craft & Management)	(Goldwyn et al., 2023)	Inconclusive	
65	Labor/Union Rules - Single vs. Double Staff Rail Operations	Field Observation	No Difference	
66	Labor/Union Rules - Unionization of Staff	(Stangas, 2023)	No Difference	
67	Labor/Union Rules - Number of staff required for operations	(Stangas, 2023)	Inconclusive	Yes
68	Governance - Ringfenced O&M Funding, Autonomy in Maintenance Scheduling	Section 2.2.3	True	Unclear
69	Governance - Political vs. apolitical agency governance	(Goldwyn et al., 2023)	No Difference	
70	Governance - Training requirements for transit operations/design, availability of training resources	Personal Observation	Inconclusive	
71	Governance - Common Law Legal Systems	Personal Observation	No Difference	Yes
72	Governance - Buy America Restrictions	(Goldwyn et al., 2023)	True	Yes
73	Governance - Disadvantages Business Enterprise Requirements	(Goldwyn et al., 2023)	True	Unclear
74	Governance - Freight rail coordination	(Goldwyn et al., 2023)	Inconclusive	Unclear

#1 Privatization – Franchised Operations

Hypothesis – Under this business model, physical infrastructure remains in public ownership, route planning is handled by a public authority, and fares are set & collected centrally. However, the public authority does not directly operate transit service. Instead, it allows private companies to bid for operations contracts for set periods of time (usually 8-10 years). The goal is to bring an element of competition and efficiency into transit operations without creating monopolies or fully privatizing public assets (see section 2.2.7).

Case Study Evaluation – While the MAX system is directly operated and maintained by employees at TriMet, TfGM does not directly operate Metrolink. Instead, Metrolink is operated & maintained by a private franchisee. Between 2007 and 2017, this company was RATP Dev. Since 2017, the contract has been held by Keolis Amey (see Table 7). When TfGM switched operators, no unionized operations or maintenance staff lost their jobs as only management was replaced (Sommers, 2023). TfGM is now in the process of incorporating Manchester's bus network (which currently entirely privately operated and deregulated) into the same franchise based system (Perry, 2023; Sommers, 2023). Apart from operating at reduced cost, these franchise operators appear to have achieved higher capacities with equivalent infrastructure.

Corroboration – This business model has become increasingly common for urban transit systems throughout Europe and Asia and has been found to reduce operating costs and increase customer satisfaction (see section 2.2.7). Prior economic analysis of this issue found that franchising reduced transit operating costs even after controlling for possible changes in labor rates (Sarriera et al., 2018). Within the US, the Phoenix light rail system operates under this model. Per Figure 1, Phoenix ranks 3rd, 6th, and 3rd in cost per passenger mile, cost per car service hour, and cost per train service hour among urban US transit systems. It has the 18th highest farebox recovery rate, but this can be attributed in part to Phoenix's low population density. As shown in Table 4, a moderate correlation exists between a transit agency's "service hours per railcar" and operating costs, and Phoenix has the second highest number of service hours per railcar among urban rail systems. This suggests that Phoenix's franchise operator can deliver more service with fewer assets than the average US transit system. Among the international transit systems noted in Table 3, the Copenhagen Metro (Aagaard, 2023), London's bus network (Kennedy, 1996, 2007), Dockland's Light Railway (Ferrovial, 2023) and London Elizabeth Line (MTREL, 2023) all operate under this business model as well.

#3 Privatization – Traditional

Hypothesis – It has been argued that transit systems should be privatized entirely, so private companies directly operate transit, own all associated facilities, and set fares according to the market. This model can theoretically improve efficiency (1) because private companies can operate more efficiently than the government and (2) because privatizing all elements of a transit system can lead to efficiencies associated with vertical integration (section 2.2.7).

Case Study Evaluation – While neither MAX nor Metrolink have ever been fully privatized, Manchester's bus network has historically been fully privatized and deregulated. While TfGM subsidizes some bus operators to run routes in less profitable neighborhoods, each transit operator sets their own fares and runs their own service. This has generally been viewed as a failed model for transit service, and TfGM is currently in the process of transitioning to a franchised transit operations model for its buses, similar to hypothesis #1. The fully privatized model was viewed as unsuccessful because (1) it lead to significant confusion for passengers (as each bus operator charged their own fares, set their own routes, and published their own maps, and (2) because transit operators had a tendency to over saturate a small number of high ridership routes (like between the University of Manchester and the City Center) while providing minimal service in less profitable residential neighborhoods (Perry, 2023; Sommers, 2023).

#5 Rolling Stock – Crash Requirements for Passenger/Freight Rail

Hypothesis – Because the US national rail network is primarily used for freight mobility, unique historic regulatory restrictions exist for passenger trains, as well as for light rail vehicles operating on adjacent corridors, which necessitate higher rolling stock buff strength and/or greater clearances than required internationally (see section 2.2.6).

Case Study Evaluation – MAX runs along existing freight railroads in multiple areas, including I-84 and along the Orange Line. In both places, MAX trains maintain 25' minimum clearances from mainline rail. Along the Orange line, this led to increased need for ROW acquisition. Along I-84, no clearance is provided between MAX's trackway and I-84. By contrast, Metrolink operates alongside mainline rail traffic (freight & passenger) in 3 segments without any additional clearance requirements. In one segment near Altrincham, Metrolink light rail vehicles are dispatched and controlled by the same dispatcher responsible for freight rail traffic (Shock, 2023).

Corroboration – As noted in item #74, the US rail network's uniquely high freight mode share has historically necessitated unique regulatory requirements (see hypothesis 74). However, some FRA regulations regarding mixed passenger & freight rail traffic were recently lifted (see section 2.2.6). Also, as noted in section 1, fatality rates on US railroads are higher than fatality rates in countries without such regulations. Also, per aerial imagery in Washington DC, Chicago, and Boston, transit vehicles operate within 25' of mainline railroads already in the US as well.

#6 Rolling Stock – Material and Weight

Hypothesis – Lighter trains require less energy to operate and produce less wear on railroad tracks, and US railcars appear to be heavier than their international counterparts (see section 2.2.6).

Case Study Evaluation – MAX and Metrolink rolling stock are almost identical in size (See Figure 2 and Table 7), MAX railcars (which use steel car bodies) are 6.6 metric tons (7.3 US short tons) heavier than their Metrolink counterparts (which use a combination of steel and aluminum) (see Table 7, section 3.4). TriMET staff referenced federal and industry crash readiness requirements (49 CFR part 238, and ASME-RT1) as the reason for using steel rolling stock rather than aluminum (J. Griffiths, 2023; Johnson, 2023). However, these regulations were intended for US class 1 railroads (which operate passengers and freight trains), not transit (see Hypothesis 48). Also, these regulations were modified in 2018 to allow for the use of structural aluminum and Crash Energy Management (CEM) protocols in lieu of traditional buff strength requirements (APTA, 2022; FR, 2018; Taylor, 2023) (see section 2.2.6), and other US transit agencies have been using aluminum rolling stock for decades (see Figure 7).

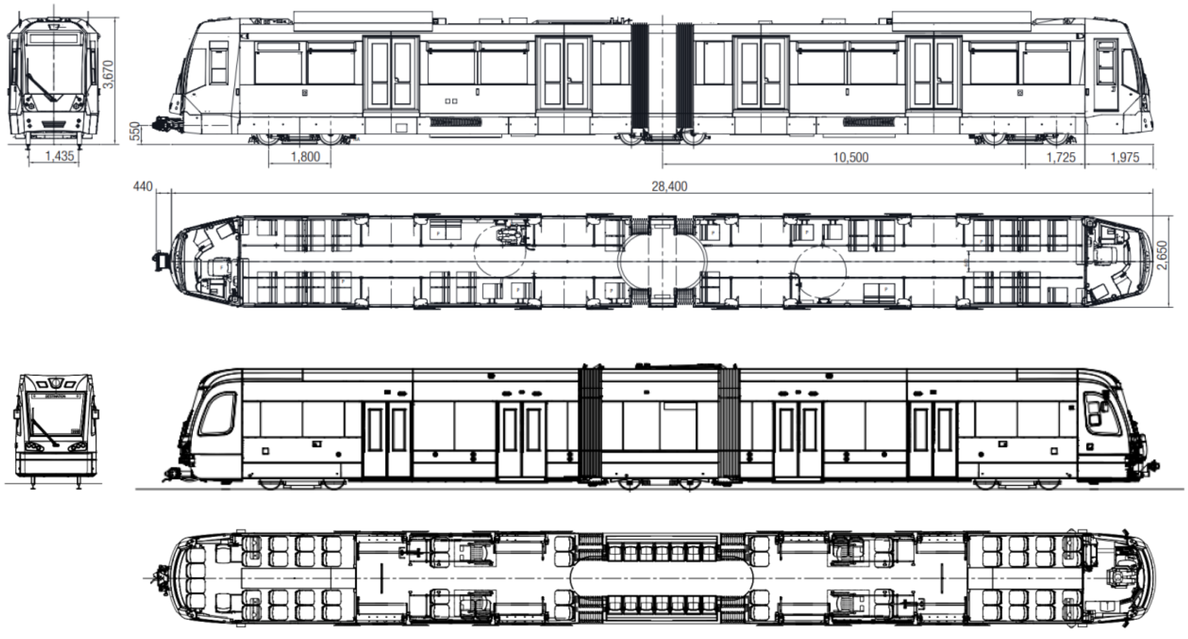


Figure 7: Plan / Profile / Section view of rolling stock for Metrolink (top) and MAX (bottom). Source: (Bombardier, 2007; Siemens, 2018)

Corroboration – Two US transit systems, BART and MARTA, have been using rolling stock using aluminum carshells since their founding (Jordan, 2019; MARTA, 2022; RT, 2014a). BART estimates their railcars to be 7.5 – 10 tons lighter than they would have been with steel carshells (BART, 2023). Per Table 4, a moderate correlation exists between energy efficiency (measured in miles/kwh) and operating cost. BART and MARTA are the most energy efficient urban transit systems in the country (per Appendix B) (FTA, 2023b). In Washington DC, WMATA has decided to procure rolling stock with aluminum carshells for new orders (Olmo, 2023; WMATA, 2023). In the SF Bay Area, Caltrain has procured aluminum railcars to reduce energy consumption and noise pollution (Sneider, 2018). Amtrak's new Acela high speed trains, which will run at speeds up to 160mph and share tracks with freight rail, will also use aluminum car bodies to cut energy consumption by 20% (Lazo, 2022). When the rolling stock manufacturer Stadler suggested NJ transit purchase aluminum railcars, NJ transit rejected the suggestion due to concerns about corrosion from seawater (Taylor, 2023). However, Amtrak's Acela trains will operate on many of the same coastal rail lines, and BART/Caltrain both operate in coastal environments. TriMet staff claimed that aluminum is only an acceptable material for heavy rail systems (like the ones noted above), but not for light rail (Johnson, 2023). However, the Flexity Swift used in Manchester (which combined steel and aluminum carbody, as noted above) also operates in Mealbourne, Istanbul, Rotterdam, and several cities in Germany (RT, 2014b). TriMet staff also referenced two steel carshell LRVs (Alstom's Citadis, and Siemens' Avenio) widely used abroad as additional basis for the use of steel on MAX (Johnson, 2023). However, Siemens Avenio LRVs of equivalent size to MAX LRVs are actually 11 metrics tons lighter than MAX rolling stock (Siemens, 2020), suggesting that there are additional factors beyond carshell material that are contributing to unusually heavy US rolling stock.

#8 Rolling Stock – Passenger door control for temperature control

Hypothesis – Many transit systems outside the United States require passengers to press a button if they want their door to open at a station. This is intended to reduce wear on doors (Stangas, 2023), and reduce Heating, Ventilation, and Air Conditioning (HVAC) needs (Taylor, 2023). They can also improve dwell times at less used stations if passengers are familiar with the functionality (Taylor, 2023).

Case Study Evaluation – Metrolink requires passengers to press a button to open train doors at stations. Doors close automatically after a set period, although the driver can also override the system to close the doors whenever desired (Sommers, 2023). MAX does not have this functionality. However, MAX rolling stock has associated functionality, and uses it to deploy wheelchair ramps for those who need Americans with Disabilities Act (ADA) access (fieldnotes, 2023).

Corroboration – TEXRail, a service operated by Trinity Metro between Fort Worth, TX and DFW airport, has elected to introduce passenger door control for the reasons described above (Taylor, 2023). The London Underground, which (uniquely in the UK) did not use passenger door control historically due to ventilation concerns has elected to reintroduce this functionality on new trains for the same reason (Nicholas, 2020).

#10 Rolling Stock – Timeline for vehicle replacement

Hypothesis – As rolling stock gets older, its maintenance costs increase. If a transit agency holds on to old rolling stock for too long a time, its associated O&M costs will increase (Taylor, 2023).

Case Study Evaluation – The first fleet of light rail vehicles procured by TriMET, which began operations when the first MAX line opened in 1986, are still in operation. TriMET released a Request for Proposals (RFP) in 2019 for their replacement, partly due to high maintenance costs, although they are still in operation as of 2023 (J. Griffiths, 2023; Johnson, 2023). By contrast, the Metrolink line opened in 1992, but the first vehicles used at the time have already been retired due to high maintenance cost. And Metrolink is able to procure additional vehicles of the same model under a prior procurement contract as needed, which helped Metrolink staff address technical issues with interoperability between new / old rolling stock by simply retiring old railcars early and procuring additional new vehicles from Bombardier (Shock, 2023).

Corroboration –A 2010 report by the Government Accountability Office noted several regulations which make the procurement process for new rolling stock expensive and cumbersome on transit agencies, which in turn inhibits agencies from proactively replacing old rolling stock. These include Buy America provisions (hypothesis 72), and a 5-year limit on transit agencies ordering additional railcars under an existing contract, which would not allow MAX to adopt the kind of scalable procurement contract used be Metrolink (GAO, 2010)

#12 Rolling Stock - Standardization

Hypothesis – Standardization of rolling stock simplifies maintenance and reduces cost.

Case Study Evaluation – TriMET operates 5 separate models of rolling stock, although 4 of them come from the same manufacturer, Siemens (J. Griffiths, 2023; TriMET, 2023i). Metrolink operates a uniform Bombardier fleet and has an agreement with Bombardier allowing TfGM to procure additional vehicles of the same model under a prior procurement contract as needed (Shock, 2023).

Corroboration – A 2010 report by the Government Accountability Office (GAO) cited the lack of standardization of rolling stock in the United States between transit agencies as a contributor to high procurement and maintenance costs. However, the GAO did not determine if lack of standardization for rolling stock within a particular transit system does/doesn't lead to cost escalation (GAO, 2010).

#14 Rolling Stock – Adjustment of train lengths based on demand

Hypothesis – Adjusting the number of cars in each train based on demand can help reduce operation costs by reducing unnecessary excess capacity.

Case Study Evaluation – MAX runs 2 car trains at all times, and MAX's Type 5 LRVs do not have driver cabs on one side, meaning they must always operate as couplets. However, TriMET has planned to reintroduce drivers cabs on both sides of each vehicle in future orders. (J. Griffiths, 2023). Metrolink runs both 1 and 2 car trains based on demand (fieldnotes, 2023), and provides higher service frequencies with fewer total rolling stock (see Table 7).

Corroboration – A study of the Washington Metro based on 1980 schedules found that adjusting the number of cars on metro trains between peak and off peak periods lead to an energy cost reduction that was 11 times greater than the associated increase in labor cost needed to modify trains during the day (Uher et al., 1984). Beyond this, FTA data shows that while 60%-70% of the O&M costs for the transit systems in Figure 1 are labor costs, only about 40% of those labor costs are associated with vehicle operations, which includes drivers, security, cleaning staff, and fare inspectors. By contrast, approximately 47% of those costs are associated with vehicle or facility maintenance (FTA, 2023b). Operating fewer railcars when demand is low would reduce cost associated with vehicle and facility maintenance, as well as cleaning and possibly security and fare inspection (see section 2.3.3). Separate from labor costs, shorter trains lead to lower energy consumption, and Table 4 shows moderate correlation between energy efficiency (measured in miles per kWh) and operational efficiency.

#16 Construction Methods – Standardized, publicly available unit costs

Hypothesis – The availability of comprehensive data on unit prices across agencies and owners can aid in cost control, and help facilitate negotiations relating to change orders in construction (See section 2.4.2) (Goldwyn et al., 2023).

Case Study Evaluation – Neither TriMET nor TfGM have unit bid libraries of their own, nor can they reference comprehensive unit bid libraries developed by others which cover their project elements pertaining to their facilities (Akimoto, 2023; Kelly, 2023). However, TfGM is currently in the process of developing a unit bid library of its own (Kelly, 2023). Also, because the Airport Line was developed by the same DB firm which delivered multiple previous Metrolink projects under the same contract, it can be assumed that data from previous projects was available to the team at the time of the airport line's construction. The case study analysis for this hypothesis is therefore inconclusive.

Corroboration – As shown in section 2.4.2, Italy, France, and Turkey require the publication of public unit bid libraries on a regional basis and deliver transit projects using unit price contracts based on these values. Italian and French projects show up among the cheapest tunneled and at grade projects listed in Table 2. In Italy, capital costs for transit projects spikes between the 1970s and 1990s, but began to decrease again after the passage of reforms to the Italian Public Works Code in 1994, which included the creation of publicly available unit bid libraries (Goldwyn et al., 2023).

#26 Economies of Scale – Building large numbers of projects in succession

Hypothesis – Agencies which engage in continuous construction of capital projects over time can build institutional knowledge, and therefore become more efficient in delivering successive projects (Goldwyn, 2023; TVO, 2023).

Case Study Evaluation – MAX's Orange line was delivered as a standalone project, and its previous system extension opened 5 years earlier (TriMET, 2023f). By contrast, Metrolink's Airport Line was delivered along with multiple other projects under a single contract, using a single DBM contractor and cleared through a single environmental and planning process (Kelly, 2023; Sommers, 2023). Metrolink staff credit this as a key reason for reduced capital costs (Sommers, 2023).

#27 Fare Payment – Fare evasion rates

Hypothesis – High rates of fare evasion can lead to lost fare revenue and, therefore, lower rates of farebox recovery. Higher fare revenue also allows transit agencies to pay for infrastructure maintenance in a more proactive manner, reducing long term operations and maintenance costs (Perry, 2023; Sommers, 2023).

Case Study Evaluation – Fare evasion rates in Portland were 16.6% and 18.2% in 2018 and 2019 respectively. In Manchester, comparable rates of fare evasion were 3.2% and 5.2% during the same years (see Table 7). TfGM staff noted that transit agencies do not measure fare evasion rates in a consistent manner (Perry, 2023), which may explain a portion of the discrepancy in fare evasion. However, reported fare evasion rates in Portland are 3 to 5 times as high as Manchester, implying that this discrepancy cannot exclusively be explained through measurement methods.

Corroboration – Studies from San Francisco found fare evasion rates of 9.5% in 2009 and 7.9% in 2014. San Francisco Muni characterizes these as acceptably lower fare evasion rates (Bialick, 2017), but they are higher than fare evasion rates for Metrolink . In New York City, fare evasion was estimated to be 13.5% on subways and 37% on buses in 2022, leading to estimated revenue loss of $285 million on subways and $315 million on buses (MTA, 2023b). Beyond this, an analysis from Imperial College London found fare evasion to be a more prevalent issue in North America as compared to Europe and Asia, and blamed this on a lack of political support in North America for fare enforcement when compared to European or Asian transit agencies (Saunders, 2023).

#30 Fare Payment – Flat vs. distance/time based fares

Hypothesis – Peak transit and suburban transit is often more expensive to provide than all day or urban service (Per section 2.2.4 and (Cervero, 1981)). Due to this difference in operating cost, different fare structures can lead to different fare revenue, partly by encouraging or discouraging ridership.

Case Study Evaluation – While MAX utilizes flat fares regardless of distance, Metrolink charges fares based on a zone system which are also differentiated by time of day. Per Table 7, Metrolink raises approximately 60%-100% more annual revenue from fares as compared to Portland, which can allow for more proactive system maintenance (see Hypothesis 68).

Corroboration – Prior analysis from multiple California transit agencies found that distance based fares can raise more revenue for equivalent ridership as compared to flat fares (Cervero, 1981). An analyses from Los Angeles and Salt Lake City also found that off peak / short distance riders tend to have lower incomes, meaning a fare structure based on distance and time was deemed to be more equitable when evaluated on a revenue neutral basis (Farber et al., 2014; Linton, 2017).

#32 Daily Operations – End of line vs. overnight cleaning

Hypothesis – Cleaning trains exclusively overnight can lead to increased heating costs for rolling stock in the yard and increased labor costs due night shift wage increases (Stangas, 2023).

Case Study Evaluation – Metrolink staff clean trains both during operator layover times (litter picking) and overnight (Sommers, 2023). TriMET staff clean trains overnight exclusively (J. Griffiths, 2023). Climates for each city are similar (see Table 7).

Corroboration – NJ Transit staff have noted that energy costs associated with heating trains overnight for cleaning needs can at times exceed energy costs associated with revenue service during the day time (Stangas, 2023). A similar operational change was made in Toronto, partly intended to reduce track fires, tripping hazards, and other possible reliability problems (CTV, 2012).

#33 Daily Operations – Unnecessary Speed Restrictions

Hypothesis – As noted in section 2.3.3, increased speeds can reduce operations costs. Unnecessary restrictions in speed could therefore exacerbate transit costs. In New York City, previous managers noted that many temporary speed restrictions had been imposed without associated engineering analysis or justification (Finnegan, 2018), and a "speed and safety" task force was created to evaluate their necessity (PR, 2019). Similar claims have been made in regards to Boston (Taylor, 2023) and Seattle (Duke, 2022).

Case Study Evaluation – Per Table 7, MAX trains operate approximately 3mph faster than Metrolink on average if measured using aerial imagery, and approximately 2mph slower than Metrolink if using FTA data. However, this is despite significant differences in track alignment and signal operations which should allow for higher MAX operating speeds. While 91% of Metrolink runs at grade and 12% mixes with GP traffic, 85% of MAX runs at grade and only 3% mixes with other traffic. On top of this, only 2 grade crossings on Metrolink utilize active warning while 48 MAX grade crossings do so. And while Metrolink uses universal line of sight signaling and universal single wire OCS, MAX utilizes traditional fixed block signaling and dual wire OCS outside its city center. MAX rolling stock is also capable of operating at a higher top speed (55mph) as compared to Metrolink (50mph). In each of these cases, MAX utilizes a more expensive design intended to allow for faster operating speeds. While a more in-depth study would be required to know for sure, this suggests MAX could safely operate more quickly than it currently does. And previous MAX leadership has recognized this issue (WW, 2019). One example of a design change which could improve MAX speed is highlighted in Figures 8 and 9 below. While MAX has active warning (i.e. gates and flashers) in more locations, these gates often do not protect pedestrians, forcing slower MAX speed limits.

Figure 8: Metrolink crossing at Navigation Rd. Active warning extends over sidewalks and overlaps with fencing. Speed limit for Metrolink is 50mph (fieldnotes, 2023).

Figure 9: MAX at SE Harrison St. Grade crossing has quad gates, but no pedestrian control on near side (and only passive control, in the form of manually opened gates, on the far side). Speed limit for MAX is 30mph (Photo from Google Streetview).

Corroboration – As of 2020, the MTA's speed and safety task force increased subway speed limits in 279 locations after associated engineering review determined the previous speed limits were unnecessarily slow (MTA, 2021).

#35 Railroad signaling complexity.

Hypothesis – Simplified railroad signaling can lead to reduced maintenance and procurement costs (Sommers, 2023).

Case Study Evaluation – While MAX uses a line of sight signal system in in its city center, it uses a traditional fixed block signal systems with automatic train stops and signal interconnection outside its city center (J. Griffiths, 2023; TriMET, 2023i). Metrolink uses a near universal line of sight signal system in which the only signals are at railroad switches or roadway intersections and operations dispatchers notify train drivers if the train in front of them has stopped at an unusual location. Despite its associated speed implications, TfGM staff cited this as factor which contributes to Metrolink's comparatively low operating cost (Shock, 2023; Sommers, 2023).

#36 Agency Balkanization – Sharing resources and land across agencies

Hypothesis – Public agencies in the US have a tendency not to allow other agencies to use their land or other resources, or have a tendency to charge other public authorities for use of public facilities. This is less common abroad (Chitti, 2023; Goldwyn, 2020; Goldwyn et al., 2023).

Case Study Evaluation – The bulk of the Airport Line project was constructed on existing roadway ROW, or on disused mainline rail ROW. TfGM did not have to compensate any other public authority for the use of this line – either for permanent use or for temporary construction easements. By contrast, MAX's Orange Line project spent $238 million on property acquisition, $190 million of that cost on the east segment. This included $5.3 million to the city of Portland, $575,711 to the Oregon Department of Transportation (ODOT), $256,504 to the Oregon Division of State Lands (DSL), $19 million to UPRR, $172,612 to the Portland Development Commission, & $966,885 to the Oregon Board of Higher Education. The funding provided to DSL was purely in exchange for easements granting TriMET the right to build its own bridge over the Willamette River (TriMET, 2017b). Along with paying each agency above, TriMET had to develop associated ROW Plans, and engage in ROW negotiations with each agency at public expense.

Corroboration – The most expensive tunneled transit project in Table 4 is East Side Access, which brought LIRR trains into Grand Central Station in NYC. Initial designs for this project by consultants envisioned bringing LIRR trains into the existing terminal. However, the transit operator which owns those tracks, Metro North, did not want to share assets with LIRR. This forced the construction of an entirely new terminal due to "institutional problems, not transit needs" (Gelinas, 2015; Goldwyn, 2023). A similar issue has impacted expansion plans in New York City's Penn Station. An analysis by the MTA compared two capacity expansion options for the station, one involving through-running services at the station (costing $3 billion) and another not doing so (costing $13 billion). The $13 billion option was subsequently chosen in order to avoid coordination between Penn Station's three transit operator – the MTA, NJ Transit, and Amtrak (Hicks, 2023b; RTN, 2023).

#37 Agency Balkanization – Unclear / overlapping jurisdictional authority

Hypothesis – Unclear jurisdictional authority between transit agencies and other government agencies can be confusion in project delivery, and a refusal between agencies to cooperate when building or operating transit facilities can increase associated costs. It is important to avoid situations where state agencies have "authority without responsibility" (Goldwyn et al., 2023; TVO, 2023).

Case Study Evaluation – TriMET does not have permitting authority, and therefore has to obtain permits from local jurisdictions for capital projects (Schlupp, 2023). In exchange for permits, local jurisdictions required quiet zones along UPRR the Union Pacific Railroad (UPRR)'s freight tracks and level crossings, which required TriMET to update and refresh all active traffic control devices (I.e. gates & flashers) and make other upgrades to roadway channelization along the entire corridor for both itself and Union Pacific (Schlupp, 2023). TriMET also does not own signals at roadway intersections, and therefore needs to coordinate with local authorities regarding signal timing and maintenance (J. Griffiths, 2023). By contrast, TfGM owns Metrolink as well as Manchester's major roads network and traffic signals, and its authority to perform construction work along the alignment of the Airport Line comes directly from the UK government and not from local municipalities (UK, 1997).

Corroboration – An analysis of the Second Ave Subway Phase 1 project in New York City estimated that the agency spent between $250 million and $300 million satisfying demands from local authorities in exchange for permit approval (Goldwyn et al., 2023). By contrast, a recently completed grade separate transit project in Montreal called the Reseau Express Metropolitan (REM) was completed at a cost of $124 USD/mile, comparatively low for North American transit projects. The Quebec government credits this reduced cost to (a) a law giving the project greater authority over land expropriation, and (b) a decision to have the line be owned and operated as a private company owned by the Provincial pension fund to reduce the extent to which government agencies can micromanage design (MacDonald, 2023). Beyond this, an Italian law stipulates that any construction permit application which is not responded to within a set timeframe is automatically approved (Chitti, 2023), and as can be seen in Table 5, Italian projects are among the cheapest at grade and tunneled projects analyzed.

#45 Overdesign – Clearance requirements for track / shoulders on roadway

Hypothesis – Unnecessarily high clearance requirements, either from mainline tracks or highway shoulders, can increase construction and property acquisition costs for transit projects.

Case Study Evaluation & Corroboration – See hypothesis 5

#47 Overdesign – Oversized stations

Hypothesis – Transit agencies can oversize transit stations beyond what's necessary, increase construction and land acquisition costs (Goldwyn et al., 2023).

Case Study Evaluation – At Metrolink's Altrincham terminus (where Metrolink uses fixed block signals, just like MAX), Metrolink operates 6 minutes headways from a 2-track terminus and through a 0.4 mile single track segment. By contrast, the MAX orange line is designed for 10-minute headways using a 3-track terminus and no single tracking. Meaning Metrolink is able to operate higher service frequency and more reliable service (see Table 7), using lower capacity stations.

Corroboration – On the Second Avenue Subway's Phase 1 in NYC, station boxes extended between 60% and 114% beyond the length of platforms. By contrast in French, Swedish, and Italian subway projects, those stations boxes extended just 5% beyond platforms on average. The Second Ave Subway phase 1 is the 3rd most expensive tunneled project in Table 5 (Goldwyn et al., 2023).

#48 Overdesign – Unclear or overlapping design guidance

Hypothesis – Lack of clarity or standardization in facility design can increase capital and operations costs for facilities (Section 2.2.5).

Case Study Evaluation – Metrolink facilities are designed in accordance with the UK's national design standards for light rail transit (ORR, 2006). By contrast, TriMET develops its own facility design standards exclusively for its own facilities (Schlupp, 2023; TriMET, 2017a). While these facility design standards are partly based on national design guidance developed by AREMA, this national design guidance is primarily meant for freight rail as opposed to passenger rail or transit (TriMET, 2017a).

Corroboration – A significant number of the cheapest at grade and tunneled transit projects noted in Table 5 were built in EU countries or in South Korea. In the EU, the European Committee for Standardization seeks to develop common engineering standards across multiple standards, including rail and transit (CEN, 2022; Chitti, 2023). In South Korea, engineering standards are developed by the central government through the Ministry of Land, Infrastructure, and Transportation (Molit) (Eno, 2022b). In both cases, developing and/or harmonizing design standards at the national level can reduce ambiguity or inconsistencies in engineering design.

#49 Civil / Structural Design – Asphalt vs. Concrete Paving

Hypothesis – The use of asphalt vs. concrete pavement around embedded track could have an associated cost implication.

Case Study Evaluation – Metrolink's embedded trackways in mixed traffic environments use both asphalt and concrete pavement. MAX embedded track is built purely with concrete (fieldnotes, 2023).

Corroboration – Multiple life cycle cost benefit analyses suggest that concrete is cheaper than asphalt when used for paving. These included studies conducted by the American Society of Civil Engineers (ASCE) (Rehan et al., 2018), the Minnesota Department of Transportation (Embacher & Snyder, 2001), the city of Red Deer, Alberta (Czarnecki, 2017), and Amity University in India (Kumari et al., 2022).

#52 Civil / Structural Design – Ballast track vs. slab track

Hypothesis – While ballast track can be constructed at lower capital costs than slab track, associated operations and maintenance expenses for ballast track can be greater (J. Griffiths, 2023; Kollo et al., 2015)

Case Study Evaluation – While a much larger proportion of the Airport Line was built using slab track than the Orange line, both of these projects were constructed too recently to evaluate lifecycle cost (Per Table 8). Looking at the systems overall, 87% of MAX's at grade network is made up of ballast track while only 58% of Metrolink's at grade network is. The remaining 13% and 41% of MAX and Metrolink respectively is predominantly made up of slab track. This means Metrolink utilizes slab track to a much greater degree than MAX (per Table 7).

Corroboration – Prior study of lifecycle costs for both ballast and slab track have found that ballast track is cheaper once combining capital costs with long term maintenance and replacement (Kollo et al., 2015).

#56 Planning – Environmental documentation requirements

Hypothesis – The process of developing environmental documentation and receiving associated permission to build new transit can delay transit construction schedules, increase project scope, and increase project cost (see Section 2.2.8).

Case Study Evaluation – Both the US and UK have an Environmental Assessment process. The UK equivalent of an EIS is called an Environmental Impact Assessment (EIA) (UK, 2020). TfGM published an EIA for the project in 1994, as part of a package of documentation for phase 3 of Metrolink's expansion (GMPTE, 1994; Sommers, 2023). According to the GAO, federal agencies do not track the cost of developing NEPA documentation (GAO, 2014). TriMET budgeted approximately $52 million for preliminary engineering as well as permits & review (Akimoto, 2023; TriMET, 2016). Some of this likely involved the development of an EIS, but this value includes other efforts as well. And because Metrolink delivered the Airport Line EIA as part of a package of projects, an equivalent value could not be obtained from TfGM. When comparing overall design & PM/CM costs, MAX Orange line expenses were approximately 54% greater than Metrolink Airport Line expenses, although these figures also include costs other than those associated with EIS/EIA document development.

However, an alternative approach was used to compare the level of effort involved in environmental documentation for both projects. Cost estimates for engineering documentation and design are often quantified by estimating the size of the resulting documentation, and assuming an associated number of hours per sheet or word. Given the relative similarity in scope of the Airport Line and Orange Line projects, the relative level of effort of developing associated EIA/EIS documentation can be obtained by comparing the size of associated EIA/EIS documentation. While the Airport Line's EIA summary report was 4,552 words and 19 pages long (GMPTE, 1994), the Orange Line's EIS summary documentation was 72,682 words and 579 pages long (TriMET, 2016), approximately 15 and 30 times the size when measured by word or page respectively. During discussion with TfGM staff, it was noted that some issues which are documented in an EIS in the US may be documented through the UK's planning permission process. For this reason, the Transport and Works Act Order (TWAO) for the airport line was also obtained (Moore, 2023), along with the FTA record of decision for the Orange Line (Akimoto, 2023; TriMET, 2016). When comparing the length of both of these documents together – the TWAO and EIA for the Airport Line, and the EIS & Record of Decision for the Orange line, it was found that documentation for the Orange Line was 9.1 and 3.3 times larger when measured by page and by word respectively. It appears that TriMET had to analyze environmental impacts to a much greater degree than Metrolink, and to a greater expense, to obtain approval for a similar project.

Corroboration – In 2003, the city of London in the UK introduced a congestion charge system whereby drivers pay a fee to enter the city center, and associated revenue is directed towards investments into transit service (Livingstone, 2007). New York City is in the process of implementing a similar congestion pricing system modeled off London's example. Environmental permitting requirements for these two projects diverge significantly despite their similarity in scope. In London, it was determined that that no EIA would need to be developed for the congestion charge program as associated impacts on environmental pollution, noise, or traffic would be too small to merit analysis (GLA, 2002; Howard, 2023). By contrast, when the New York State Legislature authorized the congestion pricing program in 2019, the Federal Government refused to decide if the project qualifies for an EIS, EA, or Categorical Exclusion due to its political opposition. Once the federal administration changed, it was determined that congestion pricing in NYC will require an EA. Work for the EA began in August 2021 and did not complete until June 2023, 22 months later (Colon, 2023; FHWA, 2023; MTA, 2023a). The Final EA that was published by New York's MTA for the congestion pricing plan is approximately 183,400 words and 958 pages long without appendices (MTA, 2023a). And additional lawsuits have been filed claiming this process has not been extensive enough (Dolmetsch & Kaske, 2023; Strahan, 2023).

Lack of clarity regarding which projects trigger an EIS at all have lead to extensive legal disputes. One such example of this is the Prospect Park West bike lane in New York City, where disputes over whether the city had adequately analyzed the environmental impacts of a one mile bike lane on the west side of Prospect Park lead to 6 years of legal action (Cheah, 2016; Mixson, 2016). By contrast, UK law states that EIA documentation is only required for roadways which will be wider than 4 lanes for 10 or more kilometers in length (UK, 2017a, 2017b, 2020). In Turkey, transit authorities can obtain waivers to avoid the development of an Environmental Impact Assessment, recognizing that mass transit projects are a net environmental positive once factoring in reductions in single occupancy vehicle traffic. The associated documentation required to apply for such a waiver is known to take approximately one month, and the associated approval is known to take approximately two months. When reviewing two recent environmental approval documents for Istanbul's recent M5 and M7 metro lines in the same means described above, they were 84 and 67 pages respectively (considerably smaller than associated documents for MAX, but not Metrolink) (Ensari, 2023). On average, such a process in the US could reduce project schedules by 4.5 years (Goldwyn et al., 2023). Both the Canadian Province of Ontario and the Australian Federal Government have introduced new streamlined environmental review processes for transit, recognizing its net environmental benefits (Lewis, 2022). In South Korea (which has delivered many of the lower cost transit projects in Table 5), a formal environmental review process is required for transit but prior study has found significantly lower levels of pushback to new transit based on environmental review (Eno, 2022b).

#57 Planning – Yard / depot Location

Hypothesis – A centrally located rail depot could allow for more efficient transit operations by minimizing the need for deadheading, especially at the beginning and end of a shift.

Case Study Evaluation – MAX and Metrolink both have 2 operations and maintenance depots. Both of MAX's depots are located in Gresham and Hillsboro, two suburbs located at each end of the Blue line (TriMET, 2023i). By contrast, both of Metrolink's depots are located more centrally – one is adjacent to Victoria station (within the municipal limits of the city of Manchester), and the other adjacent to the Old Trafford Cricket ground.

Corroboration – Of the low floor light rail systems which operate 1-3 car trains shown in Figure 1, all systems with lower costs/service hour (Charlotte LYNX, Minneapolis Metro, Phoenix Valley Metro, Utah TRAX, and San Diego Trolley) have more centrally located light rail depots than MAX (per analysis of aerial imagery). However, all of these systems logged a proportionately higher number of deadheading hours than MAX. This suggests that depot location has limited impact on deadheading. Also, per Table 3, the correlation between hours spent on deadheading and operations costs appears limited.

#68 Governance - Ringfenced O&M Funding, Autonomy in Maintenance Scheduling

Hypothesis – Per section 2.3.3, political micromanagement of infrastructure maintenance, or an associated unwillingness to fund maintenance, and increase operations and maintenance costs over time.

Case Study Evaluation – While TriMET staff did not believe their maintenance activities had been micromanaged by elected officials, they did express concerns regarding a lack of appropriate funding associated with system maintenance (J. Griffiths, 2023). In particular, TriMET staff noted that, pre-pandemic, deferred maintenance issues had begun to develop on parts of TriMET's trackway, particularly in sharp curves where track had worn out. During the pandemic, TriMET scheduled a series of system shut downs to address this concern, but staff are unsure if these shut downs have contributed to TriMET's slow post-pandemic ridership recovery (J. Griffiths, 2023). Also, as noted in hypothesis 10, TriMET still operates the rolling stock that began operation in 1986 when the system first opened due to lack of funds for replacement. These trains break down more often than their modern counterparts, and are more expensive to maintain. Funding to proactively replace these railcars earlier would have saved TriMET on maintenance expenditure. Like TriMET, Metrolink staff also did not believe their maintenance activities had been politically micromanaged. But in regards to maintenance funding, Metrolink staff believe their high fare revenue has allowed the agency to handle maintenance concerns proactively, as TfGM is able to raise this revenue without requesting appropriation from any legislative authority (Sommers, 2023). Per Table 7, Metrolink raises approximately 60%-100% more annual fare revenue per year than MAX.

Corroboration – Previous legislation has been passed in both London and New York to ring fence transit maintenance spending in an effort to provide stability in maintenance funding. In London, this has largely been viewed as a success (Byford, 2023). However, London also raises significant fare revenue which can be used to finance maintenance (see Table 3). In New York, ring fence legislation was passed in 2019, meaning it's too early to tell what impact this may have on long term O&M costs for the MTA (Albany, 2019; Rosenthal, 2017).

#72 Governance – Buy America restrictions

Hypothesis – The imposition of Buy America restrictions, which require that certain products and materials procured by transit agencies be built in the United States, can increase procurement and operating costs by restricting the number of available suppliers for transit agencies to source from (Goldwyn et al., 2023).

Case Study Evaluation – TriMET, like all US transit agencies, is subject to Buy America restrictions. These requirements have impeded TriMET's ability to replace malfunctioning or outdated electronic hardware on trains (J. Griffiths, 2023), and limited availability of vendors for new rolling stock. The last two times

TriMET procured rolling stock for MAX, the agency received proposals from just 3 firms in 2012 (CAF, Siemens, and Stadler), and 2 firms in 2019 (CAF and Siemens) (Johnson, 2023; Kelsey, 2019; McFarlane, 2012). By contrast, UK transit agencies have no corresponding “make in Britain” regulatory requirements. Metrolink received 4 proposals for its rolling stock, but that was viewed as an unusually low number of vendors by UK standards, and was attributed to Metrolink’s use of high floor vehicles. On other UK light rail projects, agencies are used to receiving proposals from 6 or 7 vendors for rolling stock (Sommers, 2023). Buy America has also likely impacted TriMET’s LRV procurement costs. Metrolink spends approximately $3.8 million per LRV to procure new rolling stock per its scalable order with Bombardier (Shock, 2023; Sommers, 2023). While TriMET initially budgeted $5 million per railcar for the Orange Line (Akimoto, 2023; TriMET, 2016), its associated 2012 order paid Siemens $4.1 million per railcar (McFarlane, 2012), which is just 8% higher than Metrolink. However, between 2012 and 2019, LRV procurement costs for MAX went from $4.1 million to $5 million, an 18% cost escalation in 7 years. During this time, multiple steps were taken to expand Buy America regulations, including new tariffs on foreign steel and aluminum (Gertz, 2020; Horsley, 2018; Tausche, 2018), which likely contributed to this escalation in cost.

Corroboration – According to the Government Accountability Office, only about 5% of the worldwide transit rail car fleet is in the United States, compared to 11% in Japan and 35% in Europe. And demand for new US railcars tends to fluctuate significantly between years. These factors make it difficult for rolling stock manufacturers to comply with Buy America requirements in a cost-effective manner. Often, manufacturers build temporary US manufacturing facilities to comply, which can impede US transit agencies from procuring replacement parts for rolling stock after the manufacturer has decommissioned their temporary manufacturing facility (GAO, 2010). Beyond this, a cost comparison of materials between the US and Italy from 2020-2021 found that steel prices in the US are approximately 40% higher than prices in Italy (Goldwyn et al., 2023), which can likely be attributed in part to US Steel tariffs.

#74 Governance – Freight Rail Coordination

Hypothesis – While interagency coordination has often been cited as a cause for escalating infrastructure costs (see hypothesis 36, 37). Coordination with class 1 private freight railroads has been cited as a unique impediment to project delivery in the US (Goldwyn et al., 2023).

Case Study Evaluation – As noted in item 36, TriMET paid UPRR $19 million for land acquisition and temporary construction easements on the Orange Line. On top of this, TriMET had to reconfigure UPRR tracks north of Milwaukie, OR (at TriMET’s expense), and install new active warning facilities along the entirety of UPRR alignment along the Orange Line (also at TriMET’s expense) (Schlupp, 2023). Also, the imposition of 25’ clearances requirements by UPRR (see #5, #45) forced TriMET to incur additional expense in land acquisition and civil work (Akimoto, 2023). While Metrolink’s airport line was not built near the UK’s national rail network, Metrolink operates adjacent to the UK national freight / passenger network in 3 locations without the same clearance requirements specified by UPRR (Shock, 2023; Sommers, 2023). In one location near Alrincham, Metrolink trains and mainline trains are both dispatched by the UK's national rail dispatcher, Network Rail (Shock, 2023). That being said, the lack of mainline track or ROW adjacent to the Airport line means the case study evaluation is inconclusive.

Corroboration – Unlike much of the rest of the world, the US rail network is uniquely focused on transporting freight. Therefore it has been argued that special care must be taken when building or operating mixed passenger and freight corridors in the US. There is some validity to this argument. Measured per ton-mile, the US rail network's freight mode share is approximately 28% (FRA, 2020). The equivalent mode share in the UK is approx. 17% (Woodburn, 2017). In Spain, France, and Germany, equivalent rail freight mode share value are 4%, 9%, and 14% respectively (Millar, 2022). However, it also appears that America's freight rail mode-share is declining (Blaze, 2022; Semuels, 2022), at a time when freight rail mode-share elsewhere (including the UK and Germany) is increasing (Millar, 2022; Woodburn, 2017). Also, several countries have managed to achieve rail freight mode-share levels almost as high as the US without compromising passenger service. For example, Switzerland's equivalent rail freight mode share metric is 24% (Fries et al., 2008), while India's is 27% (Sahu et al., 2022) (nearly the same as America's 28%). While this issue merits separate study, it appears possible to operate a rail network which transports as much freight as the US network without undermining the construction or operations of passenger service in adjacent corridors or shared corridors.

Section 5: Findings & Recommendations

5.1 Capital Costs

1. Address abuse of the NEPA/Environmental Review process, and recognize that transit has a net positive environmental impact

The environmental review process set out by the National Environmental Policy Act (NEPA) and its state/local equivalents in the US appear to be more laborious, more vague, and more prone to bad faith misuse than comparable processes in other advanced democracies, including the United Kingdom. The result of this is a situation where environmental review appears to be used to, ironically, slow down the expansion of environmentally beneficial infrastructure, like transit.

MAX's Orange Line project, and Metrolink's corresponding Airport Line project, share many attributes, including their design and project size (see Section 3). However, the level of effort TriMET engaged in to document environmental impacts appears to exceed TfGM's equivalent documentation efforts by a factor of roughly 9 or 15 to 1, depending on the means of measurement (see hypothesis #56). This discrepancy exists even though the UK still requires transit projects to go through a full Environmental Impact Assessment process (EIA, the UK equivalent of an EIS). Elsewhere in the world (including Ontario, Australia, and Turkey), governments have allowed transit authorities to obtain waivers exempting transit projects from environmental review (Lewis, 2022), recognizing the futility of slowing down transit expansion on environmental grounds given that transit expansion is a net environmental positive. While the average US transit project is held up for 4.5 years due to environmental review, these waivers have taken as little as 3 months to complete elsewhere in the world (Ensari, 2023; Goldwyn et al., 2023). While an abridged "Environmental Assessment" process exists in the US for certain projects, even this can take multiple years to complete (see hypothesis #56). In part, the need for in-depth environmental review comes from vague guidance regarding what does or does not need to be reviewed or what projects qualify for different forms of review. This opens transit agencies to legal challenges in bad faith by organizations claiming insufficient environmental review was conducted. By contrast, the UK government clearly lists the types of projects which qualify for an EA (for example: roads exceeding 4 lanes in width for at least 10km in length) (See hypothesis #56).

To minimize abuse of the NEPA process, Federal Lead Agencies (and other regulatory bodies) can clearly specify the types of projects which qualify for EISs, EAs, or Catagorical Exclusions, and limit the scope of impacts which should be analyzed accordingly. This guidance should also clearly state that transit projects do not require EIS documentation, but instead require either an EA or categorical exclusion given their net positive environmental impact.

Reference hypotheses & sections: hypotheses 56, 71, section 2.2.8

2. Ensure consistency between authority and responsibility in project governance.

When determining how transit projects are governed, it's important to avoid situations where agencies have regulatory authority over a project without responsibility for its completion. Such agencies, public or private, have a tendency to increase the scope of transit projects without regard for the resulting impact on project cost or timeline, and without performing any cost / benefit analysis of the new project elements they're seeking to add.

TfGM, the agency which owns Metrolink, is responsible for all aspects of the transportation network in Greater Manchester, including major roads, freeways, traffic signals, and transit. By contrast, TriMET, the agency which owns MAX, must coordinate with State and municipal DOTs (which own/operate Portland's road network) as well as private railroads (which own/operate Portland's mainline railroads) when constructing capital projects. These authorities can impose design requirements on TriMET, but are not accountable for project cost or project delivery. During the construction of the Orange Line, these agencies significantly increased the scope of the project by (among other things) imposing increased clearance requirements and quiet zone requirements that forced TriMET to buy additional land, and make additional updates to roadways and railroad grade crossings for both itself and Union Pacific Railroad (see hypothesis 37) (Schlupp, 2023). Related to this, TriMET had to pay other public agencies in Oregon for land acquisition and temporary construction easements, even though this meant money was moving between two organizations that are funded and owned by the same group of constituents (I.e. Oregon taxpayers) (Akimoto, 2023). By contrast, TfGM did not have to seek approval from local jurisdictions or other agencies to construct the Airport Line, and TfGM's road and transit divisions agreed that no temporary construction agreements were necessary on the project, and no compensation was required for land swaps between agencies (hypothesis #36). Elsewhere in the US, an analysis of the 2nd Ave Subway in NYC found that the MTA spent between $250 & $300 million just to satisfy demands from other authorities in exchange for permits (hypothesis #37).

To minimize waste of the kind described above, agencies tasked with building transit should be given the associated authority to do so without being "held hostage" by other agencies seeking to extract concessions. And because all public land is eventually owned by the same taxpayers, permanent or temporary land transfers between public agencies should be made possible without compensation or complicated right of way agreements which have to be developed and negotiated as public expense and can complicate the construction process.

Reference hypotheses & sections: hypotheses 5, 36, 37, 69, 74, section 3.2.1, 3.3.1

3. Develop comprehensive design standards for transit.

Clarity and standardization in facility design can reduce capital and operations costs by reducing confusion among designers, contractors, operators, and manufacturers, reducing conflict between multiple agencies, reducing the risk of overdesign, and reducing reliance of novel but unproven technologies.

Like all transit systems in the United States, TriMET has to develop its own facility design standards (Schlupp, 2023; TriMET, 2017a), and rely on standards developed by other jurisdictions like ODOT and UPRR where applicable. By contrast, Metrolink facilities are built in accordance with the UK's national design standards for light rail transit (ORR, 2006) (see hypothesis 48). While extensive national design standards exist in the US for roadway projects (published by AASHTO and NACTO) and for freight rail (published by AREMA), this is not the case for transit (see section 2.2.5). By contrast, other developed countries have national standards organizations which publish facility design standards for transit, like South Korea's Ministry of Land, Infrastructure, and Transportation (Molit), or the EU's Center for European Standardization (see hypothesis 48). And as noted in section 2.4.1, many of the cheapest urban rail projects built in advanced democracies are built in these countries.

To better standardize transit facilities in the United States, industry groups and/or regulatory authorities should develop national facility design standards specifically geared towards transit. While part of this work has already been done by the American Public Transit Association (APTA), the APTA design standards are not yet sufficiently detailed or extensive enough to be used in lieu of AREMA or local design guidance (see hypothesis 48). Examples of areas where additional design guidance could be provided includes quad gates with pedestrian protection (hypothesis 33), overhead catenary design and voltage (hypothesis 46), ballast vs. slab track usage (hypothesis 52), rolling stock door design (hypothesis 15), and rolling stock materials (hypothesis 6), among others. The international examples referenced above can be used as a reference for the development of these standards.

Reference hypotheses and sections: hypothesis 48, section 2.2.5

4. Avoid overdesign and over customization

Capital costs for new transportation facilities can become inflated as a result of unnecessarily oversized or overdesigned facilities, partly as a result of insufficient facility standards (recommendation 3), as well as demands made by outside stakeholders (recommendation 2). This appears to be a problem in US transit projects, and steps should be taken to avoid excessively designed transportation facilities.

The southern terminus of MAX's Orange line, designed for 10-minute headways, has three platforms with Spanish solution platforms. By contrast, Metrolink operates 2-track termini with single platforms and adjacent to single track segments with 6-minute headways (see Hypothesis 47). And, as noted in Table 7, on time performance on Metrolink is greater than MAX. This suggests that there are opportunities for systems like MAX to provide equivalent levels of service with smaller facilities. Elsewhere in the US, prior study of the Second Ave Subway found that the project built unnecessarily large station boxes with more track switches than operationally necessary (Goldwyn et al., 2023).

In part, addressing issues of overdesign can be improved by the creation of comprehensive transit design standards (recommendation 3) and clarifications in project governance (recommendation 2). Beyond this, project managers should clearly determine what project elements are "need to haves" or "nice to haves" when building new transit facilities.

Reference hypotheses and sections: hypothesis 36, 45, 47, 48, section 2.2.5

5. Make unit bid information on transit projects public, and avoid lump sum contracting

To control construction costs, relevant public agencies, engineers, and regulatory bodies need to know what those costs are. Currently, in many cases, they don't. State DOTs in the US publish unit bid libraries containing information on the installation cost and quantity for various bid items from their previous construction projects. However no comparable information is made public by transit authorities or municipal DOTs. In the case of some agencies (including TriMET) it's unclear if such information is collected at all. This means the cost estimating process for transit facilities is largely opaque. To control capital costs, estimates from previous capital projects should be collected, made public, and used for comparison with future capital projects.

In other developed democracies with a track record of low cost transit construction (including Italy and France), comprehensive unit bid libraries are collected and published at the regional level for all previous capital projects – public or private. Based on these libraries, maximum unit cost tables are published annually and used as a basis for engineer's estimates and construction change orders. While contractors bid using their own unit prices when competing for construction contracts, total bids which exceed the engineer's estimate are automatically rejected (See section 2.4.2). Many arguments against implementing similar processes in the US (for example, the claim that increased transparency will somehow increase contractor collusion) are made without evidence and should be treated accordingly.

The FTA's capital cost database provided an opportunity for the development of a comprehensive unit bid library for transit projects in exchange for minimal effort. The capital cost database follows Standard Cost Categories used by both the FRA and FTA. While these categories are not sufficiently detailed for final design or construction, the FTA also develops before and after studies which could not be developed without more detailed unit bid information. Unit costs have likely already been collected or obtained in the process of developing these before / after studies. Collecting this information and publishing it as part of the FTA's capital cost database would provide a useful first step towards improving cost transparency and cost control for US transit projects.

Note – of the 3 analysis steps in this study (literature & data review, case study analysis, and corroboration), the case study analysis was inconclusive. However, evidence was sufficiently compelling from other sources to include this recommendation regardless.

Reference hypotheses and sections: hypothesis 16, section 2.4.2

5.2 Operations

1. Embrace modern rolling stock design

Modern rolling stock widely in use in Europe and Asia is often lighter and more energy efficient than equivalent rolling stock in the United States. While many US transit agencies have begun to procure new vehicles, some technologies which are widely in use internationally have yet to be widely adopted in the US. These technologies, particularly the use of aluminum in car body construction, and passenger door control, should be adopted more extensively in the US.

Despite being almost identical in size, Metrolink railcars, which are partially built out of aluminum, are roughly 7 US tons lighter than their MAX counterparts (which are made of steel) (see Table 7 & hypothesis 6). Likewise, the BART system has estimated that their railcars would be approx. 7.5 – 10 tons heavier per car if they'd opted (like most US transit agencies) to use steel in lieu of aluminum in carshell construction (BART, 2023). The decision by most US transit agencies to exclusively use steel appears to be based on misunderstandings regarding federal regulations or manufacturer preference. While FRA regulations effectively precluded the use of aluminum in mixed passenger and freight environments previously, these regulations were modified in 2018, and never applied to transit (see hypotheses 6 & 74). Likewise, rolling stock manufacturers have unsuccessfully recommended the use of aluminum in vehicle design to transit agencies in the past (see hypothesis 6). The use of unnecessarily heavy steel rolling stock, which is still being specified by some US transit agencies despite the issues noted above, is apparently being done purely out of transit agency preference, and not due to any regulatory requirements or manufacturer recommendation (Taylor, 2023). In part, this preference is due to concerns about corrosion in coastal environments, however significant precedent exists in the US and globally for transit agencies which operate aluminum rolling stock in coastal environments without issue (see hypothesis 6).

Unlike MAX, Metrolink passengers press a button on a train door if they wish to open it at a station. This reduces energy and HVAC maintenance expense by reducing the need to heat or cool railcars, and reduces maintenance expense on doors by reducing the number of times each door must open and close. MAX trains can operate in this manner, but this functionality is only used by those who need wheelchair ramps. The use of passenger door control is widely in use internationally and allows for reduced energy and maintenance expense (see hypothesis 8).

Some transit agencies have begun to adopt the technologies referenced above, including WMATA, Caltrain, and Amtrak (in regard to aluminum in rolling stock) as well as Trinity Metro (in regards to passenger door control), but more transit agencies should follow their lead. The design modifications specified (widely in use internationally) have already been successfully implemented in the United States, meaning the agencies which have begun to adopt such technologies can provide guidance to others in their implementation within the America's unique regulatory framework.

Reference hypotheses and sections: hypotheses 6, 8, 74, section 2.2.6

2. Embrace operational franchising

In most US transit agencies, operations and maintenance staff are direct agency employees. This governance model is less common in many European or Asian countries, including the UK. Many transit agencies abroad, and one US system noted in Figure 1 (Phoenix's Valley Metro), operate under a franchise model. Under this model, the public transit agency continues to own all infrastructure, set and collect fares, and set routes / service levels. However, the day-to-day operations and maintenance of de the system is contracted out to private operators in 8-10 year competitive franchise contracts. This approach maintains public ownership, public accountability, and provides a single coherent system for passengers, while introducing an element of competition into daily operations and maintenance work. It has been found to reduce operating cost and improve customer satisfaction in multiple cases around the world (see section 2.2.7 & hypothesis 1).

Like most US transit agencies, MAX is operated and maintained entirely in house. By contrast, Metrolink's franchise operator runs at lower costs while delivering better safety and on time performance metrics as compared to MAX (see section 3.4). And Metrolink's franchise contracting system operates with 100% union labor and without undermining job security for unionized staff (see hypothesis 1). Several global systems noted in Table 3 operate under this model as well, including the Copenhagen Metro, London Elizabeth Line, Docklands' Light Railway, London Bus system (see hypothesis 1). This franchise model is also used to run Singapore's bus system, and buses in the Netherlands (see section 2.2.7).

Many transit agencies today are struggling to hire new staff, partly due to their own HR policies (Brey, 2023b). This is an opportunity for transit agencies to begin introducing operator franchises to both address this shortage and evaluate the effectiveness of this policy. As Phoenix's Valley Metro already operates under a franchise contract and performs well across 3 out of 4 operations metrics in Figure 1, it can set an example as to how this policy can be implemented under American regulatory restrictions.

Reference hypotheses and sections: hypotheses 1, section 2.2.7, 3.4

3. Prioritize transit speed

Because approximately 60%-70% of operations and maintenance costs for transit agencies are made up of labor, and because labor is paid by hour, increased average operations speed can reduce operating costs (see section 2.3.3). And it appears that opportunities exist for US transit agencies to increase operating speeds without compromising safety (see hypotheses 33).

As evaluated in Table 4, a moderate correlation exists between operator speed and operational efficiency. This further suggests that efforts to increase average transit speed can lead to an associated cost benefit. In 2019, the MTA in New York created a Speed and Safety Task force, which identified over 600 locations where temporary Subway speed restrictions could potentially be lifted. This was because many of these locations had been reduced in speed not as a result of a robust engineering analysis, but generally on order to be cautious, while elsewhere minor design modifications could address the underlying safety issue. (PR, 2019). By 2021, speeds had been raised in 279 locations, either with better engineering analysis of the potential safety problem or with minor design modifications (MTA, 2021). When comparing Metrolink and MAX, it appears that an opportunity exists to engage in similar efforts vis-à-vis MAX, and other US transit systems. Average operating speeds for these two systems are similar (within 3mph of each other). However, this is despite multiple MAX design elements which allow for much higher speeds – including more grade separation, more active traffic control (i.e. gates and flashers), more advanced signaling, and higher maximum operating speeds. Beyond this, a comparison of active traffic control devices between MAX and Metrolink suggests that, where it does exist, active traffic control on Metrolink allows trains to safely operate at higher speeds than MAX (see hypothesis 33).

To make sure transit service is operating as quickly as is safely possible, more transit agencies should follow the lead of the MTA and develop speed and safety task forces to comprehensively evaluate temporary speed restrictions and determine where speeds can be increased. Also, (related to recommendation 3 in section 5.1), standards should be developed to improve active traffic control design for pedestrian crossings and sidewalks (as exists in Manchester) to safely operate trains at higher speeds without fear of pedestrian collisions (see hypothesis 33).

Reference hypotheses and sections: hypotheses 33, section 2.3.3

4. Cater fares more closely to the market, and use fare revenue for proactive maintenance

Proactive maintenance is key to the long-term cost effectiveness of a transit system. However, transit agencies often struggle to obtain funding for maintenance as its associated benefits cannot be seen immediately (see section 2.2.3). One way to address this problem is for transit agencies to raise more fare revenue directly by developing a fare structure which more closely aligns with passenger's ability to pay and use this funding for long term system maintenance.

Metrolink raises between 60%-100% more annual fare revenue than MAX (see Table 7). This is, in part, a product of Metrolink's fare structure. While Metrolink charges higher base fares than MAX, it provides significantly more concessions for those who can't afford it. Discounts are available for those who travel during off peak periods, children, seniors, families, college students, those in a job training program or on unemployment insurance, and others who may not have the means to pay (see Table 7). Metrolink fares are also distance based using a zone structure. Prior study from California and Utah has found that low income passengers tend to travel shorter distances (Farber et al., 2014; Linton, 2017), meaning that distance based fares improve fare equity and increase fare revenue. The result is that Metrolink raises approximately 50% more revenue per passenger while ensuring those who are unable to pay can still use the system.

Beyond fare structure, Metrolink also has lower rates of fare evasion than MAX (see Table 7). Prior study has found less political support for tougher fare enforcement in North America than in either Europe or Asia. In part (Saunders, 2023), this opposition comes from a reticence around "criminalizing poverty" by more strongly enforcing fare evasion. By providing additional discounts for those who need it, Metrolink has addressed this issue proactively rather than simply allowing some passengers to evade fare payment.

Because it is cheaper to "fix before failure" than after, transit agencies should seek to ensure that sufficient revenue is available for system maintenance. By developing a fare structure that is closely related to passengers' ability to pay, and taking steps to reduce fare evasion, transit agencies can raise sufficient revenue for operations & maintenance without falling prey to the political process. If higher base fares are not preferred politically, policy makers should ensure that maintenance expenditure is ringfenced to ensure stability in long term maintenance funding.

Reference hypotheses and sections: hypotheses 27, 30, 68, section 2.2.3, 2.3.4, 3.4

5. Reform procurement regulations as they apply to transit agencies.

When procuring new equipment, US transit agencies can have difficulty finding manufacturers who are able to provide products in a cost effective or timely manner. This is partly because the market for transit equipment in the US has been relatively small and unstable when compared to other advanced economies in recent decades. However, several procurement regulations have exacerbated this problem (GAO, 2010). Making it easier for transit agencies to obtain Buy America waivers when US suppliers are limited or nonexistent, and allowing transit agencies to sign scalable contracts to procure additional supplies as needed for periods longer than 5 years, would help address this issue.

The last time TriMET procured new rolling stock, only 2 manufacturers responded with proposals – CAF (a Chinese company) and Siemens (a German company) (Johnson, 2023). By contrast, Metrolink received 4 proposals. But even this was viewed as unusually low by UK standards due to Metrolink's use of high floor vehicles. Other UK operators are used to getting 6 or 7 proposals when seeking to procure rolling stock (Sommers, 2023). MAX also paid approximately $1.2 million more per railcar than Metrolink for rolling stock of similar size and specification (see Table 8). While Buy America is intended to protect American manufacturing jobs, American manufacturers for transit equipment are often few in number or non existent. And the high cost for new rolling stock or other equipment can lead agencies to hold onto old equipment for longer periods of time than their European or Asian counterparts, which shrinks the market for manufacturers further and exacerbates the issue (see hypothesis 10). While a system exists for transit agencies to obtain waivers, its complicated and slow, and transit agencies can have difficulty navigating the process (GAO, 2010).

Along with the issue above, transit agencies are often unsure about how many vehicles they need when placing an order, so having the ability to order extra rolling stock as needed without beginning an entirely new procurement process can be beneficial. TfGM has an agreement with Bombardier which allows the purchase of additional Metrolink railcars at a an agreed upon price as needed. When operators ran into problems operating a mixed vehicle fleet, they were able to retire their old railcars earlier than expected and order new cars from Bombardier quickly (Shock, 2023)

It's likely that the issues noted above in regards to rolling stock procurement is true in regards procurement of other equipment as well. Modifications to existing procurement regulations, particularly for Buy America waivers and scalable procurement contracts, would allow transit agencies to operate more efficiently.

Reference hypotheses: hypotheses 10, 72

6. Adjust train car lengths based on demand

Many US transit agencies run trains with the same number of cars at all times of the day regardless of demand. This may be based on the assumption that the marginal cost of adding additional rail cars is low or negligible since it does not impact the number of drivers, or based on the assumption that any cost savings gained by adjusting train car lengths will be lost through the labor involved in modifying trains in the yard. These assumptions are incorrect. Adjusting the length of trains to match demand can reduce operating costs for transit agencies.

While MAX operates 2 car trains at all times of day, Metrolink varies between 1 and 2 car trains based on the expected demand along the line. Prior study of the Washington Metro found that the cost savings in energy consumption associated with reductions in train size during low ridership periods was greater than labor cost increases associated with adjusting trains (Uher et al., 1984), while Table 4 shows that a moderate correlation exists among US urban transit systems between energy efficiency and overall operating costs. And while driver labor costs will not change as a result of this adjustment, reducing the length of trains during low ridership periods will reduce labor costs associated with maintenance, security, and cleaning (see hypothesis 14).

Those transit agencies which don't already do so should pilot adjustments to train lengths during off peak or other low demand periods to evaluate the impact of this operational shift on O&M cost. The information above suggests it will have a beneficial impact on their operations and maintenance expenditure.

Reference hypotheses and sections: hypotheses 14, section 2.3.3

7. Clean trains during the day to the extent feasible

Whenever possible, transit operators should clean trains during operator layover, or at other times during the mid-day, as opposed to overnight. This will be beneficial from both an operations cost and customer satisfaction standpoint.

MAX performs almost all cleaning overnight, only opting for daytime cleaning if a biohazard is present (J. Griffiths, 2023). By contrast, Metrolink cleans its trains at the during the day (at the end of the line during operator layover) and overnight (Sommers, 2023). This has three benefits. First, performing some cleaning during the daytime ensures that trash does not build up on trains throughout the day. Second, wages for night work are often higher than corresponding day time wages due to the inconvenience of working overnight. And third, in colder climates, heating trains overnight to allow them to be cleaned can have significant expense. At times, it has been observed by NJ transit staff that more energy was used heating trains overnight than moving trains during daytime revenue service hours (Stangas, 2023).

Those transit agencies which do not already do so should pilot daytime cleaning to the extent feasible. The information above suggests it will have a beneficial impact on operations and maintenance expenditure.

Reference hypotheses: hypothesis 32

8. Avoid mixing capital & operations contracts (I.e. DBO, DBM, DBOM)

It has been debated whether Design Build (DB) or Design Bid Build (DBB) contracting is better for transit. While this study can't contribute to this debate, It's apparent that construction contracts which mix design and operations responsibility (like Design Build Operate (DBO), Design Build Maintain (DBM) or Design Build Operate Maintain (DBOM)) are not cost effective, and should be avoided.

As noted in section 2.4.4, several transit projects delivered using DBOM contracts are unusually expensive to operate, even when compared to other transit systems that are operated by the same agency, the same region, and use the same rolling stock – including the Hudson-Bergen line in New Jersey and the Denver RTD's A, B, G, and N lines in Colorado. Also, Manchester Metrolink was delivered using a "bespoke" construction contract. Initially this contract resembled a DBM project delivery method. However, Manchester determined it would not have the same agency build and maintain its system. In part, this was due to the experience of another LRT system, the Sheffield Supertram, which was determined to be in poor condition due to negligence by its DBOM contractor near the end of the operations period (Sommers, 2023).

Transit agencies should avoid building new projects through DBO, DBM, or DBOM contracts. While franchising operations to private companies can be beneficial (see item 2), this should be done through a separate competitive bidding process, and not be combining capital and operations contracts. Transit agencies should avoid seeking to reduce capital costs in a manner which will increase their long term operations and maintenance expenditure.

Reference hypotheses and sections: hypotheses 22, 23, section 2.4.4

9. Future study – Consider automation to improve transit service quality while reducing cost

Precedents from around the world, particularly Vancouver and Copenhagen (see section 2.3.3), show that automation is a proven transit technology that not only reduces operations cost but can also improve service quality.

Both the Vancouver Skytrain & Copenhagen Metro are fully automated metro rail systems which provide very high levels of service frequency (roughly every 5 minutes from 5am to 1am, 7 days per week) and reliability (see Section 2.3.3). While labor accounts for roughly 60%-70% of O&M costs in most US transit systems and in Manchester, labor accounts for roughly 35% of O&M costs for the Skytrain and Copenhagen Metro. Based on this adjustment, and assuming that automation does not impact non labor expenses, it can be assumed that Automation will lead to a roughly 46% O&M cost reduction. This means that automation alone could generate an operational profit on the Boston T's Red, Blue, and Orange Line, as well as the New York Subway, Philadelphia Subway, BART, and Caltrain (See Appendix B).

The Honolulu Skyline in Hawaii, which opened in 2023, is America's first fully automated urban transit system (Vantuono, 2023). As the Skyline reports operations metrics to the FTA in future, the impact of automation on O&M costs can be further studied.

Note – of the 3 analysis steps in this study (literature & data review, case study analysis, and corroboration), the case study analysis was inconclusive as neither MAX nor Metrolink are automated. However, evidence was sufficiently compelling from other sources to include this recommendation for future study regardless.

Reference sections: section 2.3.3

Section 6: Conclusion

Much of America's transportation infrastructure, particularly its transit infrastructure, is in need for modernization and expansion. This modernization and expansion cannot take place until and unless construction, operations, and maintenance costs are brought under control. In order to do so, one must first understand what can be done to address the problem of high US transit costs.

This study seeks to understand why US transit costs are more expensive than comparable costs elsewhere in the developed world, and provide a shortlist of potential policy, engineering, or operational changes which may help in address these issues. This was done by first reviewing data and literature available covering transit costs in developed countries to create a series of hypotheses for factors impacting transit costs. Then these hypotheses were evaluated through a comparative case study analysis of two transit systems that are similar in specification but divergent in operations & capital costs, and an attempt to corroborate or dismiss the resulting findings by reviewing data, prior study, or examples from other transit systems.

Some of the resulting findings of this report cover issues of governance, operations, and engineering practice. Some findings are consistent with findings from prior study on transit costs. These include the Transit Cost Project, who's findings corroborate with capital cost recommendations 1, 2, 4, and 5, as well as the Eno Center, who's findings are consistent with items 2, and 4, and who also found that mode has limited impact on transit cost (contrary to conventional wisdom). In regards to operations costs, less comprehensive research has previously been done. While the findings of this report partially reaffirmed prior research on Baumol's cost disease (Sarriera & Salvucci, 2016; Sarriera et al., 2018), they also show that transit operations can (and have) been made more efficient than they currently are in cities and regions with high levels of economic development and high wages. The findings of this report also confirm prior research pertaining to operational franchising (Van-De-Velde & Eerdmans, 2016), higher transit speed (Walker, 2011), and transit procurement reform (GAO, 2010).

This study will hopefully be one of many that evaluate the issue of high US transit costs. Like any study, it has limitations. First, prior study has determined that transit cost are disproportionately high in English speaking countries (Goldwyn et al., 2023) , and are exacerbated by common law legal systems (Lewis, 2022). As the UK and US are both English speaking with similar governance and legal systems, these claims could not be evaluated. Second, both MAX and Metrolink are LRT systems with limited grade separation and relatively slow speeds. There may be issues pertaining to transit costs which do not apply to these systems, and therefore could not be evaluated. Finally, this is a case study based analysis and does not follow a process of statistical evaluation. However, the information provided in this study could serve a precedent for future analyses that addresses these limitations.

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Appendices

Appendix A – Full Hypothesis Evaluation Table

Appendix B – Operating Cost Data & Analysis

Appendix C – Capital Cost Data