Benefit-Cost & Social Equity Value Analysis Narrative

Houston METRO Northline Transit Center Project

Houston METRO

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Executive Summary

The Benefit-Cost Analysis (BCA) conducted for the Houston Metro Northline Transit Center project compares the costs associated with the proposed investment to its monetized benefits. To the extent possible, benefits have been monetized. Houston METRO is pursuing Houston-Galveston Area Council (HGAC) funding to improve transit user experience, as well as safety and security at the Center.

The Northline Transit Center project is anticipated to have significant impacts, including:

- Installed new and improved transit amenities at the Northline Transit Center
- Improved connectivity between the transit center and Houston Community College,
- Added parking spaces to accommodate more vehicles
- Improved facility construction to become more resilient to flood events; and
- Enhanced pedestrian and bicycle safety

Table ES-1 summarizes the changes expected from the project and the associated benefits. Monetized and non-monetized benefits are provided.

The Project is estimated to cost $40.4 million (in current dollars, and $37.8 in $2022) for construction, with a start date of construction in 2025 and completion in 2026; as such, benefits are expected to begin in 2027. Present value capital costs, using a 3.1% discount rate, are estimated to be $33.9 million. Annual costs for maintaining the facilities are estimated to be 1% of project costs and amount to $4.9 million in present value terms. The total discounted cost of the project, including both capital costs and annual amenity maintenance expenditures is $38.8 million (in $2022). Additional costs for the maintenance of transit amenities throughout the Northline Transit Center were included in the total project costs.

Table ES - 1: Summary of Improvements and Valuation of Benefits, Millions of $2022

Current Status or Baseline & Problems to be Addressed	Changes to Baseline/Alternatives	Benefits	Summary of Results, $M (Discounted at 3.1%)
Unsheltered bus stops along the transit route	Improve transit amenities at all transit stations along the route	Transit Amenity Benefits	$68.1
Total Benefits			**$68.1**

The period of analysis includes 20 years of operations after construction is completed. The BCA reveals that the project is expected to generate $68.1 million in discounted benefits, which means that the Net Present Value is $29.3 million and the Benefit-Cost Ratio (BCR) is 1.8 (Table ES-2). A summary of the relevant data and calculations used to derive the total monetized benefits and costs of the project are shown in Table ES-4.

Table ES - 2: Overall Results of the Benefit Cost Analysis, Millions of $2022

Project Evaluation Metric	Constant Dollars	Present Value, 3.1% Discount Rate
Total Benefits	$91.7	$68.1
Total Costs	$45.3	$38.8
Net Present Value	N/A	$29.3
Benefit-Cost Ratio	N/A	1.75

In addition to the monetized benefits presented in Table ES-1, the project would generate other benefits that are difficult to monetize. Among these, the project aims to improve the safety of users of the facility in the area which could further encourage local business investment and tourism in the area and improve local and visitor experience, which will produce economic development benefits. These benefits (economic development benefits, complete journey quality benefits, and pedestrian safety), if they could be expressed in monetary terms, would increase the overall benefit-cost ratio. Additionally, the project will improve short-term employment by creating local construction jobs and supporting local construction material suppliers.

In addition to the BCA, a Social Equity Value Analysis (SEVA) has also been implemented to determine the societal value of the project by *weighting* the distribution of benefits and costs by income group. SEVA is a relatively new form of analysis that captures the higher values of time and cost savings, along with other benefits, for people with lower incomes. The SEVA results take income equity considerations into account based on both local and national priorities. The results of this analysis indicate that the Northline Transit Center project is likely to generate substantial level of net benefits for the community.

The SEVA analysis indicates that the majority of beneficiaries (66%) are in the lower two income quintiles. These are the users that will experience the greatest share of benefits from the project. Over 40% of the benefits accrue to the lowest income users.[1] When viewed from an income-weighted perspective, based on their value for monetized benefits would be somewhat higher. In magnitude, the standard measure of benefits amounts to about $68 million but from an income-weighted perspective, this value is more than W$70 million.

Table ES - 3: BCA and SEVA Results in Present Value Terms ($ millions)

Types and Measures	BCA Results	SEVA Results
TOTAL[2] PV Benefits - Transit Amenity Benefits	$68.1	W$70.51
TOTAL PV Costs	$38.8	W$38.81
NPV	$29.3	W$31.7
BCR	1.75	1.82

Source: HDR inc, Economic and Social Value Analysis of the Northline Transit Center Proposal. Totals may not sum due to rounding.

[1] Income-weighted analysis of project benefits.

[2] Totals may not sum due to rounding.

Table ES-4: Summary of Pertinent Data, Quantifiable Benefits and Costs, in Discounted Millions of 2022 Dollars*

CY	Transit Amenity Benefits	Total Capital Costs	Total Annual Maintenance Costs	Net Present Value
2024	$0.00	$0.00	$0.00	$0.00
2025	$0.00	$17.20	$0.00	-$17.20
2026	$0.00	$16.69	$0.00	-$16.69
2027	$3.10	$0.00	$0.32	$2.78
2028	$3.15	$0.00	$0.31	$2.84
2029	$3.19	$0.00	$0.30	$2.89
2030	$3.24	$0.00	$0.30	$2.94
2031	$3.27	$0.00	$0.29	$2.99
2032	$3.31	$0.00	$0.28	$3.03
2033	$3.34	$0.00	$0.27	$3.07
2034	$3.38	$0.00	$0.26	$3.11
2035	$3.40	$0.00	$0.25	$3.15
2036	$3.43	$0.00	$0.25	$3.18
2037	$3.45	$0.00	$0.24	$3.21
2038	$3.47	$0.00	$0.23	$3.24
2039	$3.49	$0.00	$0.22	$3.27
2040	$3.51	$0.00	$0.22	$3.29
2041	$3.53	$0.00	$0.21	$3.32
2042	$3.54	$0.00	$0.20	$3.33
2043	$3.55	$0.00	$0.20	$3.35
2044	$3.56	$0.00	$0.19	$3.37
2045	$3.57	$0.00	$0.19	$3.38
2046	$3.57	$0.00	$0.18	$3.39
2047	$0.00	$0.00	$0.00	$0.00
Total	**$68.07**	**$33.89**	**$4.92**	**$29.26**

*All benefits and costs are discounted at 3.1 percent annually. Total capital costs include preliminary engineering costs, right-of-way costs, and construction costs Annual maintenance costs include maintenance of added amenities only.

1 Introduction

This document provides technical information on the benefit-cost analyses (BCA) conducted for the *Northline Transit Center* project. This BCA focuses on the monetizable benefits of the project for comparison with the project's total costs. The benefits of the project are based on the expected impacts on users of the facility, especially those who would board or exit buses at that facility. All benefits and costs in future years are discounted to present value terms using a real discount rate established by USDOT. The BCA is implemented using a customized Microsoft Excel model that adheres to the requirements and monetization factors promulgated by the USDOT in its BCA guidance for Federal grant programs. In accordance with these guidelines, a 3.1 percent discount rate is used to compute present values for all benefits and costs.[3] BCA results include both a benefit-cost ratio (BCR) and net present value (NPV).

2 Project Overview

The Northline Transit Center will construct a new multimodal transit center to replace the existing transit center, where the current lease is set to soon expire. The new transit center will house up to eight bus bays with new canopies and demolish the existing bus bay structures. During construction, the "Rebecca Property" will be used as a temporary transit center and then afterwards be converted to parking. New traffic signals will be installed throughout the project area to improve vehicle access. The service area for the new Northline Transit Center encompasses three major activity centers: Downtown Houston, Texas Medical Center, and Greenspoint. This Signature Bus Service Plan builds on previous METRO planning efforts to define corridor and service improvements to:

- Improve overall customer experience and comfort, including service reliability and passenger amenities.
- Improve speed and reliability in the corridor to and from activity centers and increase overall system connectivity to major north-south corridors.
- Provide attractive transit service that achieves even higher ridership.

2.1 Base Case and Alternatives

The base case (no build scenario) assumes that no improvements will be made to the existing transit facilities and routes, discouraging potential riders. The alternative (build scenario) will implement the full Northline Transit Center project. Improvements to bus stations will include installing:

- Electronic real-time displays,
- Information/emergency buttons,
- PA System

[3] USDOT, Benefit-Cost Analysis Guidance for Discretionary Grant Programs. December 2023.

- Platform/stop seating availability,
- Platform/stop weather protection,
- Restroom availability,
- Staff availability,
- Step-free access to stop,
- Step-free access to vehicles,
- Surveillance cameras,
- Temperature controlled environment,
- Ticket machines,
- Bike facilities,
- Car access facilities,
- Elevator,
- On-site ticket office; and
- Taxi pickup/drop-off

The types of impacts expected from the project and corresponding benefits and beneficiaries are described in the next section.

2.2 Types of Impacts

The project will benefit individuals using transit modes throughout the Northline Transit Center project area in their daily personal or business travel. These individuals will experience improved safety and pedestrian comfort. They will also enjoy improved transit amenity benefits at the Northline Transit Center. The installation of traffic signals and security cameras will improve pedestrian safety. The Northline Transit Center project will also include drainage and stormwater improvements, which will result in a reduced risk of flooding.

2.3 Project Cost and Schedule

The Project is estimated to cost $40.4 million (in current dollars, and $37.8 in $2022) for construction, with a start date of construction in 2025 and completion in 2026; as such, benefits are expected to begin in 2027. Present value capital costs, using a 3.1% discount rate, are estimated to be $33.9 million. Annual costs for maintaining the facilities are estimated to be 1% of project costs and amount to $4.9 million in present value terms. The total discounted cost of the project, including both capital costs and annual amenity maintenance expenditures is $38.8 million (in $2022). Additional costs for the maintenance of transit amenities throughout the Northline Transit Center were included in the total project costs.

Table 1: Project Cost Summary, in Millions of $2022

Cost Type	Capital Cost, Undiscounted	Capital Cost, Discounted
Estimated Capital Cost	$37.7	$33.9
Estimated Amenity Maintenance Costs (20-year lifecycle)	$7.5	$4.9
Total Costs[4]	**$45.3**	**$38.8**

[4] Totals may not sum due to rounding.

3 General Assumptions

The BCA measures benefits and costs for a 20-year period of operations. The monetized benefits and costs are estimated in 2022 dollars with future dollars discounted in compliance with USDOT BCA methodology requirements using a 3.1 percent real rate. The methodology makes several important assumptions and seeks to avoid overestimation of benefits and underestimation of costs. Specifically:

- Input prices are expressed in 2022 dollars;
- The period of analysis begins in 2022 and ends in 2046. It includes two construction years (2024 to 2025) and 20 years of operations (2026 to 2045);
- A constant 3.1 percent real discount rate is assumed throughout the period of analysis, consistent with USDOT Guidance; and
- Unless specified otherwise, the results shown in this document correspond to the effects of the build scenario.

4 Demand Projections

HDR developed travel forecasts based on the HGAC regional Travel Demand Model (TDM) for the base year and the forecast year (2045). The model estimates current and future *boardings* at Northline Transit Center. While many more bus users travel through the Transit Center on board a bus that continues to a final destination, only those that board or alight at the Center are assumed to benefit from the amenities. It is assumed conservatively that 50% of those that board at the Northline Center also alight form a bus at the Northline facility. Both users that board and alight at the Center benefit from the amenities. It is assumed conservatively that the amenity improvements do not lead to an increase in facility use.

HDR uses the results of the Travel Demand Model to forecast annual ridership in the build and no build scenarios. The project is expected to benefit existing and new transit users along the 82 Westheimer route. The project will affect travel demand from riders, travel times, and the number of daily bus trips. Table 2 summarizes the ridership results of the Travel Demand Model.[5]

Table 2: Assumptions used in the Estimation of Travel Demand

Variable Name	2024	2030	2045
Northline TC (Average Weekday Boardings)	2,132	2,600	3,900
Northline TC (Average Weekday Boardings and Alightings)	3,838	4,680	7,020
Northline TC (Annualized)	798,304	973,440	1,460,160

[5] Information was not available at the time of the analysis to differentiate bus users by peak and off peak periods.

5 Estimation of Economic Benefits

This section describes the measurement approach used for each benefit or impact category identified in *Section 2.2: Types of Impacts*, and provides an overview of the associated methodology, assumptions, and estimates.

5.1 Benefits and Estimation Methods

The methodology used for estimating each of the benefits listed is presented below. Ridership demand is based on current volumes of bus users. This approach is a conservative estimate of benefits. The benefits include:

- **Transit Amenity Benefits:** The project will install various amenities at the Northline Transit Center. These amenities include electronic real-time information displays, information and emergency buttons, PA systems, stop seating availability, stop weather protection, restroom availability, staff availability, step-free access to station/stop, step-free access to vehicle, surveillance cameras, temperature-controlled environment, ticket machines, bike facilities, elevator, on-site ticket office, and taxi pickup/dropoff. All riders that board or alight at the Center will benefit from these amenities. The model uses the build forecasts for riders and monetizes the benefits per USDOT's BCA Guidance (December 2023).

5.2 Assumptions

The assumptions for estimating benefits are summarized in Table 3. See Table A-10 in USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs. December 2023.

Table 3: Assumptions used in the Estimation of Economic Benefits

Benefit	Variable Name	Unit	Value	Source / Notes
Transit Amenity Benefits	Electronic Real-Time Information Displays	2022 $ / user trip	$0.32	See Table A-10 in USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs. December 2023.
	Information/Emergency Button	2022 $ / user trip	$0.25	
	PA System	2022 $ / user trip	$0.32	
	Platform/Stop Seating Availability	2022 $ / user trip	$0.20	
	Platform/Stop Weather Protection	2022 $ / user trip	$0.26	
	Restroom Availability	2022 $ / user trip	$0.15	
	Staff Availability	2022 $ / user trip	$0.08	
	Step-Free Access to Station/Stop	2022 $ / user trip	$0.33	
	Step-Free Access to Vehicle	2022 $ / user trip	$0.43	
	Surveillance Cameras	2022 $ / user trip	$0.32	
	Temperature Controlled Environment	2022 $ / user trip	$0.65	
	Ticket Machines	2022 $ / user trip	$0.11	
	Bike Facilities	2022 $ / user trip	$0.10	
	Car Access Facilities	2022 $ / user trip	$0.12	
	Elevator	2022 $ / user trip	$0.07	
	On-Site Ticket Office	2022 $ / user trip	$0.10	
	Taxi Pickup/Dropoff	2022 $ / user trip	$0.05	
	Waiting Room	2022 $ / user trip	$0.21	

5.3 Aggregation of Benefit Estimates

The results indicated that at a 3.1 percent real discount rate, a $39.9 million investment would result in $68.1 million in total benefits and a benefit-cost ratio of approximately 1.7. Transit amenity benefits are the only contributor to total benefits estimated for this BCA.

Table 4: Estimates of Economic Benefits, Millions of 2022 Dollars*

Benefit Category	Over the Project Lifecycle	
	Undiscounted	Discounted at 3.1%
Transit Amenity Benefits	$91.7	$68.1
Total Benefits	**$91.7**	**$68.1**

*Total may not sum up due to rounding

6 BCA Sensitivity Analysis

The BCA outcomes presented in the previous sections rely on a large number of assumptions and long-term projections, both of which are subject to considerable uncertainty.

The primary purpose of the sensitivity analysis is to help identify the variables and model parameters whose variations have the greatest impact on the BCA outcomes: the "critical variables."

The outcomes of the quantitative sensitivity analysis for the project using a 3.1 percent discount rate are summarized below.

- Using a 10-year analysis period results in a BCR of 0.89.
- A 25% decrease in beneficiaries from transit amenities leads to a BCR of 1.32.
- A 50 percent increase in project costs results in BCRs of 1.17.

Table 5: Sensitivity Test Results, Millions of 2022 Dollars*

Parameters	Change in Parameter Value	NPV	B/C Ratio
Current Scenario	n.a.	$29.26	1.75
Benefits Period	Assume a 10 year benefits period	($3.90)	0.89
Transit Amenity Users	Reduction in volume by 25%	$12.24	1.32
Project Cost	Increasing the total project cost by 50%	$9.86	1.17

7 Social Equity Value Analysis

7.1 Overview

In addition to a standard BCA, a Social Equity Value Analysis (SEVA) is performed to evaluate the distributional effects of the Houston Metro Westheimer BOOST project. SEVA is HDR's approach to implementing the weighted BCA (wBCA) concept and was performed to represent an alternative value of the Project to society – one that considers how the resulting benefits are distributed among different income groups. The distributional aspects involved in a wBCA include:

- the distribution of benefits (relative to incomes of affected persons);
- the magnitude and type of benefits and costs (as estimated by a BCA); and,
- the value of such benefits and costs (relative to individuals' marginal utilities of income).

A wBCA uses data on the income distribution of beneficiaries to determine the shares of total benefits and costs that would be gained and incurred, respectively, by different income groups. Then, weights are applied to those shares of total benefits and costs (as shown in **EQ. 1**) to determine a new measure of the Project's value. Weights are computed following economic theory and using economic evidence that captures the value of changes in monetized outcomes relative to the incomes of beneficiaries. The results of a wBCA can be viewed alongside a BCA and according to the Office of Management and Budget (OMB, 2023), either can be used as a rationale for the Project investment. Additional information on computation and application of weights is discussed in an appendix to this report.

A wBCA produces a new measure of societal value - a weighted Net Present Value (wNPV) in the form of:

EQ. 1

$$wNPV = \sum_{i}^{I}\left[\sum_{j}^{J} w_i^{\alpha} \cdot B_{ij} - \sum_{k}^{K} w_i^{\alpha} \cdot C_{ik}\right]$$

Income weights, $w_i^{\alpha} = (y_\alpha / y_i)^{\varepsilon}$, for each income group i are composed of reference incomes y_i, a benchmark income (y_α), and the elasticity of marginal utility of income (ε), and these weights are multiplied with the shares of benefits B_{ij}, by benefit category j, for each income group and the shares of cost contributions C_{ik}, by funding source k, for each income group. The results of a wBCA are measured in different units from a BCA. It is reasonable to define results of a wBCA in terms of "weighted dollars" to distinguish its quantitative results from those of a BCA, which is estimated in actual dollars. Weighted dollars refer to the value of the project relative to someone who earns an income at the benchmark level in the study area.

7.2 Weighted Benefits and Costs Results

The results of the wBCA are presented in Table 6 in the forms of unweighted and weighted benefits and costs, net benefits and BC ratio. In both standard and weighted analyses, net benefits are greater than zero and BC ratios are greater than 1. These results indicate that from an income-weighted perspective, the weighted benefits and weighted NPV are higher relative to the same magnitude in cost. The weighted BCR is slightly higher than the standard BCA results. In summary, the weighted BCR is higher than the standard BCA. This further emphasizes the importance of benefits to users and local populations, especially lower income populations that value benefits and costs on a differently than higher income groups. Details of this analysis is contained in an Appendix.

Table 6: Comparisons of weighted and unweighted BCAs

BCA Metric	BCA	Weighted-BCA
Benefits ($M)	68.07	W$70.51
Costs ($M)	38.81	W$38.81
NPV ($M)	29.26	W$31.7
BC Ratio	1.75	1.82

8 Appendix – Social Equity Value Analysis

8.1 Overview

The key process of a wBCA involves estimating weights, based on the marginal utilities of income MU_i, for individual "i" (or income group). These weights are computed for each individual or group from $w_i^{\alpha} = (y_{\alpha}/y_i)^{\varepsilon}$, relative on income levels y_i. The elasticity of utility of income ε reflects the amount by which utility changes from a change in income. Another constant, the benchmark income level y_{α}, is included to support the interpretation of results (van der Pol, Bos, & Romijn, 2017). That is, the benchmark income "normalizes" the utility value of monetized benefits and costs by defining a unit of utility to be equal to the utility of income at the benchmark. With normalized weights, the results of a wBCA are measured in "weighted dollars" to distinguish results from actual money. Formally, weighted dollars represent societal utility relative to the marginal utility of income of a person at the benchmark income.

The marginal utility of income has been shown, in various research studies, that a person's utility in ("or value for") an additional dollar declines as a person's income increases. For instance, if a project generates out-of-pocket cost savings for transit users, those savings would be valued more by a lower income person than one earning more. Across a population, this research suggests that persons with lower incomes would value improvements more than those with higher incomes. Key inputs to a wBCA include: (a) formation of income groups; (b) estimation of weights; (c) estimation of share of benefits and costs per income group; and (d) computation of weighted benefits and costs. Additional information is contained at the end of this section.

8.2 Theoretical Foundation of Weighted-BCA

An alternative to BCA draws from concepts related to Social Welfare Functions (SWF) which recognize differences in the value of benefits and costs for individuals (Adler M. , 2019). SWFs draw from decades of academic economic research that has focused on the impact of policies and projects on social welfare. A weighted-BCA is derived from a particular form of SWF – the utilitarian SWF ("USWF") – since it has appealing properties for project valuation. The principal difference between BCA and weighted BCA entails the representation of economic utility, or "satisfaction," from an alternative (e.g., a decision, action or event). A weighted BCA recognizes a more complete value of individuals' utilities in both the *consumptive value* of a good or service (as determined by a WTP) and the *value of a change in consumption (or income)* associated with a person's income. Adapting this concept to a project, the value is based on monetized net benefits and the value of net benefits differs for individuals at different income levels.

The utility value of a project outcome to an individual is captured mathematically as a marginal utility of income for an individual i, "MU_i". MU_i for different income levels indicate how the utility of each additional dollar declines as a person's income increases (Cowell & Gardiner, 1999). At the same time, the value of an additional dollar generates more utility for a lower-income person than a wealthier one. In project evaluations, it is assumed that MU_i relates to the monetized values of project outcomes and costs.

The MU_i enters a weighted-BCA equation as a "utility weight." Utility weights are multiplied with BCA-estimated benefits and costs (Fleurbaey & Rossi, 2016) to determine the societal utility of a project. Utility weights are computed for different levels of income of persons affected by a project. Higher weights are estimated for lower income persons, and vice versa. The magnitude of a weight is also determined by an elasticity of utility of income that determines how much additional utility is gained at different levels of income. Research studies, using a variety of methods, have estimated elasticity parameters that can be used in actual project evaluations (Acland & Greenberg, 2023).

Utility weights "w_i" are computed from the utility of income by taking the utility function's first derivative $\delta U/\delta y_i$ to reveal the amount by which utility changes relative to a change in income. In economic terms, this derivative is the marginal utility of income MU_i and is assumed to differ for each individual "i" who has a different level of income. EQ. 2 shows that MU_i, from an isoelastic utility function depends on the elasticity of income utility ε, and income level y_i:

EQ. 2:

$$w_i = MU_i = \left(\frac{1}{y_i}\right)^{\varepsilon}$$

This function is consistent with analytical findings which indicate that as income increases, MU_i declines (for any value of ε). The value of ε captures the degree to which an increase in income provides additional utility (Adler M. , 2016). Note that when $\varepsilon = 0$, all weights equal 1 and USWF reduces to a standard BCA approach. Values of ε have been estimated in a variety of economics studies and the choice of which value to apply in models is an important policy decision or evaluated through sensitivity analyses.

Most literature discusses "normalizing" weights with an income level, y_α , before multiplying them with benefits and costs (van der Pol, Bos, & Romijn, 2017). A normalizing income, or "benchmark income of a reference person", entails defining this income level equal to a unit of utility. The benchmark income is therefore a reference point for considering changes in utility for all beneficiaries relative to their incomes. By normalizing weights, the utilities at all levels of income are evaluated relative to the MU at that level of income.[6] The income weights of a y_α benchmark income are:

EQ. 3

$$w_i^{\alpha} = \left(\frac{y_\alpha}{y_i}\right)^{\varepsilon}$$

The results of a weighted-BCA are in units of "weighted dollars" that are not the same as the real currency dollars with value in a market. "Weighted dollars" measure utility from the

[6] A commonly discussed benchmark income in the literature is a population's median income, and its corresponding MU is based on y_{Med}^{ε}.

perspective of persons who earn a benchmark level of income. A weighted-BCA involves a sum of individual utilities from changes in project outcomes. For a project with J benefit categories and K sources of funding (and cost burdens at an individual level), it is necessary to determine the shares of benefits and costs that are attributable to each individual. As shown in EQ. 4, the weighted net present value "$wNPV$" equals the difference in weighted benefits and costs.

EQ. 4

$$wNPV = \sum_{i}^{I} \left[\sum_{j}^{J} w_i^{\alpha} \cdot B_{ij} - \sum_{k}^{K} w_i^{\alpha} \cdot C_{ik} \right]$$

Computing $wNPV$ is straightforward since weights can be applied to already estimated benefits and costs from a BCA. Of course, applying weights to benefits and costs in present value form requires the assumption that relative incomes do not change much over time. In addition, it is assumed that individuals in each income groups have the same characteristics of project use or impact and thus, the portions of benefits and costs can be estimated as the percentage of beneficiaries per group. Also, since utility weights are derived from the utility of a change in income, *monetized values* of benefits would have to be similarly interpretable as a change in income, as noted above.

8.3 Formation of income groups ($\mathbf{y_i}$)

A first step in conducting a wBCA entails compiling and analyzing income data for the project area. All income measures are estimated after accounting for taxes and transfers using data from the U.S. Census and U.S. Treasury (US Dept. of Treasury, 2022). This step forms income groups based on US Census data[7] on household income for Houston. The income groups specific to this project are presented in Figure 1. Income groups are determined for quintiles – five income bands, each of which is approximately 20% of the population. The income levels shown in Figure 1 are 'reference incomes'.

The results in Figure 1 are estimated after accounting for taxes and transfers using data from the U.S. Census and U.S. Treasury (US Dept. of Treasury, 2022). This step forms income groups that are used in establishing weights and estimating benefits and costs to individuals. US Census data on household income for Houston is presented in Figure 2.[8] Income groups are determined for quintiles – five income bands, each of which is approximately 20% of the population. Specifically, a simple log-log linear model can be used to estimate LN(Income cutoff) as a function of LN(Cumulative Percentiles).[9] With estimated parameters, it is straightforward to determine income levels for quintiles, as well as other percentile groupings. Reference incomes of each quintile are the same way, by statistically estimating income cutoffs

[7] These data are defined a gross household income (i.e. pre-tax and transfer).
[8] These data are defined a gross household income (i.e. pre-tax and transfer).
[9] The log-log models produce high r-squared statistics and provide good fits for incomes between the 5th and 95th percentiles.

and mid-points with a log-log function of cumulative percentiles. The results of the statistical analysis generate reference incomes for each quintile that are in turn used as values of y_i in computed weights.

Figure 1: Reference Incomes ($2022, thous.), Adjusted - Equivalized, Post-tax & Transfer

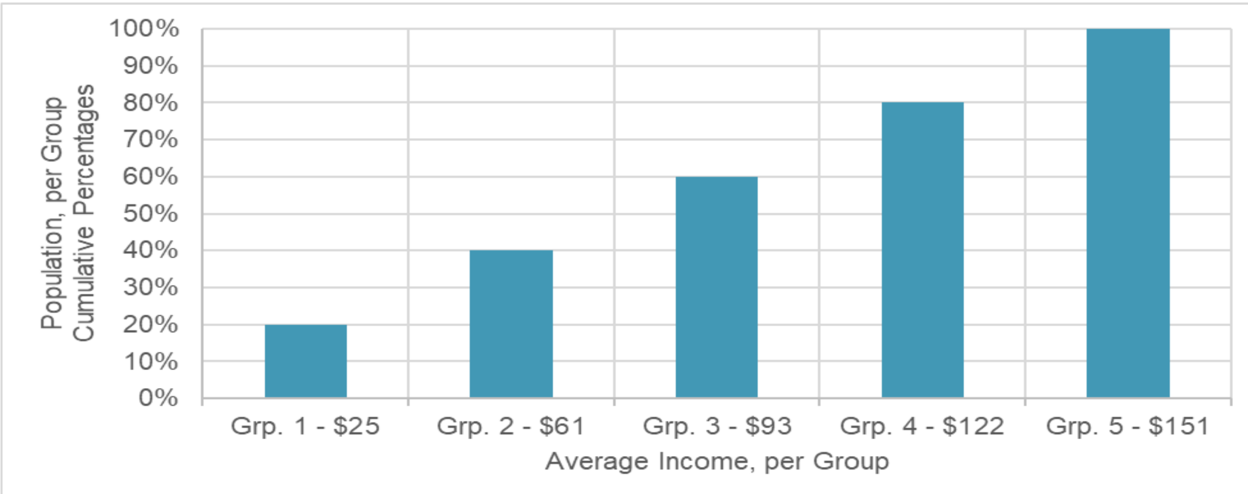
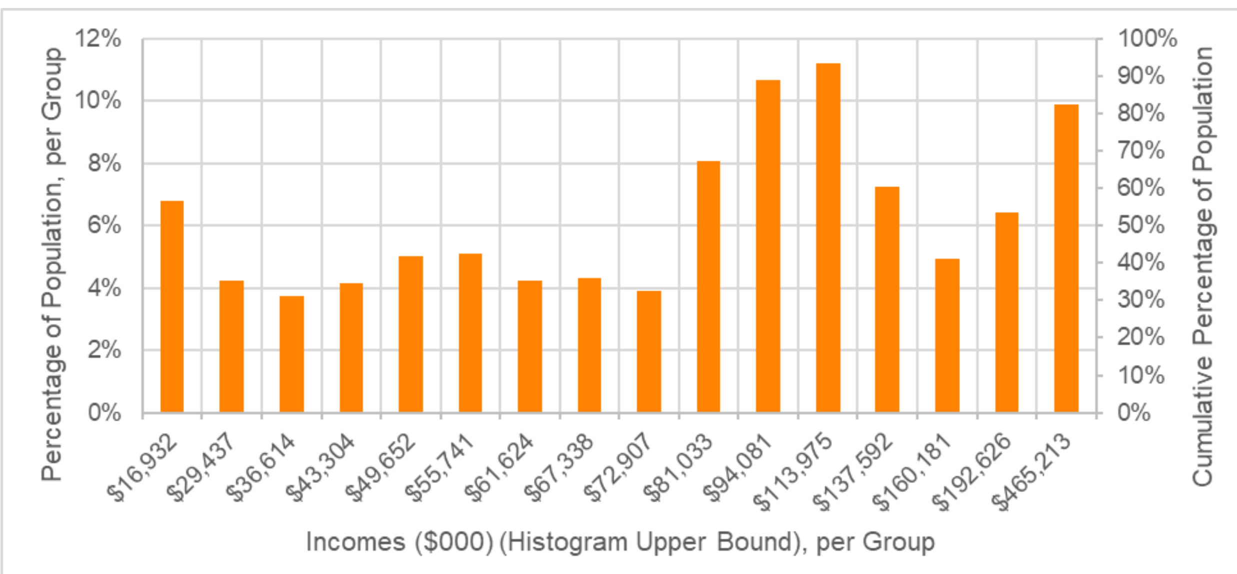


Figure 2: Regional Income Distribution, Houston Area ($2022)



8.4 Estimation of Weights

As noted above, income weights $w_i^{\alpha} = (y_{\alpha}/y_i)^{\varepsilon}$ require data for each income group i on the reference income y_i (computed above), a benchmark income (y_{α}), and the elasticity of marginal utility of income ($\boldsymbol{\varepsilon}$). The value of elasticity is set to 1.4, following OMB (OMB, 2023).[10]

For the benchmark income, economic theory does not provide guidance. The benchmark income is a way of normalizing the marginal utility of income so that results can be measured in more familiar units.[11] The specification of a benchmark income is important when considering the results of a wBCA in terms of the WNPV (EQ. 1) because weighted net benefits are directly proportional to the benchmark.[12] Most academic and applied wBCA, including the OMB (2023), reference the median income to be an appropriate benchmark income. [13] This specification though is set without accounting for how projects are funded.

8.4.1 Analysis of Benchmark Income ($\boldsymbol{y_{\alpha}}$)

This analysis sets the benchmark income to enable direct comparisons between the weighted and unweighted results for this specific project. Here, the benchmark income is computed to *normalize* weighted costs so that they equal the magnitude of unweighted costs. A *cost-normalizing* benchmark income relies on data on individuals' cost contributions (i.e. their taxes and fees) to governmental discretionary funds that could be used for this project, as discussed above in Step 2. This benchmark income produces weighted costs equal in magnitude to unweighted costs and in turn enables comparisons of weighted and unweighted costs and benefits even though they are in different units. The benchmark income is estimated by combining the shares of cost contributions by quintile via a weighted average with the marginal utility of income per reference income. The computation process begins with solving the weighted cost part of EQ. 1 in this equation,

EQ. 5

$$\sum_{i} \left(\frac{y_{\alpha}}{y_i}\right)^{\varepsilon} C_i = C$$

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[10] Other elasticity values from the literature range from 1.0 to over 2.0 (Acland & Greenberg, 2023).

[11] Without normalizing weights with a benchmark income, the results of a weighted BCA are in units of utility. With a benchmark income, the results are interpretable relative to the utility of someone who earns the benchmark income.

[12] The benchmark income is a constant and can be moved outside the summations in EQ. 1. In contrast, the benchmark does not affect the weighted benefit-cost ratio because it divides by itself and accordingly can provide an unbiased comparison with standard BC ratio results.

[13] Many other academic approaches assume the median income is a reasonable benchmark income. In such cases, neither the magnitudes of weighted and unweighted benefits or costs are likely to be comparable. In the approach developed here, the magnitudes of costs are set equal so that comparisons of benefit magnitudes are possible.

where C_i is the cost contribution (via taxes and fees) for group i and y_i is the reference income for group i and ε is the elasticity of marginal utility of income.[14]

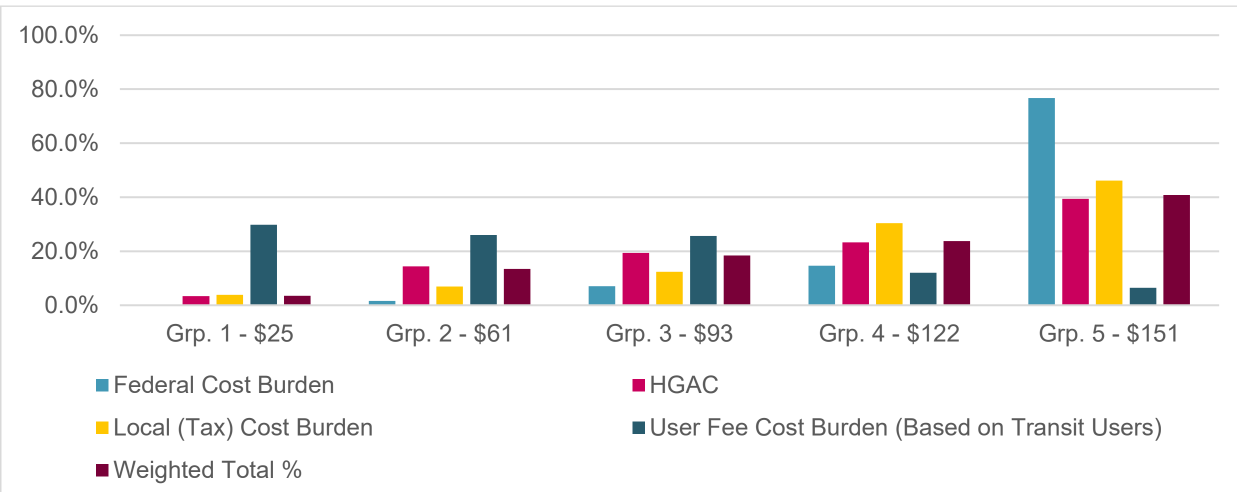
The proportions of cost burden, p_i, which indicate the percentage shares of total cost for a given funding source are defined such that $\sum_i p_i = 1$ and $p_i C = C_i$. Substituting this equality into:

EQ. 6

$$\sum_i \left(\frac{y_\alpha}{y_i}\right)^\varepsilon p_i C = C \rightarrow \left(\sum_i p_i {y_i}^{-\varepsilon}\right)^{-1} = {y_\alpha}^\varepsilon$$

The normalizing constant y_α is equivalent to a cost burden-weighted harmonic mean of incomes, for a given elasticity. Equivalently, this equation indicates that y_α is the income representing the weighted average of marginal utilities, where this weight is based on the shares of cost burdens.[15] Using the equation above and the data in Figure 3, the benchmark income is estimated to be about $91.4 thousand. The cost burden for HGAC funding is assumed to be approximated by state and local fundings sources.

Figure 3: Cost Share by Income and Funding Source



Data Sources: (METRO financials, 2023), (US Dept. of Treasury, 2022), (ITEP, 2018)

8.4.2 Adjusted Weights

For benefit categories in transportation projects that are monetized with a population average (or median) income, such as value of travel time savings, and safety (reduced accident risk), weights need to be adjusted. These adjusted weights reflect an equivalent measure of individualized benefits per income groups. Adjusted weights implicitly replace a population

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[14] This equation is applicable for one funding source, once the weighted cost burden is computed based on the overall sources of funding for different shares of total costs.

[15] A similar approach is explored by Van der Pol, Bos, & Romijn (2017).

valuation parameter with an individualized one since benefits are a function of income. For instance, the benefits of timing savings are directly proportional to the wage rates (i.e. in units of $ / hour) which are used to monetize the change in time (i.e. in minutes, say). Different adjustment weights are computed for different population value parameters (e.g. median or average incomes). The BCA categories that require adjusted weights are shown in Table 7.

Table 7: Adjusted Weights per Benefit Category

Benefit Category	Mode	Type of Weight Applied
Transit Amenity Benefits	Transit	Adjusted Weights (Average income)

The approach to adjusting weights involves combining weighted benefits with an additional ratio of incomes that includes the population-valued parameter. Standard benefits of travel time savings are computed by combining a function of the median wage rate, $f(\tilde{v})$[16], with average travel time savings $\bar{t}$. Standard benefits for individual i are $B_i^{\tilde{v}} = \bar{t} \cdot f(\tilde{v})$, but individualized benefits on a person's actual value of time v_i are $B_i^{v_i} = \bar{t} \cdot f(v_i)$. Since benefits are proportional to the valuation parameter, individualized time savings benefits can be estimated from a population-valued benefit by multiplying it with the ratio of travel time savings values, $B_i^{v_i} = \left(f(v_i)/f(\tilde{v})\right) \cdot B_i^{\tilde{v}}$.

Income-weighted benefits for travel time savings are equal to: $\hat{B}_i^{v_i} = w_i^n \cdot B_i^{v_i}$, assuming the incomes used to compute weights are proportional to wage rates $f(v)$, then weights can be computed as a ratio of wages, $w_i^n = \left(f(v_i)/f(\tilde{v})\right)^{\varepsilon}$. This assumption is reasonable if wages are the primary contributor to incomes, and this is certainly the case for most people. When benefits are estimated with a median income parameter, the ratio of the value of time savings can be combined so that $\hat{B}_i^{v_i} = w_i^n \cdot \left(f(v_i)/f(\tilde{v})\right)^{\varepsilon} \cdot B_i^{\tilde{v}}$, which simplifies to find weighted benefits per individual as $\hat{B}^{v_i} = (w_i^n)^{\varepsilon - 1} \cdot B_i^{\tilde{v}}$. The smaller elasticity value on weights, $\varepsilon - 1$, captures the remaining level of weighted dollars per income level i that be necessary to equal the total weighted benefits if the benefits were instead originally estimated at an affected persons' actual wage rate (their WTP for time savings).[17]

A general form for adjusting weights is $\tilde{w}_i^{\alpha} = \left(y_{\alpha}/y_{Pop}\right) \cdot (y_{\alpha}/y_i)^{\varepsilon - 1}$ where y_{α} is the benchmark income, y_i is the individualized valuation parameter for a benefit category, and y_{Pop} is the population value parameter with which benefits are estimated. Table 8 presents normal weights

[16] The value of travel time savings is typically defined as a function of median wages. For instance, non-business travel time is generally valued at one-half the median wage.
[17] This also means that a population parameter, such as a median wage rate, implicitly captures equity aspects of the project at an elasticity value of $\varepsilon = 1$.

and adjusted income weights based on benefits categories that are monetized with median and average incomes, respectively.

Table 8: Estimated Income Weights

Income Group	Average Ann. Adjusted HH Income ($000)	Adjusted Weights (average income)
1	$24.52	1.46
2	$60.88	1.01
3	$92.76	0.86
4	$122.47	0.77
5	$150.77	0.70

Data Source: (Replica, 2023), U.S. Census.

8.5 Estimation of Benefits and Costs by Income Group

8.5.1 Project Beneficiaries and Shares of Total Benefits

The next step in conducting a wBCA entails identifying individual project beneficiaries and their shares of total benefits. Specification of affected persons is important because each sub-group of affected persons may have a different distribution of income. These distributions of income are used to determine the shares of total benefits that would accrue to different income groups. The benefits and beneficiaries include:

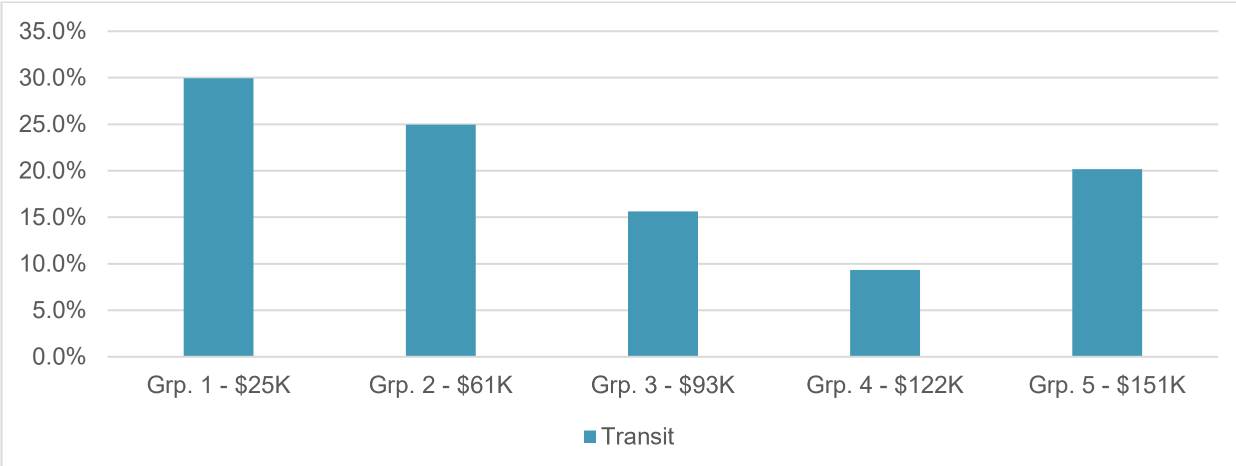
Table 9: Overview of Benefits and Beneficiaries

Benefit Category	PV Benefits (2022 $M)	Affected Persons, for Income Distribution
Transit Amenity Benefits	$68.1	Transit

Note: Present Value benefits are estimated with a 3.1% discount rate, except for GHG benefits which is estimated with a 2% discount rate.

Figure 4 presents the percentages of affected persons per income group. Income data for passenger vehicle, bike/ped users, and local households in the city are obtained from Replica and U.S. Census, respectively. These percentages are used to determine the shares of total benefits that would be gained per income group, for a given benefit category and set of affected persons. As shown, the shares of bike/ped users are highest in the lowest quintile. In addition, no one in the local city population group makes an income in the highest quintile in Houston.

Figure 4: Percentages of Users per Income Group, by Mode



Data Source: (Replica, 2023), U.S. Census

8.5.2 Sources of Project Costs and Shares of Total Cost Burdens by Quintile

Recall from EQ. 1 that project costs must also be apportioned across income groups before weights can be applied. Estimating the shares of costs contributed by people in each quintile involves analyzing the taxes and fees that contribute to discretionary funds (i.e. their 'cost burden'). It is assumed that any governmental revenues that are not dedicated to fund a specific activity would contribute to discretionary funds for use to fund projects like this.[18] In this analysis, costs are spread out among federal, state, and local sources. Thus, the cost burdens per quintile are obtained from US Treasury (US Dept. of Treasury, 2022) analysis of tax burdens by income groups for federal sources, and state and local sources, since METRO receives a combination of these sources for its capital and operating expenses. The shares of these sources of funding for METRO are obtained from its recent financial report. The allocation of costs to sources is determined by the Project and shown below in Table 10.

Table 10: Adjusted Capital Cost Burden Percentages

Cost Item and Source of Costs	Present Value Cost ($ million)	% of Funding by Source
Total Capital Cost*	$34.94	100%
HGAC	$34.94	100%
METRO	$0.00	0%
Operations & Maintenance Costs*	$4.92	100%
METRO	$4.92	100%

[18] For instance, federal payroll taxes would not be used for infrastructure projects because they would be fully directed to social security and medicare programs.

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