Demonstrating Triple Bottom Line Returns from Public Sector Investments in Bus Service Frequency

Submitted for the

West Houston Association

Submitted by

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Executive Summary

This report details our investigation of methods to evaluate the triple bottom line (TBL) returns of public transit projects seeking to increase bus service frequency. The triple bottom line refers to a framework of project evaluation that considers economic, social, and environmental costs and benefits. In light of public agencies' frequent neglect for how infrastructure investments impact community residents' wellbeing and the physical environment, the West Houston Association consulted us to conduct a literature review and develop an annotated bibliography of the most reliable and accessible tools and methods for agencies to conduct TBL return analyses of their sustainable infrastructure investments. In this effort, we adhered to three project phases: **conducting background research on TBL returns**, **identifying key measures to evaluate bus service frequency changes**, and **applying our selected measures to a real-life case study**.

In our background research phase, we develop an understanding of how public transit authorities consider economic, social, and environmental returns to determine the success of their work. We compile as comprehensive a list as possible of resources utilizing diverse methods to calculate project returns, including self-evaluation reports released by transit authorities nationwide, guidance from federal administrations, and scientific articles confirming the relevance of certain measures to financial revenues, social benefit, and environmental conservation. We compare our findings in a literature review, categorized by TBL return type.

We narrow our list of measures in phase two of the project to make recommendations for the TBL returns measures we believe are most feasible for measurement by any transit authority, impactful enough in their respective TBL domain to warrant consideration, and congruent with the motivation of emphasizing social and environmental benefits that would not necessarily be considered from a financial-only evaluation. For economic returns, we recommend **farebox revenues** and **bus fleet operating expenses**, specifically **labor costs**. For social returns, we advise agencies to consider **passenger travel and wait time saved**, **equitable targeting of high-need communities**, and **household transportation cost savings**. Lastly, we propose the environmental return measure of **greenhouse gas emissions**. For social and environmental returns, we advise methods of converting metrics into dollars for convenient comparison with economic returns.

After making our recommendations, we proceed to the final phase of calculating TBL returns using our proposed methods to evaluate the 2015 Houston METRO New Bus Network restructuring. Overall, we find sizable economic losses, social gains in passenger time saved, mediocre coverage of high-need communities, social losses in household transportation costs, and minor falls in greenhouse gas emissions. We conclude that a negative nationwide trend in ridership was the culprit for revenue losses and socially and environmentally burdensome conversions from bus to car transportation, and recommend future analyses with our TBL return

measures adopt more sophisticated statistical designs, such as difference-in-differences, to control for systemic ridership declines.

At the West Houston Association's request, we include an annotated bibliography with the resources we found most comprehensive and helpful to evaluating economic, social, and environmental costs and benefits of public transit investments in our appendix.

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Introduction and Background

The West Houston Association (WHA) is a leading nonprofit advocating for high-quality city planning and public policy for the Greater West Houston community. WHA's Sustainable Infrastructure arm consulted us to rigorously explore how to evaluate returns on public investments in sustainable infrastructure projects, utilizing the triple bottom line (TBL) framework.

The status quo of public agencies is to evaluate their infrastructure projects with a unidimensional vision of its intended outcomes, and narrow consideration of only the economic returns of the project for the implementing agency. The TBL framework challenges public agencies to consider not just the economic, but the social and environmental costs and benefits of their projects as well. This holistic understanding of sustainable infrastructure projects encompasses factors like improvements and burdens to local residents' quality of life, as well as change in the city's output of pollutants. Ultimately, we were tasked to research and present tools and methods that public agencies could access to more confidently assess the economic, social, and environmental impacts of the sustainable infrastructure projects they choose to invest in.

After initial consultation with Mr. Alan Steinberg, President and CEO of WHA, and Mr. Michael Bloom, Sustainability Practice Manager with 5engineering, our team narrowed the focus of our research to TBL return measures for mobility investments in the frequency of public bus routes. In order to fully explore and apply the literature on TBL returns as they related to increasing the frequency of public bus routes, we pursued the following phases for this projects:

Phase One: Background Research

The first step was to conduct a preliminary online investigation of professional and academic resources to fully understand the concept of triple bottom line returns and their application broadly to public infrastructure projects. We then compiled an array of sources related specifically to measures of economic, social, and environmental impacts of bus transit innovations and policy changes. Finally, we thoroughly researched each source to obtain as comprehensive a list as possible of potential methods of evaluating each type of TBL returns. Our literature review can be found in the "Findings and Analysis" section of this report. Additionally, we provided an annotated bibliography of our most relevant sources in the appendix.

Phase Two: Identify Key Measures

After developing a full list of economic, social, and environmental evaluation measures, we identified the methods we believed were most supported by the literature, feasible for the public agencies to have the relevant data for, and congruent with the West Houston Association's interests in enhancing the daily lived experiences of West Houston-area residents and long-term infrastructural sustainability. We detail our reasoning and the TBL return measures we recommend that WHA use in the “Recommendations” section of this report.

Phase Three: Case Study Application

In order to test the generalizability of our proposed measures, we utilized them in an evaluation of a real-life public transit authority's bus system reforms. Specifically, we chose to study Houston METRO’s 2015 New Bus Network project, which involved major bus system reforms that implicated dramatic increases to bus route frequency. We located raw data from Houston METRO and present our findings of their investments’ TBL return performances in the “Houston METRO New Bus Network: A Case Study” section of this report.

Findings and Analysis

What is the Triple Bottom Line?

The triple bottom line (TBL) theory advocates for businesses to prioritize social and environmental concerns alongside profits. The TBL framework introduces three bottom lines: the economic, social, and environmental. The economic line encompasses traditional financial measures like income and expenses, while the social line focuses on social responsibility, including fair wages, safe working conditions, and diverse suppliers. The environmental component assesses environmental impacts such as greenhouse gas emissions, waste generation, and ethical sourcing. Measuring the triple bottom line involves a mix of financial, social, and environmental metrics, with financial reporting being more structured compared to the complexities of assessing social and environmental impacts.

Under the context of public transit, TBL is an effective tool to measure not only the economic return but also social and environmental benefits. For example, Lane Transit District (LTD) integrates the TBL approach into sustainability efforts, emphasizing financial responsibility, environmental impact reduction, and social equity. This involves providing quality service with environmentally friendly vehicles and sustainable practices. Through initiatives like greenhouse gas inventories and strategic partnerships, LTD aims to reduce greenhouse gas (GHG) emissions by 75%, transition to electric buses, and advocate for regional priorities. Additionally, LTD's Transit Tomorrow initiative focuses on social equity, increasing access for marginalized communities through service adjustments based on community needs. Overall, LTD demonstrates a holistic commitment to sustainability in public transit operations. (Kenton, 2023)

Economic Returns

What notably distinguishes public infrastructure projects from private ventures is that, while economic returns are undoubtedly desirable, they often accept governmental economic losses as a given in order to provide a benefit to the jurisdiction’s community. Nonetheless, the financial revenues and expenses are the most straightforward to measure.

Texas transit authorities receive funding from three primary sources. The first comprises federal grants from agencies like the Federal Transit Administration and Federal Highway Administration. The state legislature does not itself allocate state funding to Metropolitan Transit Authorities but additionally authorizes MTAs to levy local sales taxes of up to one percent, which is the rate charged by Houston METRO on top of the statewide sales tax (Donald & Halbrook, 2021). Lastly, transit authorities generate revenue through the farebox, driven by the fare paid by individual transit users for each ride. Since we do not expect our policy focus of bus route frequency to have a direct, measurable impact on grant funding or sales tax revenues, we further explore how they can impact farebox revenue.

Systems to track farebox revenues are already implemented in all MTAs that collect fares. Adjacent to the economic benefit measure of farebox revenues is the measure of ridership, often measured in unlinked trips (counting every passenger boarding)—while it is a strong assumption that every bus passenger will always pay their fare for each trip, farebox revenue can be approximately calculated as:

$$Farebox\ Revenue\ =\ Unlinked\ Passenger\ Trips\ \times\ Fare\ Price\ \times\ Payment\ Rate$$

This calculation may be binned by riders that do or do not take advantage of discounted fare prices, if offered. Several studies substantiate that changes to public transit service frequency can make significant impacts on ridership—one longitudinal analysis of New York City and New Jersey transit supported a "demand follows supply" hypothesis, empirically concluding that, in independent of changes in fare and gasoline prices, increased service offerings resulted in greater ridership (Chen et al., 2011). Likewise, an analysis of public transit network optimization in Berlin held that improving bus frequency of main lines raised revenue by more than 22 percent as a product of shorter travel times and new customers attracted (Reinhold & Kearney, 2008). Another random effects meta-analysis of nine public transit projects increasing service frequency demonstrated that more frequent service generated more travels by public transport. Even further, the proportion of travel generated by service frequency was significantly greater than that of projects reducing fare prices (Brechan, 2017). Considering these examples, it's evident that not only do increases to public bus route frequency play a material role in system ridership and associated farebox revenues, they may be more consequential on revenue generation than the variable of fare price.

Turning from benefits, the primary source of economic costs implicated by bus route frequency is bus fleet operating expenses. Public transit consultant Jarrett Walker outlines a framework for breaking down operating expenses linked to bus route frequency, dividing transit service expenses into time-based (e.g., driver wages and benefits per hour), distance-based (e.g., bus maintenance, fuel), fleet-based (e.g., bus vehicle purchase, storage, maintenance), and administrative costs. His guide emphasizes that generally 70 percent or more of transit operating costs go towards labor, suggesting that the vast majority of operating costs fall under the time-based category (Walker, 2011).

A top-down approach of calculating labor expenses for a bus line begins with the simple equation:

$$Labor\ Expenses\ =\ System\ Service\ Hours\ \times\ Driver\ Wage$$

Walker breaks down how to calculate the number of service hours it takes to run one bus line:

$$Service\ Hours\ =\ Operating\ Timespan \times Vehicles\ (Drivers)\ Required$$

For instance, a line running for ten hours with six drivers would require sixty service hours of wages and benefits paid. But how to calculate the number of drivers required?

$$Vehicles\ (Drivers)\ Required\ =\ ROUNDUP(Cycle\ Time\ /\ Headway)$$

In order to understand this equation, Walker explains both cycle time and headway. Bus route cycle time is composed of running time, layover, and recovery. Running time refers to the round-trip length of the line in miles multiplied by the average speed at which the service can operate, including passenger stops:

$$Cycle\ Running\ Time\ =\ Round\ Trip\ Length\ \times\ Average\ Bus\ Speed$$

Layover is break time for bus drivers, often specified in labor agreements, and recovery time is time added to the schedule for late vehicles to catch up to scheduled times. As such, total cycle time often includes some additional percentage (e.g., 10 percent) of layover and recovery time on top of actual running time.

Meanwhile, headway—the other variable in the driver demand equation—represents the time between consecutive trips on a line. So, assuming a line has a 45 minute total run time and a transit authority seeks 15 minute intervals between bus arrivals, the number of drivers required is three (Walker, 2011). But, operating costs are lumpy. Since an agency cannot hire a fraction of a driver or operate a fraction of a bus, a line with a 45 minute cycle time and desired headway of ten minutes could not hire 4.5 drivers. Rather, non-whole quotients must be rounded up to meet the desired headway, in this case to five drivers. For this reason, determination of bus route frequency should closely consider the lumpy nature of operating expenses to minimize costs beyond that necessary to achieve a desired headway.

Walker's calculations for time-based bus line operating expenses can be summarized with the following equation:

$$\begin{aligned} Labor\ Expenses\ =\ & Operating\ Timespan \\ & \times\ ROUNDUP\left(\frac{\left(\frac{Round\ Trip\ Length}{Average\ Bus\ Speed}\right) \times (1 + Layover + Recovery\ Rate)}{Headway}\right) \\ & \times\ Driver\ Wage \end{aligned}$$

The bottom line is that an increase in bus service frequency, while potentially a generator of greater farebox revenue, will also produce operating costs by lowering the headway demanded of an agency's bus fleet. One externality of changing headway however, may be an increase in average bus speed due to less crowded and frequent passenger stops, compensating in the positive to overall economic returns.

If a change in bus frequency were accomplished by reallocating active vehicles from other lines, then operating costs (whether time-based or otherwise) would likely only be marginally impacted. However, transit authorities that purchase new vehicles to serve this need should evaluate not just the alternative operating costs identified by Walker, such as distance-based maintenance and gasoline costs, fleet-based vehicle storage and maintenance costs, and administrative costs (Walker, 2011), but the lump sum investments in new bus purchases. The dollar amount of the latter capital expenditures can be easily integrated as costs in overall calculations of economic returns, potentially as a long-term deferred expense.

Social Returns

Based on research, one of the most important features that increase the social returns of public transit is to shorten the waiting time. One strategy is to prioritize high-frequency transit (HFT). HFT offers more frequent service on key routes, which means passengers spend less time waiting for a bus or train. This is crucial because shorter wait times make public transportation more appealing and convenient for commuters. HFT systems also carry more passengers per hour due to their frequent service and focus on high-demand routes. This increased efficiency not only reduces overcrowding but also helps in lowering operational costs and environmental impact by encouraging more people to use public transit instead of private vehicles (TAAG, 2023). Frequency also increases accident rates, because travelers may engage in risky behaviors, like speeding, to catch their connections on time. This behavior is influenced by factors such as trip length and user perceptions of scheduling costs. Policymakers should be aware of these risks when considering changes to service levels, balancing the benefits of increased frequency with potential safety concerns. (Høyem, 2022)

Ridership is another factor responsible for counting social returns. To determine the social return on public transportation investment based on ridership, it's crucial to prioritize high-frequency service that maximizes access to a wide range of destinations within reasonable travel times, considering both geography and demographics. Frequency plays a critical role in attracting ridership, as it reduces waiting times, enhances travel convenience, and facilitates network connections, ultimately increasing overall transit usefulness and reliability. Balancing cost considerations, particularly in deploying high-frequency service where there is high potential ridership, easy accessibility, and manageable operational costs, is essential. This strategic approach should also include reliable weekend and evening frequency to accommodate diverse travel needs beyond traditional work hours, ensuring that public transportation remains a reliable, efficient, and attractive option for a wide range of commuters. Furthermore, high ridership is achieved when transit is both useful and liberating to a diverse range of people rather than catering to specialized needs. To maximize social return, services should be strategically placed where there are many potential customers, ensuring easy access while keeping the cost of service reasonable relative to the number of customers served. Considering factors such as density (which makes transit more useful to more people), walkability (ensuring easy access to transit lines), linearity (minimizing route miles for higher frequency and shorter duration trips), and proximity (serving short distances efficiently), can guide decisions on where to deploy transit services for optimal ridership and social impact (Walker, n.d.).

One of the topic related to social return is to target underprivileged groups. Providing job access, reducing commute times, and improving access to schools and healthcare can benefit underserved communities. Offering less-traveled routes can especially help low-income workers. Overall, this approach boosts quality of life and reduces income inequality by ensuring equal access to essential transportation resources (Urban Institute 2021).

Public transit also generates economic benefits to households. It increases participation from disadvantaged business enterprises, improves food access through initiatives like farmers market connections, and invests in employee health and professional development, thereby creating social and economic opportunities within communities. Integrating with livable communities and transit-oriented development plans efficiently allocates capital funding, while buses contribute to economic development by enhancing access to jobs and services, increasing property values, and reducing household budgets' reliance on car ownership. Moreover, initiatives promoting regional business equity, such as contracting small, minority, and women-owned businesses, further enhance economic inclusivity and social impact (SEPTA 2020).

Investments in public transportation lead to improved health outcomes by reducing motor vehicle fatalities through lower crash rates, promoting physical activity via walking or biking to transit stations, enhancing air quality due to lower emissions, facilitating access to healthcare services, and fostering affordability and equity in transportation access. Initiatives such as the LYNX Blue Line in Charlotte, North Carolina, demonstrate tangible improvements in health, including reduced BMI and obesity rates among commuters, highlighting the effectiveness of integrating public transportation with land use strategies (U.S. Department of Transportation, 2015). Public transportation greatly benefits community and individual health by providing access to events and special programs and prioritizing safety and security. During emergencies like 9/11 or natural disasters, public transit responds swiftly, evacuating people and facilitating rescue efforts. Moreover, it adapts to new challenges, employing advanced security measures to counter emerging threats. Access to essential services like work and healthcare is facilitated, empowering individuals to improve their lives and communities. Walkable communities encouraged by transit use lead to increased physical activity and reduced stress levels. Importantly, public transit offers a safer alternative to private vehicles, significantly lowering accident and fatality rates (Texas Transit Association).

Public transportation significantly alleviates traffic congestion by offering accessible, efficient alternatives to private vehicle usage. By providing services for community events and essential activities, it reduces the number of cars on the road, leading to smoother traffic flow and shorter commute times. Additionally, public transit promotes walkable communities and pedestrian-friendly zones, further reducing reliance on cars and easing congestion. Moreover, by encouraging individuals to choose public transportation over private vehicles, it contributes to cleaner air by reducing emissions, thus creating healthier environments for all. In essence, public transit plays a vital role in decreasing congestion, improving air quality, and enhancing overall community well-being (Texas Transit Association).

The comfort of riders on public transit systems holds significant implications for the social return on investment. By integrating rider comfort considerations into total cost minimization models, we can optimize service frequency and vehicle size, particularly for automated bus systems. These models account for crowding discomfort externalities, time-dependent demand, denied boarding, and stochastic travel times. Research suggests that service frequency increases are more pronounced when crowding discomfort is a primary concern for riders, especially in the case of human-driven buses. However, the rate of increase in service frequency is even higher for automated fleets. This underscores the importance of aligning supply levels with user preferences to maximize overall satisfaction and ridership. By implementing optimal levels of service supply, both human-driven and automated vehicles can achieve higher occupancy levels, contributing to enhanced rider comfort and overall public transit experience. (Sadrani & Tirachini & Antoniou, 2022)

We identify two schools of thought for converting travel time saved into workable dollar amounts: direct economic contribution and personal value. Efforts to improve service frequency and reduce travel times are key to attracting riders, especially among lower-income residents who may prioritize avoiding fares. Strategies such as reallocating funding from lightly used routes to increase the frequency of busier routes and implementing measures like dedicated bus lanes and pre-boarding fare payments can make bus travel faster and more attractive.

Additionally, public transit systems aim to integrate with livable communities, promote economic vitality through region Public Transportation Association (APTA) assesses the former in its 2020 report on the Economic Impact of Public Transportation Investment, categorized into three transit trip types: business trips, commute trips, and personal trips (American Public Transportation Association, 2020). Their report defines time on business trips ("on-the-clock" trips) for workers as a direct productivity cost, set at the same rate as their cost of employment (i.e., wages, taxes, fringe benefits). Conversely, they suggest the time spent on commute trips between home and work are generally valued at half of a worker's wage rate, sometimes compensated as a wage premium by employers identifying the additional value of workers in congested transportation areas. Lastly, APTA argues time on personal trips conducted for non-work purposes have value to travelers but do not directly affect economic income flows, thus should be excluded from analysis (American Public Transportation Association, 2020).

The U.S. Department of Transportation (2016) concurs with APTA's percentage valuation of business and commute time, but evaluates transit travel time from a less economically driven and more individualistic perspective. USDOT asserts that local personal trips by surface modes of transport (including bus) should also be valued at 50 percent of one's total earnings, just as commute time. Their memorandum provides guidelines on hourly earnings rates of $27.20 for personal trips and $25.40 for business trips in 2015 dollars—approximately $35.60 and $33.24 in 2024 dollars (Bureau of Labor Statistics, 2024) to calculate the value of travel time savings (U.S. Department of Transportation, 2016). This guidance both takes a more holistic view of travel time as inherently valuable to bus riders and standardizes the value of people's time as equal, without need for considering case-by-case income. Applied to bus service frequency, the value of bus riders' minutes saved by increased frequency can be treated as the equivalent value of their time otherwise spent traveling or waiting.

Environmental Returns

One of the environmental benefits of public transit is to reduce greenhouse gas emissions, particularly from passenger cars and light trucks. While ridership has been affected by factors like the COVID-19 pandemic and the emergence of ridesourcing and bike/electric scooter sharing systems, public transportation still holds potential for emission reduction. By encouraging the shift from single-occupant trips in personal vehicles to trains and buses, public transit can contribute significantly to reducing emissions.

The flexibility of buses to be redeployed based on changing demand adds to their effectiveness in addressing environmental concerns (Congressional Research Service, 2022). On the other hand, public transit itself can also take initiatives to reduce greenhouse gas emissions while operating the transportation. For example, the METRONext plan in Houston aims to significantly reduce greenhouse gas emissions and combat air pollution by expanding and improving public transit options. With initiatives such as expanding light rail, creating a new rapid transit bus system, and enhancing overall bus service, METRONext will eliminate 500,000 auto trips daily by 2040, resulting in a reduction of 680,000 metric tons of greenhouse gas emissions annually. This plan is crucial for Houston's future as it addresses the city's growing population and job market while mitigating traffic congestion, fine particulate matter, and smog-forming pollution. By investing in a cleaner and more modern transportation system, METRONext will provide millions of residents with clean, efficient travel options, ultimately contributing to a healthier environment and a sustainable future for Houston. (Environment Texas, 2019)

By focusing on energy efficiency, improving water efficiency, waste reduction, and addressing stormwater effects, public transit aims to minimize its environmental impact. Key factors include reducing carbon footprints by optimizing ridership, achieving mode shifts away from individual cars, relieving congestion, and decreasing land use dedicated to cars and parking. Energy efficiency is improved by optimizing gross energy consumption per passenger mile traveled, with a focus on utilizing energy primarily for passenger transportation rather than heating or station electricity. Water efficiency, waste reduction, and stormwater runoff are also targeted areas for environmental improvement.

Efforts such as regional business equity and workforce development aim to increase ridership through service expansions and enhanced user experiences, contributing to environmental sustainability while generating financial value. This approach results in cost savings, grants, and revenue generation, making public transit a viable and beneficial option for both the environment and communities (SEPTA, 2020).

The United States has already set official guidance on how to calculate the monetary social cost of greenhouse gas emissions; in January 2021, President Biden reinstated the Interagency Working Group (IWG) to publish interim estimates on the social cost of carbon dioxide, nitrous oxide, and methane (Harvard Law School, 2023). Their report—still used by the Biden administration for bureaucratic rulemaking—values the social cost of carbon at $51 per ton and methane at $1,500 per ton in 2020 dollars at a three percent discount rate (Interagency Working Group on Social Cost of Greenhouse Gases, 2021). By contrast, a more recent report by the Environmental Protection Agency (2023) places the cost of carbon at significantly higher $190 per ton and methane at $1,600 per ton, also in 2020 dollars but at a two percent discount rate. In September 2023, Biden directed federal agencies to officially consider the social cost of greenhouse gas estimates in their budgets, including grant applications and administrative penalties (Harvard Law School, 2023).

Recommendations

Economic Returns

Given grant funding and sales tax revenue are not directly related to changes in bus route frequency, we propose that public agencies chiefly consider farebox revenue in evaluating the economic benefits of changing service frequency. It should be analyzed in conjunction with monthly ridership, which is the avenue through which service frequency purports to increase fare payers, as well as a metric that is already commonly collected by all transit authorities.

Regarding costs, we point to Jarrett Walker's guide to bus fleet operating expenses and emphasize time-based labor costs as the greatest source of expenses implicated by service frequency updates. While Walker poses a variety of variables that factor into this, we specifically identify the most relevant at the route-specific level as the number of drivers required to operate a line. This measure includes two effects of bus line frequency: headway (the common measure of line frequency) and average bus speed (considers increases to overall fleet speed deriving from less congested roads and bus stops). We call particular attention to the need for transit authorities to round up for drivers required to operate a line at their desired headway, necessitating coordination of headway with route lengths and expected layover/recovery rates to minimize overspending.

Finally, we remind public agencies of the less weighty but still significant distance-based and fleet-based costs to fuel, maintain, and store active buses. Purchases of new buses to meet greater demand should be treated as an economic cost of changes to service frequency.

Social Returns

Recognizing the various factors involved in the social return of public transit, we understand that travel and waiting time saved are critical components. Firstly, improvements in public transportation yield travel time savings for both existing passengers and new users. Existing passengers benefit from reduced access and egress time, waiting time, and in-vehicle travel time due to service enhancements. New users switching to public transit experience savings in driving time and parking search time, particularly if they had previously faced unattractive or congested driving commutes. Additionally, public transportation enables passengers to utilize their travel time for productive activities, enhancing economic efficiency.

Secondly, travel cost savings represent another dimension of social return. Users who reduce or eliminate a personal car experience savings in vehicle operating costs, purchase and ownership costs, and expenses associated with for-hire vehicles. Complementary mobility options further support the reduction of personal car ownership, enhancing cost savings for public transit users.

Reliability benefits also contribute to social return. Improvements in public transportation services enhance reliability through better information dissemination, improved dispatching and scheduling, and investments in infrastructure like dedicated lanes. This reliability fosters a smoother and more efficient travel experience, encouraging greater public transit usage.

Lastly, public transportation investments have broader impacts beyond users, benefiting non-users as well. By reducing congestion-related delays, public transit investments lead to travel time savings for other road users, even those not utilizing public transit. Similarly, personal car users benefit from reduced fuel consumption and expenses incurred from driving in congested conditions.

To accurately assess the social benefits of travel time, we advocate for the adoption of the U.S. Department of Transportation's approach, which considers the broader societal benefits of convenience beyond economic output. Utilizing survey data, transit authorities can approximate individuals' overall travel and wait times and determine whether bus riders are traveling for business or personal/commuting purposes. By applying existing public transit riders' saved time, new public transit riders' saved time, and non-public-transit users' saved time, transit agencies can calculate the overall value of time saved by adjusting bus service frequency, also using the average bus rider's wage rate multiplied by overall ridership during a given period:

$$Time\ Savings\ =\ (Existing\ Public\ Transit\ Riders\ Time\ Savings\ +\ New\ Public\ Transit\ Riders\ Time\ Savings)\ +\ Travel\ Time\ Savings\ for\ Non-Users$$

Where:

- Existing Public Transit Riders Time Savings: reductions in access and egress time, waiting time, and in-vehicle travel time, it can be calculated by:

  $$Existing\ Public\ Transit\ Riders\ Time\ Savings\ =\ Riders\ \times\ Avg.\ Rider\ Wage\ Rate\ \times\ ((\frac{Business\ Trips}{Total\ Trips})\ +\ 0.5\,(\frac{1-Business\ Trips}{Total\ Trips}))$$

- New Public Transit Riders Time Savings: reduced time spent driving and finding parking
- Travel Time Savings for Non-Users: reduced congestion-related delays, primarily benefiting road users

Households can save money by using public transit through reduced car ownership costs and lower trip expenses. The formula to calculate these savings can be expressed as:

$$Annual\ Household\ Savings\ =\ Annual\ Cost\ of\ Car\ Ownership\ -\ Annual\ Cost\ of\ Bus\ Ridership\ +\ Value\ of\ Travel\ and\ Wait\ Time\ Saved$$

Where:

- Cost Savings from Reduced Car Ownership: savings from relinquishing a car, such as savings on insurance, license and registration fees, and depreciation, typically amounting to approximately $6,200 annually.
- Cost Savings per Trip using Public Transit: the average savings per trip when replacing a Transportation Network Company (TNC) trip with public transit, which is around $15 per trip.

Another factor in social return is the benefit saved from gas. By using public transportation, individuals and households can reduce their gas payments. Importing the gas price and commuting information, we can calculate the transportation cost of commuting by cars:

$$Daily\ Cost\ to\ Drive\ =\ Gas\ Price/Gallon\ \times\ (\frac{Daily\ Commute\ Miles}{Fuel\ Efficiency\ in\ mpg})\ +\ Parking\ Cost$$

The last recommendation for determining social returns related to public transit is targeting the underprivileged community. The Transportation Equity and Demographic Index (TEDI) serves as a crucial tool in identifying areas of highest need within the METRO service area. By integrating various demographic and environmental indicators, TEDI enables a comprehensive understanding of community requirements, guiding equitable transportation investments and services. Instead of having a direct formula to get the TEDI, there are a few steps to follow:

1. Normalize each indicator value into a percentile rank ranging from 1 to 100. This is typically done by comparing the indicator value for each geographic area to the values of the same indicator for all other geographic areas.

2. Once all indicator values are transformed into percentile ranks, calculate the average percentile rank for each block group. This involves adding up the percentile ranks of all indicators for a block group and dividing by the total number of indicators.

3. The result of step 2 gives the TEDI rating for each block group. This rating represents the level of need for future transportation investments and services in support of equitable outcomes.

Environmental Returns

Not only does public transit bring economic benefits and social returns, but it also decreases greenhouse gas (GHG) emissions, therefore protecting the environment. Concluded from one report article, the savings from greenhouse gas emissions can be calculated by (U.S. Department of Transportation, 2010):

$$Savings\ from\ GHG\ emissions = (1 - 0.76) \times Heavy\ Rail\ transit\ GHG\ Emissions\ per\ Passenger\ Mile + 0.09 \times U.S.\ Transportation\ Greenhouse\ Gas\ Emissions$$

Moreover, the switch from traditional metro to electronic metro better improves the air condition by further reducing greenhouse gas emissions (Du & Kommalapati, 2021):

$$GHG\ Emissions = (GHG\ Emissions\ per\ Vehicle\ Mile \times Vehicle\ Miles\ Driven) \times Number\ of\ Vehicles$$

Where:

- GHG Emissions are the greenhouse gas emissions
- GHG Emissions per Vehicle Mile represents the emissions produced per mile traveled by a vehicle type (diesel, hybrid, electric)
- Vehicle Miles Driven is the total miles driven by the vehicles
- Number of Vehicles is the quantity of each vehicle type

Seeing that federal agencies like the Federal Transit Administration and Federal Highway Administration that approve grants to large transit authorities have received recent direction from President Biden to consider the social cost of greenhouse gasses in review of grant applications, we urge public agencies to explicitly consider the monetary savings from eliminating greenhouse gas emissions: $51 per ton of carbon in 2020 according to official federal guidelines. This number is conservative relative to the $190 per ton proposed by the EPA, underscoring that monetarily budgeting for environmental returns itself is no longer exceptional, but the new expected standard under a environmentally conscious TBL framework.

Next Steps

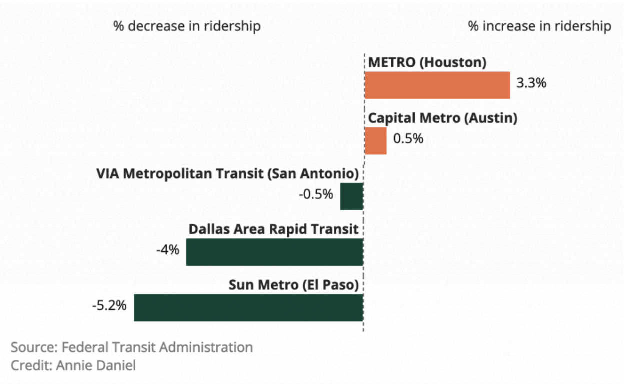
With the above proposed measures to evaluate economic, social, and environmental returns on public bus projects, we advise the West Houston Association's public agency clients—whether focused on bus service frequency or not—to apply a triple bottom line framework in evaluations of their mobility-related sustainable infrastructure investments. While we provide our outline for the most relevant and feasible tools and methods for this purpose, public agencies should take advantage of and incorporate their own agency-specific data (e.g., fare price, rider demographics, bus fleet composition) to tailor the measures to their own policy environments.

Houston METRO’s New Bus Network: A Case Study

Below, we provide an example application of our recommended measures to evaluate the TBL returns of a major bus system restructuring project. We selected Houston METRO’s 2015 New Bus Network because it featured increases to bus route frequency as its guiding principle to enhancing ridership. As a result, Houston represented one of only two major cities in 2017 in which transit ridership did not decrease, but increased (Schmitt, 2017). After offering context on Houston METRO’s transit investment, we incorporate data provided by the agency and profiles from the Federal Transit Administration to estimate the economic, social, and environmental returns of the New Bus Network. Although we lack full access to some of the data required for wholly accurate analysis, we approximate missing data and anticipate this case study acts at least as a proof-of-concept of the workability of our key TBL return measures.

In 2015, Houston METRO entirely redesigned its bus network to eliminate duplicative and low-demand routes and reallocate resources such that 80 percent were dedicated towards serving high-ridership and high-frequency lines compared to expensive to serve locations (Walker, 2014). The new system, founded on the principle of a high-frequency grid, was designed to maximize urban accessibility to high-frequency routes requiring only a single connection. In contrast with the former “hub-and-spoke” system centralizing downtown Houston as the primary network hub, bus routes extended into the rapidly growing westward and northward residential and job-dense areas of Houston (see Appendix A.1) (Walker, 2014). Many bus routes began earlier in the morning and ran later into the night, and 22 bus routes became part of a Frequent Network, running in 15-minute frequencies (Olin, 2020). This redesign, which took a blank-slate approach to Houston’s bus network, was widely lauded for its immediate positive impact on Houston public transit ridership (see Figure 1).

Figure 1. Change in Houston METRO ridership before and after Sep. 2015 vs. other Texas MTAs (Zbikowski 2019)



Source: Federal Transit Administration
Credit: Annie Daniel

Economic Returns

To calculate Houston METRO’s economic returns on the New Bus System, we will compare its farebox revenues, operating expenses, and new bus purchases from 2014 to 2016, the year before and after the restructuring was implemented.

In 2014, Houston METRO reported 59,993,163 annual unlinked trips on conventional transit buses, accounting for approximately 70.27 percent of systemwide ridership, translating to farebox revenues of $33,092,101 (Federal Transit Administration, 2015). In 2016, annual unlinked conventional transit bus trips fell to 58,852,033 (65.41 percent of trips), representing $25,625,235 in farebox revenues (Federal Transit Administration, 2017). Although this two-year decrease of 1 million trips in ridership and about $7.5 million dollars in farebox revenue may be an unexpected product of the New Bus System, it is compensated for by dramatic increases in light rail ridership and explained at least in part by greater network efficiency requiring fewer transfers (and therefore fewer unlinked trips) (Binkovitz, 2016). So, while financial revenues from the redesign may have fallen, social returns have risen. Yet, this finding is still worrisome in light of METRO officials’ original aim to increase ridership by 20 percent after two years of operation (Binkovitz, 2016). Even the increase in light rail ridership—from 12,701,038 unlinked trips in 2014 to 18,532,122 in 2016 (Federal Transit Administration, 2015; 2017)—cannot justify the evident fall in overall METRO fare revenues.

Operating expenses for METRO conventional transit buses, as expected from a decrease in headway and subsequent greater demand for drivers across the system via the Frequent Network, increased between 2014 and 2016, from $286,686,564 to $323,939,429 (Federal Transit Administration, 2015; 2017). However, the fact that the agency’s purchased transportation expenses only increased by about 3.16 percent from 2014 to 2015 (Federal Transit Administration, 2015; 2016b), we can assume changes to bus frequency did not demand large capital expenditures, but mere cost-saving reallocations of existing vehicles in their fleet.

Ultimately, we conclude that the economic returns on Houston METRO’s New Bus System are negative for the agency—about a $44,719,731 loss when narrowly comparing farebox revenues and operating expenses in years 2014 and 2016.

Social Returns

Bill payment website doxo states that 79 percent of Houston households pay for auto insurance, at an monthly average rate of $186, and 71 percent of households pay auto loans, an average of $567 per month (doxo, 2023). Multiplied by twelve months in a year, this means the average Houston household pays $4,830.84 annually on car ownership alone. Other daily flat costs of driving add to this burden: the average monthly cost of parking in Houston was $194.80 in 2023 (Assurance IQ Team, 2023), or $2,337.60 a year.

Lastly, distance-based costs create per-mile expenses of driving for Houston residents. Using an average $3.22 per gallon of gas in Harris County as of April 22, 2024 (AAA Gas Prices 2024) and nationwide average fuel efficiency of 24.4 miles per gallon of gasoline (Department of Energy, 2024):

$$Avg.\ Gas\ Cost/Mile\ to\ Drive\ in\ Houston = \frac{\$3.22}{24.4} \approx \$0.1320$$

In sum, a switch from driving to Houston METRO saves residents a sum of $7,168.44, plus about 13 cents per mile traveled.

Another product of declining conventional transit bus trips is a decrease in annual passenger miles, from 331,877,842 in 2014 to 292,209,926 annual passenger miles in 2016 (Federal Transit Administration, 2015; 2017). However, this decline of 39,667,916 passenger miles may be jointly attributed to more efficient bus routes (a decline in greenhouse gas emissions), as well as Houstonians presumably opting away from METRO buses and towards other modes of transport.

We operationalize annual vehicle revenue miles—the number of miles traveled with passengers on board—as a measure of improved route efficiency: Houston METRO conventional transit bus trip vehicle revenue miles rose from 33,271,845 in 2014 to 34,729,178 in 2016 (Federal Transit Administration, 2015; 2017), a 4.38 percent increase. We thus adjust the 2016 metric up 4.38 percent to 305,008,721 annual passenger miles, returning miles saved from efficient routes. This formulation assigns 12,798,795 passenger miles of the 39.7 million lost as miles of bus travel saved, and 26,869,121 passenger miles truly lost to alternate modes of transport.

Finally, we use data from the 2021 American Community Survey on commute methods to approximate the alternate modes of transport taken by riders who indeed switched away from bus. In Harris County, 68.7 percent of workers drove alone, 9.9 percent carpooled, 1.8 percent took public transit, 1.5 percent walked, and 15.1 percent worked from home (Understanding Houston, 2022). Given 65.41 percent of annual unlinked trips on Houston METRO were taken by conventional transit buses in 2016, we assume that 1.18 percent of Harris County residents took the bus to work, while 0.62 percent took some other Houston METRO mode. Altogether, we adjust the commute mode demographics to exclude residents working from home and public bus riders (19.28 percent of commuters) and find that about 85.1 percent drive alone, 12.3 percent carpool, 0.8 percent take non-bus public transit, and 1.9 percent walk.

Assuming 250 working days in a year and an average Houston-area daily commute of 24 miles (ABC13 Houston, 2018), the average Houston commuter travels 6,000 passenger miles a year. So, for every 6,000 passenger miles lost from bus to driving alone, a Houston resident accrues additional costs of driving:

$$Annual\ Cost\ of\ Driving\ in\ Houston = \$7,168.44 + .1320(6,000) = \$7,960.24$$

Given 292,209,926 annual passenger miles and 58,852,033 unlinked trips in 2016 (Federal Transit Administration, 2017), the average trip on a conventional transit bus was 4.97 miles. Thus, estimating that the average 24-mile commuter takes a daily average of 4.8337 trips (each costing a fare of $1.25), the annual cost of taking METRO buses is dwarfed by that of driving:

$$Annual\ Cost\ of\ Busing\ in\ Houston = 4.8337\ trips \times \$1.25 \times 250\ days = \$1,510.53$$

Returning to the 26,869,121 annual passenger miles lost in 2016 compared to 2014 (4,478.19 riders traveling 6,000 miles each), we assume an average of 2.25 people per carpool vehicle (California Division of Traffic Operations 2014) sharing the cost of car ownership and operation to calculate the average social economic loss per passenger mile converted from bus:

$$\begin{aligned} Avg.\ Change\ in\ Transportation\ Cost = {} & .851(1,510.53 - 7,960.24) \\ & + .123\left(1,510.53 - \frac{7,960.24}{2.25}\right) \\ & + .008(1,510.53 - 1,510.53) \\ & + .019(1,510.53 - 0) \approx -\$5,600.58\ per\ passenger \\ & \qquad converted\ per\ year \end{aligned}$$

$$\begin{aligned} Change\ in\ Social\ Transportation\ Costs = {} & 4,478.19\ passengers \\ & \times -\$5,600.58 = -\$25,080,438.81 \end{aligned}$$

In conclusion, the additional social economic burden imposed by decreases in bus transportation ridership sum up to over $25 million in 2016, compared to 2014.

We have, of course, identified social returns beyond those associated with car ownership. The Houston Bus Network majorly shifted resources into dense, high-ridership areas, making the moral trade-off of more expensive-to-serve Houston residents (Zbikowski, 2019). Transit advocacy group LINK Houston releases an annual Equity in Transit report on Houston METRO, and their first report after the New Bus Network was implemented reveals the dependency of marginalized communities on Houston METRO: 78 percent of transit riders are people of color (vs. 75 percent of Houston residents), 33 percent live in poverty (vs. 27 percent of Houston households), and only 2 percent of local bus riders come from $100,000-or-more income households (vs. 22 percent of all Houston households) (LINK Houston, 2018).

LINK Houston's Transportation Equity Demand Index takes fifteen indicators categorized from fundamental demographic need (e.g., poverty, low-income), likely higher transit use (e.g., zero vehicle availability, low education level), and human and built environment suitability (e.g., population density, street intersection density) to map communities in Houston with greater social need for public transportation (see Appendix A.3). High-need areas are particularly concentrated in southwestern and eastern Houston (see Figure 2). While the new bus routes from the New Bus Network appear to be concentrated around southwestern Houston and some of eastern Houston, they also dedicate a significant portion of resources to downtown areas and only reliably provide 15-minute frequency lines during peak transit times on weekdays (see Figure 3) (LINK Houston, 2018).

Figure 2. TEDI High-Need Areas in Harris County (LINK Houston 2018)

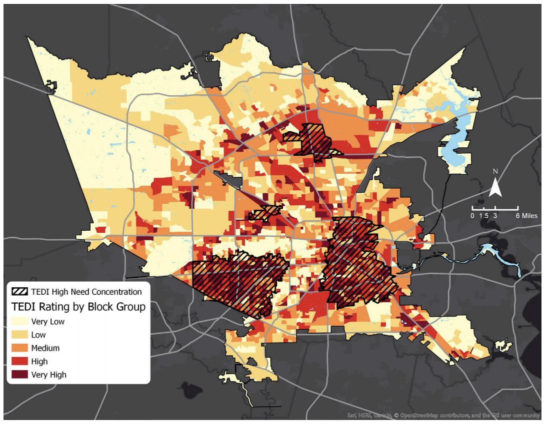
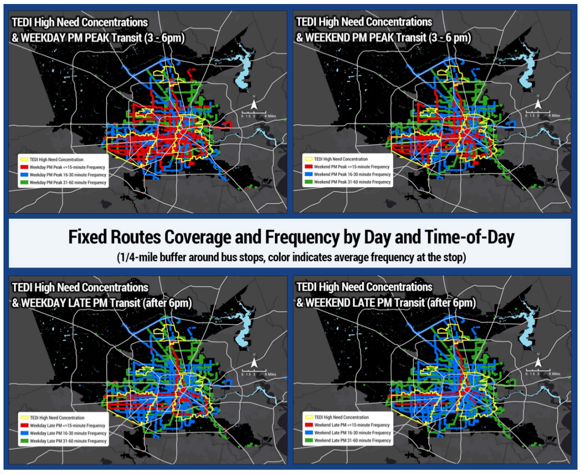
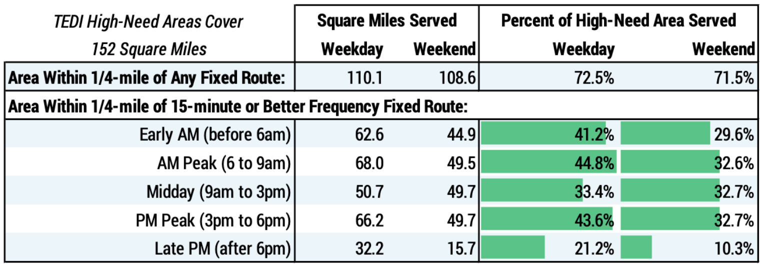


Figure 3. Houston METRO fixed route coverage by day and time-of-day (LINK Houston 2018)



Ultimately, an equity index evaluation of the New Bus Network's frequency coverage illustrates that, although over 70 percent of high-need areas are within a quarter-mile of a fixed bus route, significantly lower shares of these communities receive consistent 15-minute frequencies (see Table 1). After 6 PM, only 10 to 20 percent of these areas have a high-frequency route within a quarter mile. But even at peak weekday hours, when equitable access to transport to work and school is most crucial, still only between 43 and 45 percent—fewer than half—of TEDI high-need areas have quarter-mile access to high-frequency routes (LINK Houston, 2018). As a result, we conclude that the METRO's New Bus Network's principle of ridership-maximization may neglect expensive-to-serve areas in Houston where frequent transportation nonetheless acts as the bedrock to economic development and mobility.

Table 1. Transit Coverage and Frequency within TEDI High-Need Areas (LINK Houston 2018)



TEDI High-Need Areas Cover	**Square Miles Served**		**Percent of High-Need Area Served**	
152 Square Miles	**Weekday**	**Weekend**	**Weekday**	**Weekend**
Area Within 1/4-mile of Any Fixed Route:	110.1	108.6	72.5%	71.5%
Area Within 1/4-mile of 15-minute or Better Frequency Fixed Route:				
Early AM (before 6am)	62.6	44.9	41.2%	29.6%
AM Peak (6 to 9am)	68.0	49.5	44.8%	32.6%
Midday (9am to 3pm)	50.7	49.7	33.4%	32.7%
PM Peak (3pm to 6pm)	66.2	49.7	43.6%	32.7%
Late PM (after 6pm)	32.2	15.7	21.2%	10.3%

Our final social return measure, travel and wait time saved, can be measured for Houston METRO by again examining their FTA profiles: to begin with travel time, in 2014, conventional transit buses reported 2,537,329 annual vehicle revenue (passenger-carrying) hours for 33,271,845 revenue miles (Federal Transit Administration, 2015), or 13.11 miles per hour. Therefore, 331,877,842 passenger miles translates to 25,309,184.8 passenger hours on buses.

By contrast, 2016 travel speeds were 34,729,178 revenue miles over 2,851,972 revenue hours (Federal Transit Administration, 2017), or 12.18 miles per hour. Subtracting the miles we estimated were conversions from bus travel to alternate modes of transport, 305,008,721 passenger hours in 2016 make up 25,047,420.7 passenger hours on buses. Overall then, Houston bus riders spent 261,764.1 fewer travel hours in 2016 theoretically accomplishing the same travel as in 2014, likely due to more efficient routes given the decrease in average vehicle speed.

We must also consider changes in wait times from lower headway between buses on higher-frequency lines—a reformulation of our economic labor expense formula reveals the change in headway from before and after the New Bus Network redesign, holding all other variables constant:

$$Headway_{before} = Headway_{after}\left(\frac{Labor\ Expenses_{after}}{Labor\ Expenses_{before}}\right)$$

Holding *arguendo* that systemwide average headway per unlinked trip under the New Bus Network is 7.5 minutes (midway between zero and the 15-minute frequency), we plug in METRO's salary, wages, and benefits expenses reported by the Federal Transit Administration (2015; 2017):

$$Headway_{before} = 7.5(\frac{316{,}023{,}913}{274{,}674{,}350}) \approx 8.63\, minutes$$

Thus, bus riders save 1.13 minutes per trip under the new system. For 58,852,033 annual unlinked trips in 2016 (Federal Transit Administration, 2017), bus riders save:

$$Wait\ Time\ Saved = 58,852,033 \times \frac{1.13\, min}{60\, min/hr} \approx 1,107,450.44\ annual\ passenger\ hours$$

Summing travel and wait time together, the New Bus Network saves Houston riders about 1,369,215 hours.

Finally, we convert time saved to dollars. APTA reports that a negligible percentage of bus trips taken by Americans are for purposes other than commuting or personal reasons (e.g., recreation, schools, hospitals) (Clark, 2017). With the Bureau of Labor Statistics' recommended $27.20 standard for hourly earnings in 2015 dollars, the monetary social benefit from time saved on Houston METRO in 2016 is:

$$Overall\ Value\ of\ Time\ Saved = \frac{\$27.20}{2} \times 1,369,215 \approx \$18,621,318$$

Environmental Returns

Although METRO should have more precise data on the engine composition of its bus fleet in 2016, we concluded that in 2023, approximately 400 of its 1,200 bus fleet were diesel-electric hybrid models (Begley, 2023), and the agency had not purchased any electric buses until 2021 (Begley, 2021). Extrapolating these numbers to the New Bus Network era, we estimate about one-third of METRO's annual passenger miles were taken on hybrid buses, and two-thirds on conventional transit buses.

One study of different Houston METRO bus models found that their hybrid buses generated approximately 83 percent of the greenhouse gas emissions as conventional diesel buses (Du & Kommalapati, 2021) (see Appendix A.2). Paired with the Federal Transit Administration finding that typical bus transit with average occupancy generates about 0.64 pounds of CO_2 per passenger mile compared to 0.96 pounds by single-occupancy auto vehicles (Hodges, 2010), we estimate that trips on Houston's hybrid buses output 0.53 pounds of CO_2 per passenger mile. Additionally, a four-person carpool produces about 0.24 pounds of CO_2 per passenger mile, and light rail about 0.36 pounds (Hodges, 2010).

Putting our data together, we assume that two-thirds of the 12,798,795 annual passenger miles saved by efficient bus routes constitute pure savings of diesel bus emissions (0.64 pounds of CO_2

per passenger mile), and one-third represent savings of hybrid bus emissions (0.53 pounds of CO_2 per passenger mile):

$$Avg.\ Bus\ CO_2\ Emissions\ =\ (.64\times\frac{2}{3})\ +\ (.53\times\frac{1}{3})\ \approx\ .6033\ lbs/passenger\ mile$$

$$GHG\ Savings\ =\ 12,798,795(.6033)\ \approx\ 7,721,940\ lbs\ of\ CO_2\ diverted$$

With the aforementioned commute mode statistics, for the 26,869,121 passenger miles lost to alternate modes of transport, we assume that 85.1 percent went to single-occupancy auto vehicles (0.96 pounds of CO_2 per passenger mile), 12.3 percent to carpools (0.24 pounds), 0.8 percent to non-bus public transit (0.36 pounds for light rail), and 1.9 percent walk (0 pounds). Compared to our estimated 0.6033 pounds of CO_2 per passenger mile on METRO buses:

$$\begin{aligned} Avg.\ Alternate\ Mode\ CO_2\ Emissions\ =\ & .851(.96-.6033) \\ & +\ .123(.24-.6033) \\ & +\ .008(.36-.6033) \\ & +\ .019(0-.6033)\ \approx\ .2569\ lbs\ of\ CO_2\ emitted \\ & \qquad per\ non\ bus\ passenger\ mile \end{aligned}$$

$$GHG\ Generated\ =\ 26,869,121(.2569)\ \approx\ 6,902,677\ lbs\ of\ CO_2\ emitted$$

In sum, we witness GHG reductions of:

$$Overall\ Change\ in\ GHG\ =\ 6,902,677\ -\ 7,721,940\ =\ -\ 819,263\ lbs\ of\ CO_2$$

Divided by 2,000 pounds per ton, changes in METRO’s annual passenger miles saved 409.6315 tons of CO_2 in 2016 compared to 2014. Using the White House’s $51 per ton dollar conversion, the New Bus Network generated annual environmental returns via GHG reduction worth $20,891.21. Using the EPA’s $190 per ton recommendation, annual environmental returns are $77,829.99.

Summary

Our primary finding from this case study is that an accurate employment of our TBL return measures cannot be accomplished in isolation. Despite Houston METRO’s ambitious New Bus Network restructuring and its purported spikes in bus ridership in the immediate months after implementation, these spikes emerge for modes of transportation (i.e., light rail) that were not implicated in increased bus service frequency, and they were not sustained throughout the entirety of the year 2016. The bigger picture of the New Bus Network’s decline in ridership (and therefore economic, social, and environmental returns) is its backdrop of a nationwide trend in declining bus ridership (Schmitt, 2017) in favor of alternative modes of transport, a pattern that Houston METRO could not fully overcome.

The corresponding falls in bus ridership damaged Houston METRO's farebox revenues, transportation savings for households, and GHG emissions diverted from individual conversions of single-occupancy vehicles to public transit. Still, after accounting for ridership roll-off, coinciding reductions in bus line miles traveled due to more efficiently planned routes brought significant returns in the form of time saved and GHG emissions prevented. In addition to the conventional narrative of maximizing new ridership, our TBL returns analysis would suggest that Houston METRO should prioritize system planning that shortens trips for its existing ridership.

We believe it is highly feasible that controlling for the nationwide decline in bus ridership may yield positive economic, social, and environmental returns for the New Bus Network project. Our calculations reveal that large economic outlays are assumed in public infrastructure improvements, compensated for by social and environmental returns. Simultaneously, we highlight the enormous, eight-figure magnitude of potential economic and social benefits if the ridership trend was reversed. Thus, while we contend our recommended TBL return measures are still tenable for the purposes of evaluating bus service frequency changes, our latest findings also illustrate that said measures are significantly more reliable when incorporated into a difference-in-differences analysis, controlling for both industry-wide declines in ridership and their disparate impacts on different transit authorities.

Conclusion

This report dives into evaluating the triple bottom line (TBL) returns of public transit projects aimed at enhancing bus service frequency, encompassing economic, social, and environmental aspects. Our investigation followed three phases: background research on TBL returns, identification of key evaluation measures, and application to a real-world case study.

We explored diverse resources, including self-evaluation reports, federal guidance, and scientific literature, to narrow down key measures aligning with social and environmental benefits alongside financial considerations. Recommendations include farebox revenues and operational expenses for economic returns, passenger travel time saved and equitable community targeting for social returns, and greenhouse gas emissions reduction for environmental returns. Our analysis applied these measures to evaluate the Houston METRO New Bus Network restructuring, revealing economic losses, social gains, and environmental impacts.

The report highlights the importance of adopting a TBL approach for comprehensive evaluation, aligning with recent federal directives on considering the social cost of greenhouse gasses. It emphasizes the need for public agencies to integrate environmental considerations into their evaluations, ensuring positive contributions to economic, social, and environmental sustainability in public transit investments.

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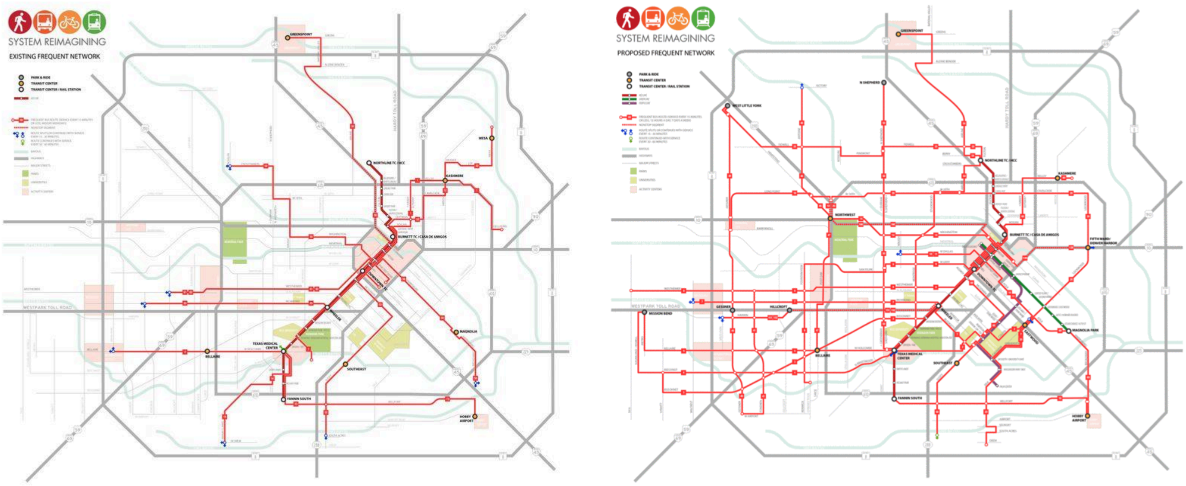
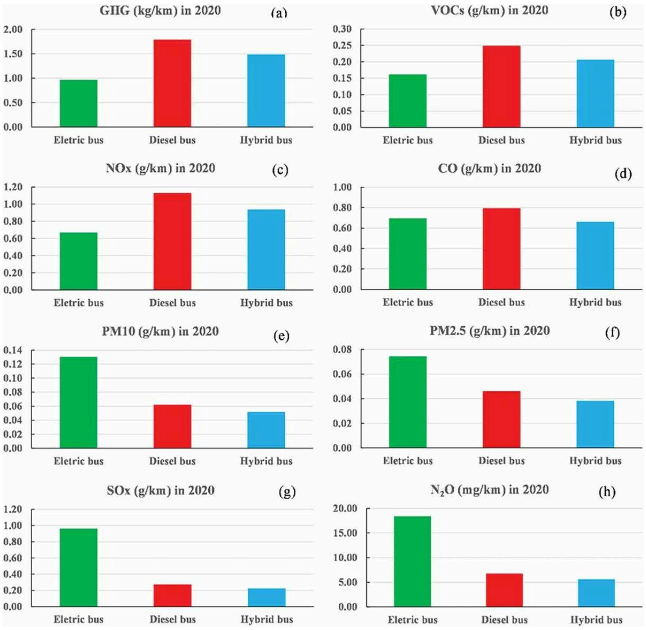
Appendix

A. Additional Figures

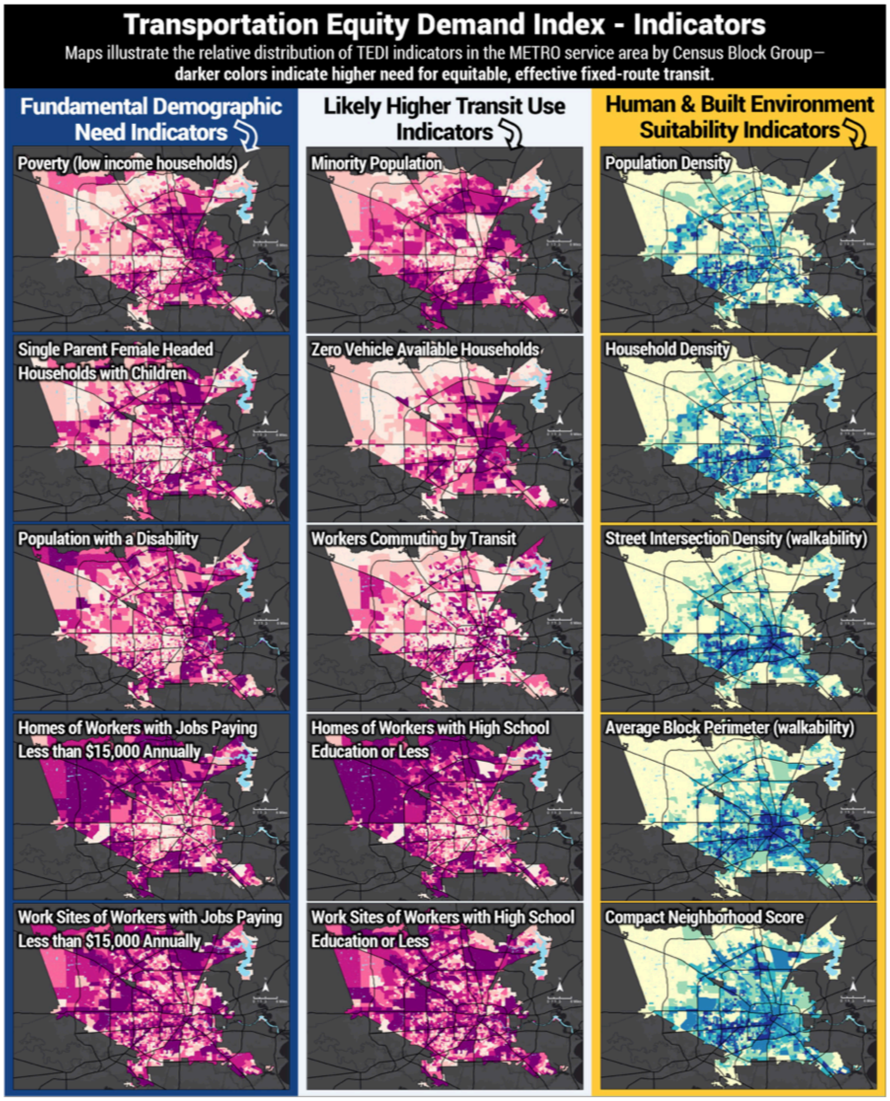
1. Houston New Bus Network System Reimagining Before and After Maps (Walker 2014)



2. Life-cycle emissions of conventional diesel, diesel hybrid, and electric buses of Houston in 2020 (Du & Kommalapati 2021)



3. Harris County Transportation Equity Demand Index Indicator Maps (LINK Houston 2018)



Transportation Equity Demand Index - Indicators

Maps illustrate the relative distribution of TEDI indicators in the METRO service area by Census Block Group– darker colors indicate higher need for equitable, effective fixed-route transit.

Fundamental Demographic Need Indicators

Likely Higher Transit Use Indicators

Human & Built Environment Suitability Indicators

Poverty (low income households)

Minority Population

Population Density

Single Parent Female Headed Households with Children

Zero Vehicle Available Households

Household Density

Population with a Disability

Workers Commuting by Transit

Street Intersection Density (walkability)

Homes of Workers with Jobs Paying Less than $15,000 Annually

Homes of Workers with High School Education or Less

Average Block Perimeter (walkability)

Work Sites of Workers with Jobs Paying Less than $15,000 Annually

Work Sites of Workers with High School Education or Less

Compact Neighborhood Score

B. Annotated Bibliography

American Public Transportation Association. (2020, April). *Economic Impact of Public Transportation Investment*. American Public Transportation Association. Retrieved April 15, 2024, from https://www.apta.com/wp-content/uploads/APTA-Economic-Impact-Public-Transit-2020.pdf

This APTA report reveals the multifaceted extent to which promoting ridership on public transportation can create unexpected but tangible economic gains, both for individuals and their broader communities. The study highlights productivity impacts of travel and vehicle ownership cost savings, reduced traffic congestion (and its positive externalities on even non-transit riders), and business productivity from broader access to labor markets. In addition to workforce productivity, investments in reliable, frequent public transport generates jobs in public transportation and its adjacent industries. Ultimately, sustained investment in public transportation can yield economic value of up to five times to original investment after 20 years.

This guide provides a comprehensive guide to the externalities of public transit improvements and can be beneficial to public agencies seeking an unambiguous monetary return on their investments. We note that this report takes a relatively idealistic and all-encompassing perspective on economic benefits, such as assuming time and money saved will be reinvested through additional consumerism or labor, or suggesting worker productivity will improve from access to diverse labor markets. Further, the report is largely qualitative and provides only macroeconomic estimates of investment multipliers. Still, we recommend this report to understand the full extent of how social returns overlap with economic returns.

Bharadwaj, S., Hostetter, K., & Stacey, B. (2018). *North Nashville's Transportation Future: An Employment, Environmental, and Equity Analysis*. University of Michigan Library. Retrieved April 15, 2024, from

The document outlines various considerations related to transit equity, community engagement, systems, infrastructure, development, affordability, employment, accessibility, environmental projections, and a transit sustainability index. Key points include the importance of understanding residents' transit choices, addressing historical

injustices like highway divisions, balancing growth and inclusivity to avoid gentrification, targeting low-income communities for accessibility improvements, and assessing environmental impacts and emissions. It also discusses transit-related employment opportunities, travel time considerations, and methods for evaluating transit sustainability based on demographic and social factors, employment destinations, and transit accessibility metrics.

Hodges, T. (2010, January). *Public Transportation's Role in Reducing Greenhouse Gas Emissions (January 2010)*. Federal Transit Administration. Retrieved April 15, 2024, from https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/PublicTransportationsRoleInRespondingToClimateChange2010.pdf

This report by the FTA presents detailed statistics on the expected greenhouse gas emissions of different modes of transportation, arguing that public transportation generates significantly fewer GHG emissions per passenger mile compared to auto, and particularly single-occupancy vehicle, trips. These findings continue into describing examples of how U.S. communities have integrated public transportation and land use strategies to synergize environmental effectiveness and user quality of life, then conclude by reviewing the FTA's institutional agenda to combat climate change, including increasing transportation choice, promoting equitable housing, and supporting existing communities.

Readers should note that this report was last updated in 2010, so precise numbers may not be as reliable as more recent studies. Otherwise, it offers robust insight into the relative environmental costs of a variety of modes of transportation, presenting metrics on how GHG emissions are affected by seat occupancy and broken down by activity source (e.g., fuel production, vehicle operation). The report places a large emphasis on interaction with land use and housing development, making it particularly useful for transit planners with flexibility in complete system redesigns. Lastly, the appendix includes extensive raw data on specific nationwide transit authorities' environmental returns, which can guide comparative analysis.

Kenton, W. (2023, December 17). *Triple Bottom Line*. Investopedia. Retrieved April 15, 2024, from https://www.investopedia.com/terms/t/triple-bottom-line.asp

This article introduces the concept of TBL. The triple bottom line (TBL) in economics emphasizes that companies should prioritize social and environmental concerns alongside profits. It introduces three key elements—profit, people, and the planet—to assess a company's commitment to corporate social responsibility and environmental impact. Coined by John Elkington in 1994, the TBL theory aims to evaluate a corporation's financial, social, and environmental performance over time. While implementing TBL can lead to benefits like employee retention, increased investments, and improved sales to socially conscious consumers, it also poses challenges such as measurement difficulties, high costs, and potential conflicts between different TBL components.

LINK Houston. (2018). *LINK Houston Equity in Transit: 2018 Report*. LINK Houston. Retrieved April 15, 2024, from https://linkhouston.org/wp-content/uploads/2018/11/LINKHouston_EquityinTransit2018_Report.pdf

LINK Houston's report on the equity of Houston METRO introduces background on ridership and trip characteristics of each mode offered by Houston METRO. It offers a full profile on METRO riders, from demographic characteristics to residential concentration to frequent transit destinations. Lastly, LINK Houston employs its Transportation Equity Demand Index (TEDI) of 15 indicators of transportation need to identify tracts in Harris County in greatest need of access to transportation. This equity lens results in recommendations that METRO extends its hours of high-frequency operation and shifts resources from highest-frequency lines to serve areas with less consistent access to proximate 15-minutes-or-less bus lines.

The *Equity in Transit* report provides for a clear method and example parameters through which public agencies can identify locales in greatest need of transportation for the purpose of advancing equity. Most of the data needed to implement such an analysis in any area is readily accessible through Census data and the American Community Survey. Most importantly, the report explains the rationale behind why equity in transit is a key factor to prioritize in an industry quick to hail raw ridership above all.

Urban Institute. (2021, December 28). *Transportation Access | Boosting Upward Mobility (Urban Institute)*. Upward-Mobility.urban.org. https://upward-mobility.urban.org/transportation-access

This report suggests that transportation inequity can lead to income inequity, affecting job accessibility, commute times, school access, absenteeism rates, and access to non-emergency medical appointments. Projects aimed at addressing transportation disparities should focus on improving access to social and economic opportunities for underserved and underrepresented communities. Low-income workers especially benefit from less frequently traveled routes that enhance their mobility and access to essential services.

U.S. Department of Transportation. (2015, August 24). *Expand Public Transportation Systems and Offer Incentives*. US Department of Transportation. https://www.transportation.gov/mission/health/Expand-Public-Transportation-Systems-and-Offer-Incentives

Transit travel boasts significantly lower crash rates and severity compared to automotive travel, with less than half the total death rate per passenger mile and a one-tenth fatality rate per mile. Additionally, transit contributes less to air pollution, emitting fewer CO, volatile organic compounds (VOC), and carbon dioxide (CO2) compared to automobiles. Moreover, individuals who walk or bike to transit stops tend to get more daily exercise, promoting healthier lifestyles.

U.S. Department of Transportation. (2016, September 27). *The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations*. Department of Transportation. Retrieved April 15, 2024, from https://www.transportation.gov/sites/dot.gov/files/docs/2016%20Revised%20Value%20of%20Travel%20Time%20Guidance.pdf

The Department of Transportation introduces the value of passenger travel time savings (VTTS) as a significant social return to consider in transit authorities' benefit-cost analyses. Even beyond VTTS, DOT defines social measures such as reliability and comfort that, although more difficult to measure, play important roles in the passenger experience. This report aggregates literature on VTTS in specific percentage and dollar terms, explicitly setting national guidance that agencies should employ median income measures rather than fine-tuned traveler-specific incomes to evaluate VTTS.

Given individuals' time is operationalized as a large portion of median hourly wage rates, VTTS constitutes a very large social return, rivaling the more conspicuous social benefit of financial savings on transportation costs. Public agencies can benefit from objective DOT guidelines on how to calculate their own transit networks' VTTS with a wide battery of variables that, without provided recommendations, may be too subjective to measure and confidently compare against other TBL returns and transit authorities.

Walker, J. (n.d.). *The Transit Ridership Recipe*. Human Transit. https://humantransit.org/basics/the-transit-ridership-recipe

This article outlines key factors influencing ridership in public transit systems. It emphasizes the importance of maximizing access to destinations, which is influenced by geography, demography, and frequency of service. Frequency is highlighted as a crucial factor, often more significant than speed, as it reduces waiting times and enhances the overall experience for passengers. The network effect of frequent service also improves connections across a city and ensures reliability in case of disruptions. Productivity and ridership increase with higher frequency.The success of transit service relies on strategic deployment in areas with high potential demand, easy accessibility, and manageable costs relative to customer base. Factors like density, walkability, linearity, and proximity are considered in determining locations for transit service. The example of Houston's weekend service parity with weekdays illustrates the importance of reliable service throughout the week for attracting ridership.

Walker, J. (2011, July 5). *Basics: Operating Cost (02box)*. Human Transit. Retrieved April 15, 2024, from https://humantransit.org/2011/07/02box.html

Jarrett Walker, a leading public transit consultant on Houston METRO's New Bus Network reimagining, goes into depth on the various factors that compose transit operating cost, the cost side of economic returns. Walker reviews various types of operating costs, then provides an array of equations relevant to calculating time-based labor costs, which he asserts comprises the dominant share of transit project costs. This guide provides both detailed technical equations to calculate service hours, as well as high-level reminders of how increasing bus frequency increases operating cost, while increasing bus speed lowers operating cost.

While likely simplified, Walker's guide elucidates the directions of relationships of different variables influencing operating costs, including specific considerations like

layover rates and the lumpy nature of operating cost. This helps transit authorities to pinpoint particular variables through which time-based costs can increase or decrease in a model accessible enough for public understanding. Public agencies should consider this resource in conjunction with others that can elaborate on the still significant operating distance-based, fleet-based, and administrative costs from vehicle purchases, fueling, maintenance, and storage.