MEMORANDUM

To: York County Economic Development Alliance

From: Alta Planning + Design

Date: 04/08/2022

Re: Draft RAISE Benefit-Cost Analysis Memo

Benefit-Cost Analysis for Codorus Greenway RAISE Grant Application

Executive Summary

This Benefit-Cost Analysis (BCA) includes the benefits and costs for the proposed project that would be fully constructed if the RAISE grant is awarded. The analysis period was 22 years (2 years of construction and 20 years of operation) and assumes a useful service life of 30 years for the project. All costs and benefits are presented in 2020 dollars.

The following categories of benefits were considered in the BCA:

- **Safety:** The expected reduction in collisions and associated costs.
- **Environmental Sustainability:** Includes reductions in the following pollutants that impact air quality, CO_2, NO_X SO_2, and $PM_{2.5}$.
- **Quality of Life:** The expected reduction in mortality rates due to increased physical activity from new users of the project.
- **Economic Competitiveness:** Includes savings in household transportation costs and traffic congestion costs.
- **State of Good Repair:** Includes reductions in roadway maintenance costs.
- **Maintenance costs (dis-benefit):** Covers the ongoing costs of upkeep to the proposed project

It must be highlighted that one of the most innovative features of the project is its integration of the greenway with a complete reconstruction of the existing flood control system along Codorus Creek for the City of York and York County. The cost of the reconstruction of the system are included in the project and in this BCA. However, the benefits of the flood control system were not included in this analysis, thus skewing the benefit-cost ratio to a number lower than it will be in reality. Even though the flood control benefits would be anticipated to be of a significant scale, there are also other that could not be quantified through the BCA analysis, including:

- **Stormwater runoff:** In addition to the local and regional flood control benefits, this project directly addresses stormwater runoff from the project area and immediate surroundings, by removing hardscape and introducing more natural vegetated surfaces that better infiltrate runoff. However, the benefits could not be monetized because USDOT does not currently have recommended methodology for valuing reductions in stormwater runoff.
- **Resilience benefits:** This project enhances the ability for York to withstand adverse weather events, for example, by being the necessary first phase for a planned reconfiguration and future enhancements to the watershed flood control system; and by providing additional shade and vegetation near downtown York, thus potentially improving the microclimate in adjacent neighborhoods and decreasing the risks of heat stress in a warming climate. Benefits associated with resilience are difficult to calculate due to the unpredictable occurrence of disruptive events. The flood control benefits were not calculated because the USDOT BCA guidance does not provide guidance for such calculations.

- **Property Value Increases:** This project will significantly improve the quality and beauty of the Codorus creek and adjacent neighborhoods. This will have a positive impact on surrounding land values. Additionally, the stream reconfiguration will create new public space for York residents. Due to complexity and lack of available data the benefits could not be monetized.

Result Summary

Table 1 displays the total benefits by category included in the BCA. The capital costs included in the BCA are $30 million. This BCA estimates the project compared to the no-build scenario over a 22-year evaluation (2024-2045) and at a 7 percent real discount rate will have a net present value of **$12,625,078** and a benefit-cost ratio of **1.50 : 1.0.**

Table 1. Total Undiscounted Benefits over 20 years of Operation

CATEGORY	MONETARY VALUE (In 2020 dollars)
Safety Benefits	**$73,200,000**
Environmental Sustainability	**$69,000**
Quality of Life	**$11,740,000**
Economic Competitiveness	**$688,200**
State of Good Repair	**$89,700**
Maintenance Costs	**$(2,600,000)**
Residual Value	**$10,000,000**
TOTAL BENEFITS (UNDISCOUNTED)	**$93,240,000**

Table 2. Benefit-Cost Analysis Summary

CATEGORY	DISCOUNTED [1] VALUE (in 2020 dollars)
Net Discounted Benefits	**$38,040,000**
Net Discounted Capital Costs	**$25,420,000**
Net Present Value	**$12,625,078**
Benefit - Cost Ratio	**1.50**

[1] A 7% discount rate was used for all benefits and costs with the exception of carbon benefits which were discounted at 3% per year.

alta

Background

The benefit-cost analysis (BCA) for this project follows the principles documented in the USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs (2022), and uses the recommended parameter values where applicable. The BCA includes the benefits and costs for the project that would be fully constructed if the RAISE grant is awarded. The analysis period was 22 years (2 years of construction and 20 years of operation) and assumes a useful service life of 30 years for the project. All costs and benefits are presented in 2020 base year dollars. Benefits and cost streams were discounted using a 7% per year discount rate, with the exception of carbon benefits which were discounted at 3% per year. This memo contains a detailed explanation of the BCA methodology and the parameter values that were used.

Approach to Benefits and Study Area

This BCA approach expands on the methods suggested by the National Cooperative Highway Research Program (NCHRP) Report 552: Guidelines for Analysis of Investments in Bicycle Facilities by incorporating detailed local demographic information and using new data and research that has become available since Guidelines for Analysis was published in 2006.

While construction of the project will benefit all residents of and visitors to the region, those living within three miles (about a 15-minute bike ride) and one-half mile (about a 10-minute walk) of the project will have the most convenient access and will gain the most from its completion. Accordingly, this BCA focuses on the bicycling benefits attributed to residents living within three miles of the project and on the walking benefits attributed to residents living within one-half mile project. There are several benefit categories that benefit the region more widely (reduced roadway maintenance, healthcare costs), but these ranges are used to constrain this analysis to the main beneficiaries.

Benefits were primarily calculated by comparing walking and biking activity (including collisions) under the baseline to a Build scenario in which the Connecting Communities project has been implemented. The baseline and build scenarios encompass an identical geography (Census Tracts within 3 miles of the project). **The benefits included in the Net Present Value and Benefit-Cost Ratio calculations are the net difference between the two scenarios.**

Table 3: Summary Matrix

Baseline	Build Scenario	Type of Impacts
Walking and biking activity within 3 miles of the study area.	Construction of a multi-use trail to complete a citywide connection, with stormwater and public space improvements, and the estimated impacts on walking and biking activity within 3 miles of the study area.	Reduced mortality benefits, reduced bicycle and pedestrian collisions, reduced roadway maintenance, reduced traffic congestion, and reduced household transportation costs

Capital Costs

Refer to the main application for a detailed breakdown of projects costs. The capital cost schedule is shown in **Table 4.** This schedule includes design, engineering, permitting, contracting and installation.

Table 4. Project Construction Schedule and Cost

Construction Year	Anticipated Cost
2024	$16,150,000
2025	$13,850,000
Total Capital Costs	***$30,00,000***

The total annual maintenance costs are **$130,000 per year** (undiscounted) and they were included as a disbenefit in the benefit-cost ratio. An opinion of probable maintenance cost for the Codorus Beautification Initiative was prepared by engineering firm Buchart Horn on July 13, 2018 through the course of the 2020 Codorus Master Site Development Plan.

Useful Life

The expected useful life of the proposed trail facilities is 30 years. The window of analysis used was 20 years. A residual value of $10,00,000 (undiscounted) was claimed as a benefit in the final year of the analysis period, assuming linear depreciation.

Demand

To understand the benefits of the proposed project, demand analysis was conducted to support the 2020 DCNR Master Site Development Plan. Projected participation rates for users of the Codorus Greenway are based on the 2017 Park User Survey and Economic Impact Analysis for the nearby York County Heritage Rail Trail. The study bases its user counts on methodology published in the Rails-to-Trails Conservancy's Trail User Survey Workbook.

In 2017, approximately 263,850 user-trips were estimated to have been made on the 21-mile Heritage Rail Trail. The MSDP estimates that users of the Codorus Greenway will come from the county at large, by providing a missing connection for York residents west of the Codorus. Additionally, some users may visit the trail from the greater South-Central Pennsylvania region. The MSDP estimates there will be approximately 180,000 user-trips on the Codorus Greenway. The MSDP covered a 1.4 mile greenway. Further assessment following the completion of the MSDP concluded that the northern sections are infeasible in the short-term due to bridge replacements needed to accommodate the trail, and right of way needed along the rail line. Thus, the RAISE grant project is submitting for a shorter 0.9-mile segment. As such, the projected user trips were adjusted for the length of the RAISE grant project. Multiplying 180,000 by 64% resulted in 115,714 annual trips, or 317 trips per day. This figure was compared with similar greenways in Pennsylvania, using the counter dashboard maintained by the Rail-Trail Conservancy.[2] **Table 5** presents trail counts for identified similar trails in Pennsylvania.

The bicycle and pedestrian mode share was determined using the heritage rail trail 2017 Park User Survey and Economic Impact Analysis report. This included a user survey of 414 trail users on the Heritage Rail Trail. Some respondents stated other trail uses aside from walking and biking, including jogging, nature studies, fishing, and geocaching. These uses were considered walking, presuming they start or end with a walking trip. Horseback riding (0.4% of users) was not included when determining the mode split, as it did not fall in either category, and will not be permitted on the Codorus Greenway. This resulted in an estimated 43% bicycle share and 57% pedestrian share.

Table 5. Comparable trail and greenway demand

Trail	Location	Average Daily Users
Enola Low Grade – Manor Twp.	River Road/ Turkey Hill Nature Preserve	297
NW River Trail	Old River Road (NW Lancaster)	398
Weissport D&L Tral	Lehigh Canal	213
Lackawana Heritage Trail	S 7th Avenue (Scranton)	322

Benefits

Walking and Biking Activity

The CBA estimated current levels of walking and biking within the project area using American Community Survey (ACS) 2019 5-year data. **Table 6** displays the existing commute to work mode share for people within walking and biking distance of the proposed project. Population and demographic forecasts from the York County Planning Commission at the Transportation Analysis Zone (TAZ) level were used to estimate population growth in the study area over the analysis period. Population forecasts were collected for 2018, 2025, 2035, and 2045, and were interpolated for each intermediate year in the analysis.

[2] Rail-to-Trail Conservancy PA Dashboard, https://data.eco-counter.com/ParcPublic/?id=4275

Table 6. Means of Transportation to Work of People Living in the Study Area (2019 American Community Survey)

GSP Corridor	Employed Population	Drove Alone	Carpool	Public Transit	Bicycled	Walked	Worked from Home	Other
Walkshed (within half-mile)	12,606	67%	14%	6%	2%	7%	3%	1%
Bikeshed (within 3 miles)	52,156	78.9%	11%	2.5%	0.6%	3.3%	3.2%	0.3%

The means of transportation to work data was converted to daily estimates and extrapolated to annual trip volumes and broken into different trip types (i.e. commute, school, college, and utilitarian) using the existing travel patterns (**Table 7**) and data from the National Household Transportation Survey. The annual extrapolations account for the expected number of trips per week by trip type (i.e., commute, school, and college trips are expected five out of seven days a week, and other trip types are expected to occur seven days a week).

Table 7: Trip Purpose Multiplier[3]

	Bike	Walk
Utilitarian Trip Multiplier	5.33	8.77

Increase in Walking and Biking Activity

The Baseline assumes that the walking and biking mode share will remain constant and that trips will increase annually with expected population growth. In the Build scenario, the demand estimates for the proposed project were added to the existing walking and biking activity starting in 2026 (the expected opening year). The demand estimates were escalated by the expected population growth factor each year.

Decrease in Motor Vehicle Trips

Some of the estimated annual bicycle and pedestrian trips within the proposed project area are expected to replace motor vehicle trips. Calibrated to modal shift factors reported in literature[4], a univariate regression model estimates the motor vehicle trip replacement factor based on the percentage of trips that terminate in census block groups within ¼-mile of the proposed facility that are less than 4 miles. Additional details on the methodology are included in **Appendix I**. Trip distance data is provided by Replica for a typical travel Thursday in Fall 2019[5]. The motor vehicle trip replacement factor for all active mode trips is **0.356**.

[3] Travel Day Person Trips (in millions), NHTSA 2017 https://nhts.ornl.gov/
[4] Volker et al (2019). Quantifying Reductions in Vehicle Miles Traveled from New Bike Paths, Lanes, and Cycle Tracks
[5] Replica Places (2019). https://replicahq.com/

To estimate the number of vehicle-miles that might be replaced by bicycling and walking trips, **Table 8** shows the average trip distance of bicycling and walking trips by trip purpose. The number of vehicle miles reduced due to bicycle and pedestrian trips was calculated by multiplying the number of biking or walking trips by the trip replacement and trip distance factors.

Table 8: Trip Distance (miles)

	Bike	Walk
Commute Trips[6]	2.47	0.72
College Trips[7]	1.31	0.43
K-12 School Trips[8]	1.36	0.69
Utilitarian Trips[9]	2.28	0.83
Social/Recreational Trips[10]	2.73	1.12

Environmental Sustainability Benefits

For every vehicle-mile reduced, there is an assumed decrease in greenhouse gases and criteria pollutants. **Table 9** lists the reduction in greenhouse gases and criteria pollutants by vehicle-mile traveled. The cost to mitigate or clean-up those pollutants was calculated using the monetary values provided by the 2022 USDOT BCA Guidance Table A-6 for the corresponding year. Emissions types not listed in that table were not included in the analysis.

Table 9: Environmental Sustainability Multipliers

	Value (metric tons/VMT)
Particulate Matter 2.5 ($PM_{2.5}$) [i]	0.0000000044
Nitrous Oxides (NOx) [ii]	0.0000008
Sulfur Oxides (SO_2) [iii]	0.00000001
Carbon Dioxide[iv]	0.00044

[6] NHTS (2017). http://nhts.ornl.gov/tables09/fatcat/2009/aptl_TRPTRANS_WHYTRP1S.html
[7] Ibid.
8 Safe Routes National Center for Safe Routes to School, Trends in Walking and Bicycling to School from 2007 to 2013 (2015). http://www.saferoutesinfo.org/sites/default/files/SurveyTrends_2007-13_final1.pdf
9 NHTS (2017). http://nhts.ornl.gov/tables09/fatcat/2009/aptl_TRPTRANS_WHYTRP1S.html
10 Ibid

Quality of Life Benefits

More people bicycling and walking can help encourage an increase in physical activity levels, increased cardiovascular health, and other positive outcomes for users. The benefits from reduced mortality were calculated using the recommended values provided in the 2022 USDOT BCA Guidance (Table A-12) and the national distribution of age ranges and travel patterns. These benefits were only applied to the estimated number of walking and biking trips induced by the project (see **Demand** section). **Table 10** displays the multipliers that were used.

Table 10: Mortality Reduction Multipliers

Mortality Reduction Benefits of Induced Active Transportation	Value
Walking Value per Induced Trip	$7.08
Cycling Value per Induced Trips	$6.31
Walking Ae Proportion (20-74 years old)	68%
Cycling Age Proportion (20-64 years old)	59%
Trips induced from non-active modes	89%

Economic Competitiveness Benefits

For every vehicle-mile reduced, there is a reduction in household transportation costs and congestion costs. **Table 11** displays the multipliers use to calculate economic competitiveness benefit.

Table 11: Economic Competitiveness Multipliers

Value	
Household Transportation Cost Savings	**$0.43 per VMT**[11]
Congestion Cost Savings	**$0.06 per VMT**[12,13]

Safety Benefits

The proposed project would decrease conflicts between people walking and biking with motor vehicles. Collision data was covering a ten-year period (January 2011 through December 2020) was extracted from the Pennsylvania Crash Information Tool (PCIT).[14] Collisions under consideration all involved a bicycle and/or pedestrian and were located within a ¼ mile Euclidian radius of proposed greenway, where it would be expected that people walking and biking

[11] Our Driving Costs, AAA (2016). http://exchange.aaa.com/automobiles-travel/automobiles/driving-costs/#.Vw_xCPkrKUk
[12] Crashes vs. Congestion: What's the Cost to Society? AAA (2011). http://www.camsys.com/pubs/2011_AAA_CrashvCongUpd.pdf
[13] Crashes vs. Congestion: What's the Cost to Society? AAA (2011). http://www.camsys.com/pubs/2011_AAA_CrashvCongUpd.pdf
[14] Pennsylvania Crash Information Tool. 2022. https://crashinfo.penndot.gov/PCIT/welcome.html

would use the proposed project facilities when implemented **(Table 12**). The Crash Reduction Factor (CRF) Install Shared Use Path (CM ID: R37) was applied to the selected crashes and the benefits were monetized using the values provided in the 2022 USDOT BCA Guidance Table A-1 on MAIS Level data.

Table 122. Summary of Collisions within a 0.25 mile buffer distance

Project	Number of Collisions (2011-20)	Fatal	Critical	Severe	Serious	Moderate	Minor*	PDO
Total Collisions (2011-2020)	116	3	-	-	6	-	106	1
Average Annual Collisions	11.6	0.30	-	-	0.60	-	10.59	0.10

**Minor injury crashes included crashes labeled as "possible injury" and "injury of unknown severity" in PCIT. PennDOT defines possible injury as "Any injury reported or claimed which is not a fatal, suspected serious or suspected minor injury. Examples include momentary loss of consciousness, claim of injury, limping, or complaint of pain or nausea. Possible injuries are those which are reported by the person or are indicated by their behavior, but no wounds or injuries are readily evident."*[15]

Sate-of-good Repair Benefits

Table 13 shows the estimated roadway maintenance cost savings associated with a reduction in vehicle-miles traveled.

Table 133: State of Good Repair Multiplier

	Value (metric tons/VMT)
Roadway Maintenance Cost Savings	$0.06 per VMT[v]

[15] 2020 Pennsylvania Crash Facts and Statistics, Pennsylvania Department of Transportation. https://www.penndot.pa.gov/TravelInPA/Safety/Documents/2020_CFB_linked.pdf

Results

Table 14 through Table 23 display the results of the benefit-cost analysis for each year of the analysis period. This BCA estimates the project compared to the no-build scenario over a 22-year evaluation (2024-2045) and at a 7 percent real discount rate will have a net present value of **$12,630,000** and a benefit-cost ratio of **1.50 : 1.0.**

Table 144: Estimated Annual Bicycle and Walk Trips

Year	Baseline	Build Scenario	Additional Trips
2024	8,837,100	8,837,100	-
2025	8,940,000	8,940,000	-
2026	9,042,800	9,182,000	139,200
2027	9,145,600	9,285,700	140,100
2028	9,248,400	9,389,500	141,100
2029	9,351,200	9,493,200	142,000
2030	9,454,000	9,597,000	143,000
2031	9,556,800	9,700,700	143,900
2032	9,659,600	9,804,500	144,900
2033	9,762,400	9,908,200	145,800
2034	9,865,200	10,012,000	146,800
2035	9,968,000	10,115,700	147,700
2036	10,070,900	10,219,500	148,600
2037	10,173,700	10,323,200	149,500
2038	10,276,500	10,427,000	150,500
2039	10,379,300	10,530,800	151,500
2040	10,482,100	10,634,500	152,400
2041	10,584,900	10,738,300	153,400
2042	10,687,700	10,842,000	154,300
2043	10,790,500	10,945,800	155,300
2044	10,893,300	11,049,500	156,200
2045	10,996,100	11,153,300	157,200
		Total Additional Trips:	**2,963,400**

Table 155: Estimated Annual Vehicle Miles Reduced

Year	Baseline	Build Scenario	Additional Vehicle Miles Reduced
2024	3,414,100	3,414,100	-
2025	3,453,900	3,453,900	-
2026	3,493,700	3,559,300	65,600
2027	3,533,500	3,599,500	66,000
2028	3,573,300	3,639,800	66,500
2029	3,613,100	3,680,000	66,900
2030	3,652,900	3,720,300	67,400
2031	3,692,700	3,760,500	67,800
2032	3,732,500	3,800,800	68,300
2033	3,772,300	3,841,000	68,700
2034	3,812,100	3,881,300	69,200
2035	3,851,900	3,921,500	69,600
2036	3,891,700	3,961,800	70,100
2037	3,931,500	4,002,000	70,500
2038	3,971,300	4,042,300	71,000
2039	4,011,100	4,082,500	71,400
2040	4,050,900	4,122,800	71,900
2041	4,090,700	4,163,000	72,300
2042	4,130,500	4,203,300	72,800
2043	4,170,300	4,243,500	73,200
2044	4,210,100	4,283,800	73,700
2045	4,250,000	4,324,000	74,000
Total Additional Vehicle Miles Reduced:			**1,396,900**

Table 16: Estimated Annual Environmental Sustainability Benefits (Undiscounted)

Year	Baseline	Build Scenario	Benefits
2024	$-	$-	$-
2025	$-	$-	$-
2026	$151,100	$153,900	$2,800
2027	$155,500	$158,400	$2,900
2028	$161,600	$164,600	$3,000
2029	$166,100	$169,200	$3,100
2030	$171,000	$174,200	$3,200
2031	$174,500	$177,700	$3,200
2032	$178,100	$181,300	$3,200
2033	$181,600	$184,900	$3,300
2034	$185,200	$188,600	$3,400
2035	$188,900	$192,300	$3,400
2036	$194,300	$197,800	$3,500
2037	$198,000	$201,600	$3,600
2038	$201,800	$205,400	$3,600
2039	$205,600	$209,300	$3,700
2040	$209,500	$213,200	$3,700
2041	$213,300	$217,100	$3,800
2042	$217,300	$221,100	$3,800
2043	$223,100	$227,000	$3,900
2044	$227,100	$231,000	$3,900
2045	231,100	235,100	$4,000
		Total Benefits:	**$69,000**

Table 17: Estimated Annual Quality of Life Benefits (Undiscounted)

Year	Baseline	Build Scenario	Benefits
2024	$ -	$ -	$ -
2025	$ -	$ -	$ -
2026	$ 37,200,000	$ 37,750,000	$ 550,000
2027	$ 37,620,000	$ 38,170,000	$ 550,000
2028	$ 38,040,000	$ 38,600,000	$ 560,000
2029	$ 38,460,000	$ 39,030,000	$ 570,000
2030	$ 38,890,000	$ 39,450,000	$ 560,000
2031	$ 39,310,000	$ 39,880,000	$ 570,000
2032	$ 39,730,000	$ 40,310,000	$ 580,000
2033	$ 40,160,000	$ 40,730,000	$ 570,000
2034	$ 40,580,000	$ 41,160,000	$ 580,000
2035	$ 41,000,000	$ 41,590,000	$ 590,000
2036	$ 41,420,000	$ 42,010,000	$ 590,000
2037	$ 41,850,000	$ 42,440,000	$ 590,000
2038	$ 42,270,000	$ 42,870,000	$ 600,000
2039	$ 42,690,000	$ 43,290,000	$ 600,000
2040	$ 43,120,000	$ 43,720,000	$ 600,000
2041	$ 43,540,000	$ 44,150,000	$ 610,000
2042	$ 43,960,000	$ 44,570,000	$ 610,000
2043	$ 44,380,000	$ 45,000,000	$ 620,000
2044	$ 44,810,000	$ 45,430,000	$ 620,000
2045	$ 45,230,000	$ 45,850,000	$ 620,000
		Total Benefits:	**$11,740,000**

Table 18: Estimated Annual Economic Competitiveness Benefits (Undiscounted)

Year	Baseline	Build Scenario	Benefits
2024	$-	$-	$-
2025	$-	$-	$-
2026	$1,721,300	$1,753,700	$32,400
2027	$1,741,000	$1,773,500	$32,500
2028	$1,760,600	$1,793,300	$32,700
2029	$1,780,200	$1,813,200	$33,000
2030	$1,799,800	$1,833,000	$33,200
2031	$1,819,400	$1,852,800	$33,400
2032	$1,839,000	$1,872,600	$33,600
2033	$1,858,600	$1,892,500	$33,900
2034	$1,878,200	$1,912,300	$34,100
2035	$1,897,800	$1,932,100	$34,300
2036	$1,917,400	$1,952,000	$34,600
2037	$1,937,100	$1,971,800	$34,700
2038	$1,956,700	$1,991,600	$34,900
2039	$1,976,300	$2,011,500	$35,200
2040	$1,995,900	$2,031,300	$35,400
2041	$2,015,500	$2,051,100	$35,600
2042	$2,035,100	$2,070,900	$35,800
2043	$2,054,700	$2,090,800	$36,100
2044	$2,074,300	$2,110,600	$36,300
2045	$2,093,900	$2,130,400	$36,500
		Total Benefits:	**$688,200**

Table 19: Estimated Annual Safety Benefits (Undiscounted)

Year	Baseline	Build Scenario	Benefits
2024	$-	$-	$-
2025	$-	$-	$-
2026	$-	$3,660,000	$3,660,000
2027	$-	$3,660,000	$3,660,000
2028	$-	$3,660,000	$3,660,000
2029	$-	$3,660,000	$3,660,000
2030	$-	$3,660,000	$3,660,000
2031	$-	$3,660,000	$3,660,000
2032	$-	$3,660,000	$3,660,000
2033	$-	$3,660,000	$3,660,000
2034	$-	$3,660,000	$3,660,000
2035	$-	$3,660,000	$3,660,000
2036	$-	$3,660,000	$3,660,000
2037	$-	$3,660,000	$3,660,000
2038	$-	$3,660,000	$3,660,000
2039	$-	$3,660,000	$3,660,000
2040	$-	$3,660,000	$3,660,000
2041	$-	$3,660,000	$3,660,000
2042	$-	$3,660,000	$3,660,000
2043	$-	$3,660,000	$3,660,000
2044	$-	$3,660,000	$3,660,000
2045	$-	$3,660,000	$3,660,000
		Total Benefits:	**$73,200,000**

Table 20: Estimated Annual State of Good Repair Benefits (Undiscounted)

Year	Baseline	Build Scenario	Benefits
2024	$-	$-	$-
2025	$-	$-	$-
2026	$224,600	$228,800	$4,200
2027	$227,200	$231,400	$4,200
2028	$229,700	$234,000	$4,300
2029	$232,300	$236,600	$4,300
2030	$234,800	$239,200	$4,400
2031	$237,400	$241,700	$4,300
2032	$239,900	$244,300	$4,400
2033	$242,500	$246,900	$4,400
2034	$245,100	$249,500	$4,400
2035	$247,600	$252,100	$4,500
2036	$250,200	$254,700	$4,500
2037	$252,700	$257,300	$4,600
2038	$255,300	$259,900	$4,600
2039	$257,900	$262,400	$4,500
2040	$260,400	$265,000	$4,600
2041	$263,000	$267,600	$4,600
2042	$265,500	$270,200	$4,700
2043	$268,100	$272,800	$4,700
2044	$270,700	$275,400	$4,700
2045	$273,200	$278,000	$4,800
		Total Benefits:	**$89,700**

Table 21: Estimated Annual Maintenance Disbenefits (Undiscounted)

Year	Baseline	Build Scenario	Benefits
2026	$-	$(130,000)	$(130,000)
2027	$-	$(130,000)	$(130,000)
2028	$-	$(130,000)	$(130,000)
2029	$-	$(130,000)	$(130,000)
2030	$-	$(130,000)	$(130,000)
2031	$-	$(130,000)	$(130,000)
2032	$-	$(130,000)	$(130,000)
2033	$-	$(130,000)	$(130,000)
2034	$-	$(130,000)	$(130,000)
2035	$-	$(130,000)	$(130,000)
2036	$-	$(130,000)	$(130,000)
2037	$-	$(130,000)	$(130,000)
2038	$-	$(130,000)	$(130,000)
2039	$-	$(130,000)	$(130,000)
2040	$-	$(130,000)	$(130,000)
2041	$-	$(130,000)	$(130,000)
2042	$-	$(130,000)	$(130,000)
2043	$-	$(130,000)	$(130,000)
2044	$-	$(130,000)	$(130,000)
2045	$-	$(130,000)	$(130,000)
		Total Benefits:	**$(2,600,000)**

Table 22: Estimated Annual Benefits (Undiscounted)

Year	Baseline	Build Scenario	Benefits
2024	$-	$-	$-
2025	$-	$-	$-
2026	$39,290,000	$43,410,000	$4,120,000
2027	$39,740,000	$43,870,000	$4,130,000
2028	$40,190,000	$44,320,000	$4,130,000
2029	$40,640,000	$44,780,000	$4,140,000
2030	$41,090,000	$45,230,000	$4,140,000
2031	$41,540,000	$45,680,000	$4,140,000
2032	$41,990,000	$46,140,000	$4,150,000
2033	$42,440,000	$46,590,000	$4,150,000
2034	$42,890,000	$47,050,000	$4,160,000
2035	$43,340,000	$47,500,000	$4,160,000
2036	$43,790,000	$47,950,000	$4,160,000
2037	$44,240,000	$48,410,000	$4,170,000
2038	$44,680,000	$48,850,000	$4,170,000
2039	$45,130,000	$49,310,000	$4,180,000
2040	$45,580,000	$49,760,000	$4,180,000
2041	$46,030,000	$50,210,000	$4,180,000
2042	$46,480,000	$50,670,000	$4,190,000
2043	$46,930,000	$51,120,000	$4,190,000
2044	$47,380,000	$51,580,000	$4,200,000
2045	$47,830,000	$62,030,000	$14,200,000
		Total Benefits:	**$93,240,000**

Table 23: Estimated Discounted Net Costs and Benefits (discounted at 7%)[16]

Year	Discounted Costs	Discounted Benefits	Net Cumulative Discounted Costs and Benefits
2024	$(14,110,000)	$-	$(14,110,000)
2025	$(11,310,000)	$-	$(25,410,000)
2026	$-	$3,150,000	$(22,270,000)
2027	$-	$2,940,000	$(19,320,000)
2028	$-	$2,750,000	$(16,570,000)
2029	$-	$2,580,000	$(13,990,000)
2030	$-	$2,410,000	$(11,580,000)
2031	$-	$2,250,000	$(9,330,000)
2032	$-	$2,110,000	$(7,220,000)
2033	$-	$1,970,000	$(5,250,000)
2034	$-	$1,850,000	$(3,400,000)
2035	$-	$1,730,000	$(1,670,000)
2036	$-	$1,620,000	$(60,000)
2037	$-	$1,510,000	$1,450,000
2038	$-	$1,410,000	$2,870,000
2039	$-	$1,320,000	$4,190,000
2040	$-	$1,240,000	$5,430,000
2041	$-	$1,160,000	$6,580,000
2042	$-	$1,080,000	$7,670,000
2043	$-	$1,010,000	$8,680,000
2044	$-	$950,000	$9,630,000
2045	$-	$3,000,000	$12,630,000
Total Net Discounted Costs: $ (25,420,000)		**Total Discounted Net Benefits: $38,040,000**	**Net Present Value: $12,630,000**
			Benefit-Cost Ratio: 1.50

16 Carbon reduction benefits were discounted at 3%

Multiplier Notes

---

[i] The Safer Affordable Fuel-Efficient Vehicles Rule for MY2021-MY2026 Passenger Cars, BUILD Guidance 2020, Table A-7 and Light Trucks Preliminary Regulatory Impact Analysis (October 2018) https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/ld_cafe_co2_nhtsa_2127-al76_epa_pria_181016.pdf
[ii] The Safer Affordable Fuel-Efficient Vehicles Rule for MY2021-MY2026 Passenger Cars, BUILD Guidance 2020, Table A-7 and Light Trucks Preliminary Regulatory Impact Analysis (October 2018) https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/ld_cafe_co2_nhtsa_2127-al76_epa_pria_181016.pdf
[iii] The Safer Affordable Fuel-Efficient Vehicles Rule for MY2021-MY2026 Passenger Cars, BUILD Guidance 2020, Table A-7 and Light Trucks Preliminary Regulatory Impact Analysis (October 2018) https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/ld_cafe_co2_nhtsa_2127-al76_epa_pria_181016.pdf
[iv] Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf
[v] Kitamura, R., Zhao, H., and Gubby, A. R. Development of a Pavement Maintenance Cost Allocation Model. Institute of Transportation Studies, University of California, Davis. https://trid.trb.org/view.aspx?id=261768

MEMORANDUM

To: BCA Reviewers

From: Grace Young, Rohan Oprisko, Mike Sellinger, and David Wasserman, Alta Planning + Design

Date: April 1, 2022

Re: Appendix I: Modal Shift Model Notes

Modal Substitution Rates: Introduction

Modal substitution rates refer to the percentage of users of a facility who substituted one mode for another (Volker et al. 2019). These rates are often determined from survey instruments asking about alternative modes. When users substitute a carbon-free mode like biking for a carbon-intensive mode like driving, there is an associated emissions savings, proportional to the length of the trip. The following model provides a means for estimating the percentage of future facility users that will substitute a carbon-free mode in place of driving. This serves as a crucial step in identifying reductions in vehicle miles traveled and the emissions-saving benefits of the proposed facility.

Methodology

A series of univariate regression models were tested on peer-reviewed auto-to-bike substitution rates for projects in 10 cities around the United States. Six variables were collected at the city level and tested as inputs in a univariate regression model predicting the modal shift factor using an ordinary least squares regression from the statsmodels Python library. The variables are described in Table 1. The same variables were also tested in predicting the natural log of the modal shift percentage.

Data Review

Table 1. Peer-reviewed auto-to-bike modal shift factor and six demographic variables reported for the respective project cities[1]

City	Modal Shift (ratio)	Population Density (people per sq. mi.)	Median Income ($)	Travel Time to Work (min.)	% of Trips <4 Miles (ratio)	Active Mode Split (ratio)	Bike Mode Split (ratio)	Source
Los Angeles, CA	0.109	8,092	62,142	32	0.471	0.147	0.030	Matute et al. (2016)
Denver, CO	0.237	3,923	68,592	26	0.531	0.251	0.015	Piatkowski et al. (2015)
Boulder, CO	0.571	3,948	69,520	20	0.652	0.283	0.045	Piatkowski et al. (2015)
Littleton, CO[2]	0.724	3,215	76,105	26	0.512	0.254	0.060	Piatkowski et al. (2015)
Sacramento, CA	0.273	4,764	62,335	26	0.437	0.195	0.090	Piatkowski et al. (2015)

City	Modal Shift (ratio)	Population Density (people per sq. mi.)	Median Income ($)	Travel Time to Work (min.)	% of Trips <4 Miles (ratio)	Active Mode Split (ratio)	Bike Mode Split (ratio)	Source
Davis, CA	0.250	6,637	69,3709	23	0.636	0.220	0.095	Piatkowski et al. (2015)
Austin, TX	0.146	2,653	71,576	25	0.502	0.179	0.016	Monsere et al. (2014)
Chicago, IL	0.374	11,841	58,247	35	0.598	0.377	0.070	Monsere et al. (2014)
Portland, OR	0.202	4,375	71,005	27	0.538	0.267	0.027	Monsere et al. (2014)
San Francisco, CA	0.263	17,179	112,449	34	0.547	0.245	0.060	Monsere et al. (2014)
Washington, DC	0.202	9,856	86,420	31	0.564	0.311	0.018	Monsere et al. (2014)

Notes:

min. : minute

sq. mi. : square mile

1. Adapted from Volker et al. 2019.
2. Littleton, CO, was removed as an outlier in this modeling exercise for both final models.
3. All sources can be found in the Volker, J et. al (2019) paper specified in the references section.

Results

We found two acceptable models for contextual estimation of modal substitution rates given the available data: the examination of short trips (under 4 miles) and the active mode split model. Alta's preferred model is the examination of short trips due to its theoretical consistency with the idea that short trips are indicators that a higher proportion of vehicle trips can be converted to active modes given improved infrastructure and support. Alta uses the active mode split model depending on the available data sources on a given project or for sensitivity analysis to generate a conservative estimate.

Correlation and R-Squared

Table 2. Variable performance in correlation test and ordinary least squares univariate regression

Variable	Source	Correlation with Modal Shift	Correlation with ln (Modal Shift)	Adjusted R-Squared Predicting Modal Shift		Adjusted R-Squared Predicting ln (Modal Shift)	
				No Constant	With Constant	No Constant	With Constant
Population Density	Census	-0.21	-0.11	0.411	-0.063	0.663	-0.098

Variable	Source	Correlation with Modal Shift	Correlation with ln (Modal Shift)	Adjusted R-Squared Predicting Modal Shift		Adjusted R-Squared Predicting ln (Modal Shift)	
				No Constant	With Constant	No Constant	With Constant
Median Income	Census	-0.01	0.03	0.689	-0.111	0.813	-0.110
Travel Time to Work	Census	-0.32	-0.30	0.653	0.001	0.864	-0.014
Percent of Trips Under 4 Miles	Replica Places (2022)	0.31	0.41	0.744	-0.005	0.805	0.076
Active Mode Split (all trips)	Replica Places (2022)	0.39	0.53	0.763	0.057	0.709	0.200
Bike Mode Split	Replica Places (2022)	0.32	0.43	0.654	0.003	0.479	0.090

Note:
All values reported in this table are for models without the Littleton, CO outlier removed.

Linear Relationship Plots

Figure 1 and Figure 2 show the linear relationship between the log of modal shift and the percentage of trips less than 4 miles or active mode share, respectively. Littleton, CO, is identified as an outlier in both cases and thus removed for the final model development.

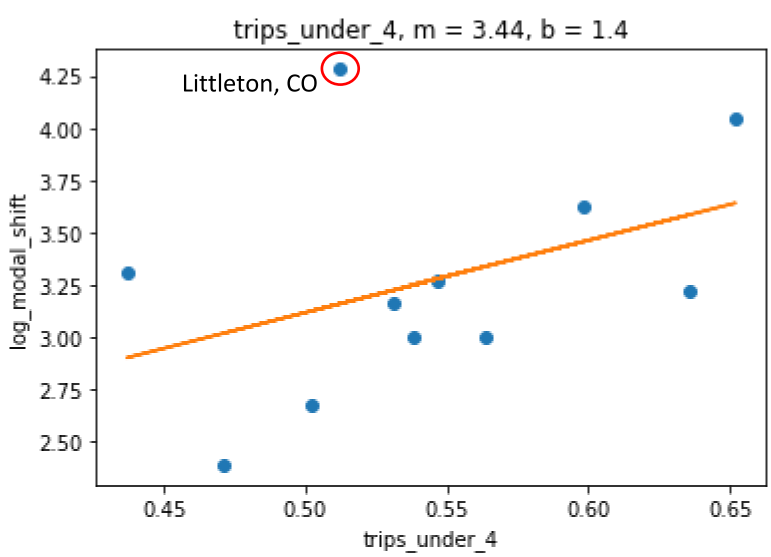

Figure 1. Modeled Relationships Between the Percentage of Short Trips and the Log of Modal Shift

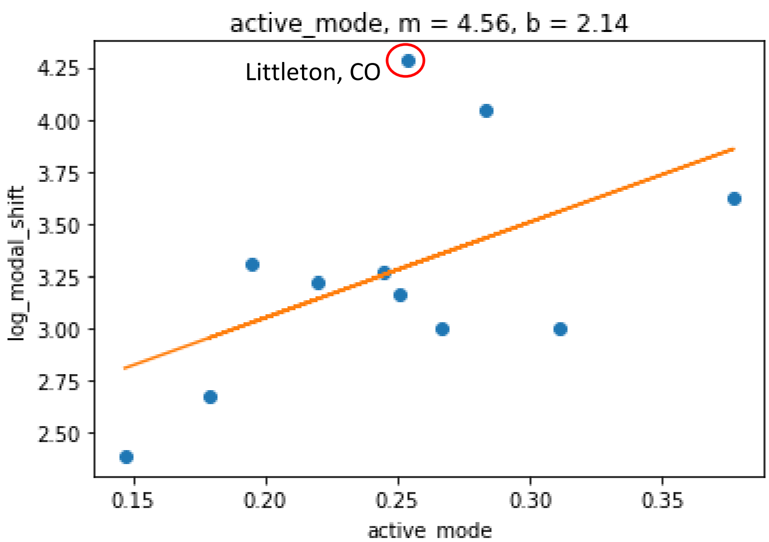

Figure 2. Modeled Relationships Between Active Mode Share and the Log of Modal Shift

Final Model Summaries

The two acceptable models are summarized in Table 3, along with the derived equations for applying each to a project-specific context.

Table 3. Model summaries for acceptable final models

Dependent Variable	*Log modal shift percentage*		Dependent Variable	*Log modal shift percentage*	
R-squared	*0.424*		R-squared	*0.414*	
Independent Variable	Coefficient	P-Value	Independent Variable	Coefficient	P-Value
Percent of trips under 4 miles	4.39	0.041	Active mode share	1.85	0.045
Constant	0.77	0.462	Constant	2.08	0.002
Equation			Equation		
ln(modal shift %) = 0.77 + 4.39*(% trips under 4 miles)			ln(modal shift %) = 2.08 + 1.85*(% active mode share)		

Discussion

These models enable a flexible and actionable approach to provide context-sensitive estimates of potential modal substitution rates given investments in multimodal infrastructure that are suitable for transportation planning practice. This approach aligns well with the understanding that compact, mixed-use locations with small urban footprints and high destination access encourage shorter trips and active travel (NASEM 2014). These models provide a decision-support tool to make informed and context-sensitive assessments of potential modal substitution rates given a project study boundary. Understanding how much reduction in vehicle miles traveled is possible given investments in active transportation is relevant to choosing a quick and responsive model.

However, there are limitations to this approach worth considering:

- While significant relationships were identified between these variables and modal substitution rates from literature, they are based on small sample sizes and depend on the removal of outliers.
- These models are not using any control variables. These univariate linear regression models are intended to enable quick determinations of possible modal substitution given a specific built context. While other variables such as population density or travel time to work were evaluated, they were not used as controls within the same model.
- Many other factors can influence rates of modal substitution beyond those identified here, and they warrant further study. It is highly complex result of localized intercept surveys, but their ranges from literature benefit from a context sensitive approach for analysis.

References

NASEM (National Academies of Sciences, Engineering, and Medicine). (2014). *Estimating Bicycling and Walking for Planning and Project Development: A Guidebook*. Washington, DC: The National Academies Press. https://doi.org/10.17226/22330

Volker, J., S. Handy, A. Kendall, and E. Barbour. (2019). *Quantifying Reductions in Vehicle Miles Traveled from New Bike Paths, Lanes, and Cycle Tracks: Summary Report.* California Air Resources Board (CARB). March 25, 2019.

Replica Places (2022). Replica Platform. Retrieved from https://replicahq.com/

technical documentation.

replica methodology

0. Executive Summary

Replica produces high-fidelity activity-based mobility models, at “megaregion” scale (~30 million people), with disaggregate data outputs down to the network-link level.

Activity-based models are transportation models in which travel demand is derived from people's daily activity patterns. Activity-based models predict which activities are conducted when, where, for how long, for and with whom, and the travel choices they will make to complete them.

Replica generates its data by running large scale, computational-intensive simulations. Rather than simply cleansing, normalizing, and scaling individual data sources, Replica:

(1) Creates a synthetic population that matches the characteristics of a given region
(2) Trains a number of behavior models specific to that region
(3) Runs simulations of those behavior models applied to the synthetic population in order to create a “replica” of transportation and economic patterns
(4) Calibrates the outputs of the model against observed “ground-truth” to improve quality

This methodology is how Replica delivers granular data outputs that match behavior in aggregate but don’t surface the actual movements (or compromise the privacy) of any one individual.

Origin-destination pairs are consistent with human activities. Population demographics are accurate and correlate with appropriate movement. Recurring activities are coherent over time and capture a pattern of life. Routing between locations is consistent with local road networks and transportation options. And the scale of population and number of trips is appropriate for a given geographic extent.

Replica has served over 60 clients throughout the U.S., including Caltrans (the California DOT), the Metropolitan Transportation Authority in NYC, the NY State Division of the Budget, the Illinois DOT, New Jersey Transit, and the Office of the Chief Technology Officer (OCTO) in Washington, D.C.

In the following document, we outline our sources, methodology, and outputs, as well as detail regarding our uncompromising approach to protecting individual privacy.

I. Overview

Replica simulations are delivered as megaregions, each covering between 20 and 50 million residents and multiple states, enabling the entire contiguous United States to be produced in 14 megaregions. The output of each simulation is a complete, disaggregate trip and population table for an average weekday and average weekend day in the subject season (e.g., Fall 2021). The model represents a 24-hour period with second-by-second temporal resolution, and point-of-interest-level spatial resolution. In essence, each row of data in the simulation output reflects a single trip, with characteristics about both the trip (e.g, origin, destination, mode, purpose, routing, duration) and trip taker (e.g., age, race/ethnicity, income, home location, work location). In aggregate, the output dataset reflects the complete activities and movements of residents, visitors, and commercial vehicle fleets in the target region and season on a typical day.

Each year, Replica produces a spring simulation and a fall simulation for each megaregion. Each completed model also includes an associated quality report, which compares the outputs of the simulation to ground truth data, enabling comparisons between modeled outputs and observed counts.

II. Source Data

Replica utilizes a diverse set of public and private third-party source data to inform its simulations. These sources include five categories of data:

Mobile location data: Multiple types (currently five unique sources) of de-identified location data collected from personal mobile devices and in-dashboard telematics are used to create a representative sample of daily movement patterns within a place.

Consumer resident data: Demographic data from public and private sources provides the basis for determining where people live and work, and the characteristics of the population, such as age, race, income, and employment status.

Land use / real estate data: Land use data, building data, and transportation network data are used to paint a complete picture of the built environment, and where people live, work, and shop.

Credit transaction data: Credit transactions from financial companies are used to model consumer spending. With this input, Replica depicts the level and types of spending that occurred at a particular time and place.

Ground truth data: Ground truth data is used to calibrate and improve the overall accuracy of Replica outputs. The types of ground truth collected by Replica include auto and freight volumes, transit ridership, and bike and pedestrian counts.

By building a composite of these diverse sets of data, Replica minimizes the risk of sampling bias that exists in any single source on its own. For example, a product that relies more heavily on data from personal mobile devices risks failing to adequately simulate the portions of the population that do not have mobile devices or those who opt out of device tracking technologies. Our composite approach also creates resiliency against data quality issues and protects against disruptions of individual data sources.

III. Methodology & Approach to Privacy

At a high level, Replica's approach to generating its simulations is best described in four steps:

Step 1: Population Synthesis A nationwide synthetic population, statistically equivalent to the actual population, is generated for the entirety of the United States each year. Replica creates a synthetic population because census data is limited to aggregate geographies, which limits the ability to assign attributes to individuals or households. Synthetic populations also help protect privacy without compromising spatial fidelity.

The synthetic population is generated using census and consumer marketing data. Replica applies data science techniques to this data that allow for: (1) modeling the dependencies in socio-demographic parameters and structure of the households, and (2) synthesis of the population at the level of individual households so that it matches aggregate census information at the required level of aggregation such as block groups or tracts.

Each synthetic household consists of people with an assigned set of attributes: age, sex, race, ethnicity, employment status, household income, vehicle ownership status, and resident or visitor status. Workplace locations for all employed individuals are assigned based on the combination of mobile location data aggregates and census information. These assignments are static in each seasonal model, but can and do change across seasons.

The population relevant for each specific megaregion is extracted from the nationwide population to begin each simulation.

Step 2: Mobility Model Creation Modern machine learning techniques are then leveraged to develop travel personas from the composite of mobile location data for the subject megaregion and season. Personas are an extraction of behavioral patterns from individual devices that live in, work in, travel to, travel from, or pass through a specific region during the subject season.

Each persona is composed of three underlying behavioral-choice models: activity planning and sequencing (e.g., at home -> drive to work -> at work -> drive to shop -> drive to home), destination location choice (i.e., the exact location people are traveling to and from), and travel mode (i.e., the chosen mode).

Replica's composite of mobile-location data represents anywhere from 5% to 20% of a local population. Replica intentionally only acquires the necessary data required to build statistically representative models, another tenet of balancing model fidelity with user privacy.

Step 3: Activity Generation To simulate activity, the outputs from Step 1 and Step 2 are joined. Each synthetic household is assigned one or more personas using home and work locations as a primary input, enhanced with matching by available socio-demographic attributes and by the role of the person in a household. In effect, with travel behavior models assigned, each synthetic person can now make choices about when, where, and how to travel.

Individuals in the synthetic population are then set into motion via three models. The **activity sequence model** determines the activities of a simulated person's day, including both recurring activities (e.g., travel to work, school drop off), as well as one-time activities (e.g., shopping, visiting a restaurant, social visit to a friend's residence). The **location choice model** determines the specific location of each discretionary activity (e.g., what restaurant is chosen for lunch, where grocery shopping gets done), assigning a location at the point-of-interest level. And the **mode choice model** determines how the trip will be made based on the state of the transportation network, accounting for available transit options and multiple driving routes.

Movement is then simulated with an agent-based approach that accounts for congestion and other interactions between individual travel itineraries.

Step 4: Calibration After each individual simulation run, the modeled outputs are compared to aggregate control group data (i.e., observed counts, or "ground truth") for quality and reporting purposes. This calibration process involves solving a set of large-scale optimization problems with an objective function defined as "fit to observed ground truth." A careful balance is struck to ensure that the calibration algorithms do not overfit the modeled outputs to the calibration data, as both outliers and a certain level of noise is often present in every dataset.

To complete this iterative calibration process, Replica always holds out some of its own ground-truth data from the initial mobility simulation. Replica can also incorporate additional ground-truth provided by its customers for additional quality enhancement.

Each completed model includes an associated quality report, which transparently displays a comparison of modeled outputs to ground truth data, enabling users to compare model outputs to observed counts.

Approach to Privacy: The approach outlined here reflects Replica's uncompromising belief that better insights should not come at the expense of personal privacy. Our methodological approach enables us to provide highly granular output data while remaining faithful to a series of privacy-first technical commitments. At Replica, we:

- Only procure de-identified data from our source vendors. The data we receive is never associated with an individual's personally identifiable information.
- Never share raw locational data with our customers — or any other third-parties
- Build models from different data sources independently so that we abstract out potentially identifying details of any individual before combining these models into our aggregate outputs
- Never join data sources on keys containing sensitive data
- Incorporate proven techniques, like statistical noise injection, into our algorithms to ensure that (1) it is impossible to ascertain if an individual's information is part of our source data by inspecting our modeled outputs; (2) it is impossible to learn which specific locations were visited by an individual whose information was part of our source data by inspecting our modeled outputs

Simply put, Replica's methodology results in outputs that make it impossible to track or identify the movements of any individual.

IV. Data Outputs

Each simulation results in a complete trip, population, and routing table.

Population Attributes: Each trip is associated with a specific person in the simulation, for whom the following characteristics are available:

- Age
- Sex
- Race
- Ethnicity
- Employment status
- Household income
- Vehicle ownership status
- Resident or visitor status

Trip Attributes: Each trip is assigned the following attributes:

- Origin and destination points
- Trip distance
- Trip duration
- Start and end time
- Complete routing information for each trip
- Trip mode, including private auto driver, private auto passenger, public transit, walking, biking, freight, and transportation network companies (TNCs)
- Trips purpose, including home, work, errands, eat, social, shop, recreation, commercial, school

Location Detail: Replica models to specific real-world locations and points of interest (e.g., a specific office building, the Starbucks at a certain address) — trips are modeled from individual building footprint to individual building footprint, rather than zone to zone. We update our nationwide catalogue of points of interest monthly, and we use the applicable set of locations for each simulation.

V. Geographic and Temporal Coverage

Replica is currently focused on covering the United States. Each year, Replica produces a spring simulation and a fall simulation for each of our megaregions. We can also run simulations for specific time periods or locations for our customers as needed; for instance, we could produce a model for December 2019 that would be distinct from our regular fall 2019 model for a given location.