RESEARCH

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Utah Department of Transportation - Research Division
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MODE SHIFT POTENTIAL EVALUATIONS USING DESIRE LINES & CONNECTIONS TO ACTIVE FUNCTIONAL CLASSIFICATION SYSTEMS

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Utah Department of Transportation
Research & Innovation Division

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16. Abstract

Understanding which active transportation facilities have a high potential for mode shift is a potent metric of success for funders seeking to make high-impact transportation investments. This report documents the development and validation of a traveler alignment analysis tool that looks at the orientation and magnitude of short trips in origin-destination (OD) data to evaluate mode shift potential. This alignment analysis operates by using line features created by a Utah statewide OD matrix of vehicle trips taken from Replica Places' activity-based modeling data platform. OD lines were then further disaggregated using a preprocessing technique known as jittering, that creates sub-OD pairs from more aggregated ones to make them more geographically diffuse and relevant to active transportation. To tune parameters related to proximity, angle, and trip distance, a sensitivity analysis was conducted comparing similar mode shift potential indices generated by the alignment analysis and 25 StreetLight Data pass-through zone analysis. This sensitivity analysis found that this method can produce reasonable results that can be used to evaluate different projects and provided some indication of what thresholds for different tool parameters were most suitable. A demonstration of this quick-response tool using Transportation Investment Fund (TIF) active facilities was submitted to the Utah Department of Transportation (UDOT) for evaluation, and its outputs illustrate that this tool can be a useful complement to existing prioritization criteria for consideration.

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UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
ATP	Active Trip Potential
FC	Functional Classification
FCS	Functional Classification System
km	kilometer
OD	Origin-Destination
MAE	mean absolute error
mi	mile
mph	miles per hour
RMSE	root mean square error
UDOT	Utah Department of Transportation
VMT	Vehicle Miles Traveled
DVMT	Daily Vehicle Miles Traveled
TIF	Transportation Investment Fund

EXECUTIVE SUMMARY

Understanding which active transportation facilities have a high potential for mode shift is a potent metric of success for funders seeking to make high-impact transportation investments. This research develops and evaluates a new Traveler Alignment tool for approximating car trips traveling along existing or proposed network segments that may reasonably be shifted to active modes by assessing the proximity and parallelism of origin-destination (OD) desire lines to segments for analysis. The tool functionality allows for it to operate on new and existing connections, essentially replicating a select-link analysis while avoiding the high resource costs of traditional travel demand model runs. The proposed tool operates on OD desire lines, which are a more readily available intermediate output of travel demand models that represent trip-making behavior via geographic aggregation. These desire lines are evaluated for their relative parallelism and proximity to the provided corridors, and trips are filtered based on literature-guided values of active mode trip distances. Desire lines are a more readily available intermediate output of travel demand models, increasing the accessibility of large-scale, relatively low-effort link-level estimates for transportation planners. The outputs of the Traveler Alignment tool may allow for application in large scale, rapid prioritization of proposed active transportation facilities. This alignment analysis operates by using line features created by a Utah statewide OD matrix of vehicle trips taken from Replica Places' activity-based modeling data platform. OD lines were then further disaggregated using a preprocessing technique known as jittering, that creates sub-OD pairs from more aggregated ones to make them more geographically diffuse and relevant to active transportation. To tune parameters related to proximity, angle, and trip distance, a sensitivity analysis was conducted comparing similar mode shift potential indices generated by the alignment analysis and 25 StreetLight Data pass-through zone analysis. The analysis determined summary metrics about all vehicle trips that passed through each zone during an average travel weekday in Fall 2019. Links were selected from road segments with planned active transportation facilities as part of the statewide bicycle plan to ensure a diversity of functional classification, land use context, and geographic coverage. This sensitivity analysis found that this method can produce reasonable results that can be used to

evaluate different projects and provided some indication of what thresholds for different tool parameters were most suitable.

A demonstration of this quick-response tool using Transportation Investment Fund (TIF) active facilities was submitted to the Utah Department of Transportation (UDOT) for evaluation, and its outputs illustrate that this tool can be a useful complement to existing prioritization criteria for consideration. This paper concludes with areas for future research and recommendations on how it could be applied by UDOT and partner agencies.

INTRODUCTION

1.1 Problem Statement

The initial intention of this research effort was to develop a method of understanding how functional classification as a concept can be extended to active modes of transportation, something not currently available in Utah. Traditionally, functional classification is understood in terms of providing an understanding of the tradeoffs between facilities serving mobility and accessibility needs. However, its relationship with active transportation is that often higher order functional classifications are barriers to active travel. A traditional framing of functional classification does not provide much guidance on how other modes might integrate into this framework. Increasingly, concepts such as modal priorities, layered networks, and multimodal functional classification systems are attempting to bridge the gaps between traditional functional classification and the growing need to integrate other modes of transportation into transportation system design frameworks. This research was initially articulated to explore whether mobile trace or modeled data might inform the definition of an active transportation functional classification system. The idea was to identify whether their dimensions could be explored by assessing how the Utah Department of Transportation's (UDOT) existing active data sets and new data sets from vendors such as StreetLight Data and Replica can be leveraged to understand the proportion of trips that can be served by active modes and the degree of trip alignment with the specific active transportation facility.

During the methodology development and literature review of multimodal functional classification systems stage, UDOT desired a more actionable output from the research to inform Transportation Investment Fund (TIF) active funding prioritization. The development of modal priorities statewide would further this effort and requires the consultation of stakeholders beyond what is possible as part of UDOT-funded research.

A need for a more actionable outcome for TIF active funding prioritization based on different sources of origin-destination (OD) information was identified in the original research proposal. The research team and UDOT agreed on a proposal to research the development of a proof-of-concept mode shift potential tool for active modes on the basis of travel behavior across the state based on facility trip distances and trip alignment to proposed facilities. This could be a building block for identifying whether there are capturable short trips aligned with UDOT facilities to prioritize TIF active funding for high impact facilities or provide future analysis of modal priorities for UDOT facilities.

1.2 Objectives

- Review functional classification and its relationship to active transportation.
- Identify what components accompany multimodal functional classification systems with special attention to how travel behavior and the built environment influence their contextual application.
- Develop a mode shift potential tool that can associate desire lines derived from an OD matrix.
- Review emerging and existing data sets and whether they have utility for future UDOT TIF active projects including StreetLight Data and Replica Places.

1.3 Scope

1.3.1 Framework and Methodology Development

The first phase of work was focused on identifying the framework to guide the development of a statewide active functional classification system.

- Literature Review – This literature review briefly reviewed previous work related to multimodal functional classifications and how travel pattern data ranging from demographics to trip distance have been used to evaluate active mode shift potential.
- Framework and Methods Identification – After the literature review, the research team worked with UDOT staff to identify an approach for a statewide network prioritization analysis for active transportation. This underlying prioritization will be used to inform an active travel functional classification system and help guide investment decisions system-wide. During this phase, the direction of the research effort transitioned to creating an actionable tool for evaluating mode shift potential based on the data sets reviewed.

1.3.2 Statewide Active Trip Potential Analysis

- Data Review – The project team evaluated how StreetLight Data, Replica, regional travel demand model(s), or other big data resources can provide scalable insights into the modal potential of different facilities. This analysis will be used in later research phases to understand which data sets have utility for understanding potential demand for active transportation.
- Statewide Flow Mapping – The project team generated a statewide desire line matrix built on a Replica Trip Table. This data will be used to generate an interactive data visualization for UDOT review, as well as graphics explaining the methodology and mapping active trip potential (ATP) statewide. This data and analysis will be used as inputs for the mode shift potential tool.

1.3.3 Tool Development and Calibration

This phase was originally oriented toward the application of a functional classification methodology in three locations with the intent to prototype and evaluate an active functional classification system. Instead, this phase focused on developing and validating a mode shift potential tool based on existing OD analysis workflows at Alta Planning + Design. This tool (which will associate desire lines derived from an OD matrix with proposed facilities based on trip distance, alignment, and proximity to the facility), was then calibrated to 25 StreetLight Data pass-through zones to identify whether the tool's desire line association process correlates with the corresponding trip characteristics identified in StreetLight Data.

1.3.4 State Prioritization Framework

Initially, this phase was intended to document the active transportation functional classification so it could be communicated and conceptualized for public and professional understanding. The research team pivoted this task to identify how this mode shift tool could be integrated into calls for TIF active funding prioritization and inform a framework for a future multimodal functional classification system (UDOT, 2021). During this phase, infographics were developed to explain how the tool would work, as well as concepts such as ATP and other prioritization concepts.

1.4 Outline of Report

1.4.1 Research Methods

1.4.1.1 Evaluating Mode Shift Potential

Establishes why shifting trips from vehicles to active modes is important and describes three methods previously employed along with their strengths and weaknesses.

1.4.1.2 Selecting Data Sources

Introduces travel demand models and OD lines as an intermediate output. Discusses the application of big data products like Replica and StreetLight Data in this project and how advanced methods may allow disaggregation of OD line pairs.

1.4.1.3 Tool Parameter Selection

Drawing on the methods discussed in Section 1.4.2.1, this section dives deeper into the three internal tool parameters: trip distance, and the proximity and parallelism of the OD desire lines with respect to the corridor of interest.

1.4.1.4 Contextualizing Mode Shift Potential

Includes a discussion on interpreting results and how functional classification systems can and must adapt to accommodate active transportation modes.

1.4.2 Data Collection

1.4.2.1 Replica Data Review

Describes Replica and its methodology. Shows data platform download interface, sample raw data, and post-processing to generate OD table and OD pair lines.

1.4.2.2 StreetLight Data Review

Describes StreetLight Data and its methodology. Describes 25 pass-through zones selected for validation along with the criteria for selection. Shows sample data.

1.4.3 Data Analysis

1.4.3.1 Replica Statewide Flow Results

Qualitatively describes OD flow trends and patterns. Provides trip table summaries and basic visualizations.

1.4.3.2 StreetLight Data Zonal Results

Reports raw results of the select-link analysis as provided by StreetLight Data including summaries of trip distance, mode, and purpose.

1.4.3.3 Validation Results

Provides comparisons and correlations between tool results and StreetLight pass-through analysis.

1.4.4 Conclusions

Recaps the quick-response traveler alignment analysis that can provide estimates of short trips aligned with on-street or off-street facilities for the purposes of identifying mode shift potential.

1.4.4.1 Discussion of Findings

Discusses sensitivity testing findings and applications of the tool in the context of prioritization with an example provided to recent TIF active projects.

1.4.4.2 Limitations of Analysis

This section discusses limitations of the analysis related to the aggregations of data, and that the result of this tool are approximations of short trip behavior. This section also discusses the limitations of the sensitivity analysis related to the comparability of data sources used and other considerations.

1.4.4.3 Areas for Future Research

Discusses potential areas for future related research such as exploring weighting systems for disaggregated jittered networks for active transportation analysis.

<u>1.4.5 Recommendations and Implementation</u>

This section summarizes key recommendations for this tool's utility and application at UDOT and brief suggestions to inform implementation.

1.4.5.1 Recommendations

The recommendations for integration of the Traveler Alignment tool into processes at UDOT included:

- Integrating into prioritization framework, and quick-response screening and evaluation tool of facilities.
- Integrating with future land use projections to understand how development may influence future projects.
- Exploring additional applications such as informing multimodal functional classification system development.

1.4.5.2 Implementation Plan

Our implementation section discusses the user guide and training provided as a resort to UDOT to use this tool and suggestions on who should maintain the tool into the future. We also provide suggestions such as providing a lunch and learn to review the tool training and its user guide at UDOT.

1.4.6 Appendices

1.4.6.1 APPENDIX A: Literature Review Active Functional Classification

This appendix documents a literature review of active transportation relationship to functional classification, and examples of explicit active transportation-focused functional classification systems.

1.4.6.2 APPENDIX B: Replica Methodology

This appendix documents a Replica's summary of its activity-based modeling methodology including their development of synthetic agents, what the data is calibrated against, and key steps in the modeling process.

1.4.6.3 APPENDIX C: StreetLight Data Methodology

This appendix documents a StreetLight Data whitepaper that describes the data sources and methodology employed by StreetLight Data to develop travel pattern metrics. This document is relevant for all StreetLight metrics that are available via the StreetLight InSight platform.

1.4.6.4 APPENDIX D: User Guide for Mode Shift Potential Tool

This appendix documents a user guide that accompanies the mode shift potential tool provided to UDOT. It provides guidance regarding its inputs and operation.

2.0 RESEARCH METHODS

2.1 Overview

Researchers and transportation planners have developed and implemented several methodologies for estimating active mode shift potential, discussed in the following section. The proposed methodology draws on this previous work to create a Traveler Alignment tool that estimates network-link-level trips that may feasibly be converted from car to active modes. The section introduces the three parameters for evaluating network demand from OD desire lines (trip distance, proximity, and parallelism), and describes emerging big data sources for OD and select-link validation data. Finally, it includes a discussion on functional classification systems and how they may be used as a framework for contextualizing segment level active transportation mode shift results.

2.2 Evaluating Mode Shift Potential

There is significant interest at the Utah state level in shifting vehicle trips to active modes, as reducing vehicle miles traveled (VMT) has been shown to have far-reaching environmental, social, economic, safety, and health benefits (de Nazelle et al., 2010; Ewing et al., 2010; Buehler & Pucher, 2012). Previous research efforts have proposed methods for estimating system-wide mode shift potential, evaluating modal shift factors retroactively, predicting existing and proposed travel demand at the link level, and assembling optimized shortest-path network links from travel data. This section provides an overview of the existing methods and identifies their strengths and shortcomings.

2.2.1 Estimating Regional Mode Shift Potential

Using results from the 2014 Vitoria-Gasteiz household travel survey, Delso et al. (2018) identified potentially replaceable car trips based on a calibrated distance threshold and mobility survey responses. From reported trip data, they calculated upper distance thresholds for active mode trip conversion equivalent to the 80th percentile of reported walking and cycling trip distances. Using this methodology, the team estimated that between 30% and 40% of car trips within the region of study could be replaced by active modes. The mode shift potential is reported at the regional level, providing no information at a network link level.

2.2.2 Project-Level Modal Shift Evaluation

2.2.2.1 Intercept Surveys

There is a great deal of interest in understanding how the implementation of specific infrastructure projects may impact mode choice and, by extension, VMT and emissions. Current methods for estimating modal substitution factors frequently rely on intercept surveys of facility users following project construction (Volker et al., 2019). These surveys are applied retroactively, so they have limited applicability for estimating modal substitution rates at the project planning stage. Compared to general estimates of potentially replaceable car trips as presented in Delso et al., however, intercept surveys have the advantage of geographic specificity at the network link level.

2.2.2.2 Select-Link Analysis

Travel demand models (discussed further in Section 2.4) have the potential to estimate demand on both existing and proposed network links via select-link analysis. Commonly built on data from household travel surveys, travel demand models like the statewide model in Oregon create a representation of the transportation network and estimate the number of trips taken on each link of the system (Travel Demand Modeling, 2022). Through a full select-link analysis, travel demand models can answer questions not only about the quantity of trips on a link, but also about where trips using that link begin and end. Travel demand models are resource intensive, and each proposed project requires a separate analysis run to evaluate the potential travel demand impacts. Additionally, evaluating the potential of active transportation typically requires the use of more detailed networks and land use data that typically accompany activity-based models (Castiglione et al., 2015).

2.2.2.3 Desire Line Analysis

The development of OD desire lines that draw lines through approximate locations of trip origins to destinations traces back to the origins of Detroit's first travel surveys and the origins of travel demand modeling (McLachlan et al., 1950). Researchers have proposed more quantitative applications of desire line analysis to transform simple OD desire lines (discussed further in Section 2.4) into assembled corridors of demand, based on their relative proximity and parallelism (Bahbouh et al., 2017). This methodology is suitable for optimizing new links in a transportation system based on existing demand and a desire for shortest-path solutions. In practice, however, the location of proposed active transportation facilities is most often dictated by the location of existing transportation corridors, limiting the applicability of this methodology in evaluating potential demand when the feasible construction corridors do not align with the optimized network link locations. The use of OD lines, a common output of travel demand models, allows for decentralized calculation of demand corridors, separating out steps and avoiding a full travel demand model run for each evaluation. Bahbouh et al. also introduce the criteria of proximity and parallelism for evaluating corridor suitability for serving network demand.

2.3 Proposed Methodology

This review of existing methods highlights the opportunity to develop a new tool for estimating mode shift potential at the early stages of active transportation project proposal, informed by elements of each of the previously discussed methods. The tool presented in this research approximates the number of car trips taken along an existing or new network link segment that may reasonably be converted to active modes, using trip data represented by OD desire lines. Implemented as an ArcGIS Pro tool, the workflow determines the minimum distance and difference in bearing between each desire line and input network link for evaluation. It then applies weights based on defined proximity and angle thresholds to estimate the fraction of trips represented by each desire line that may be attributed to the network link. Next, it considers the average trip distance of all trips represented by the desire line and applies an additional weighting procedure to estimate which trips attributed to the network link may reasonably be converted to active modes, acknowledging the role of trip distance in mode choice. An illustration explaining key concepts behind this traveler alignment analysis methodology is shown in **Figure 2.1**.

Intrazonal trips by nature cannot be represented physically by the same centroid-to-centroid desire line. For aggregated desire lines, the tool introduces a fourth parameter that establishes a defined buffer distance that proportionally allocates intrazonal trips to each network link based on the percentage of the aggregation geography covered by the buffered area.

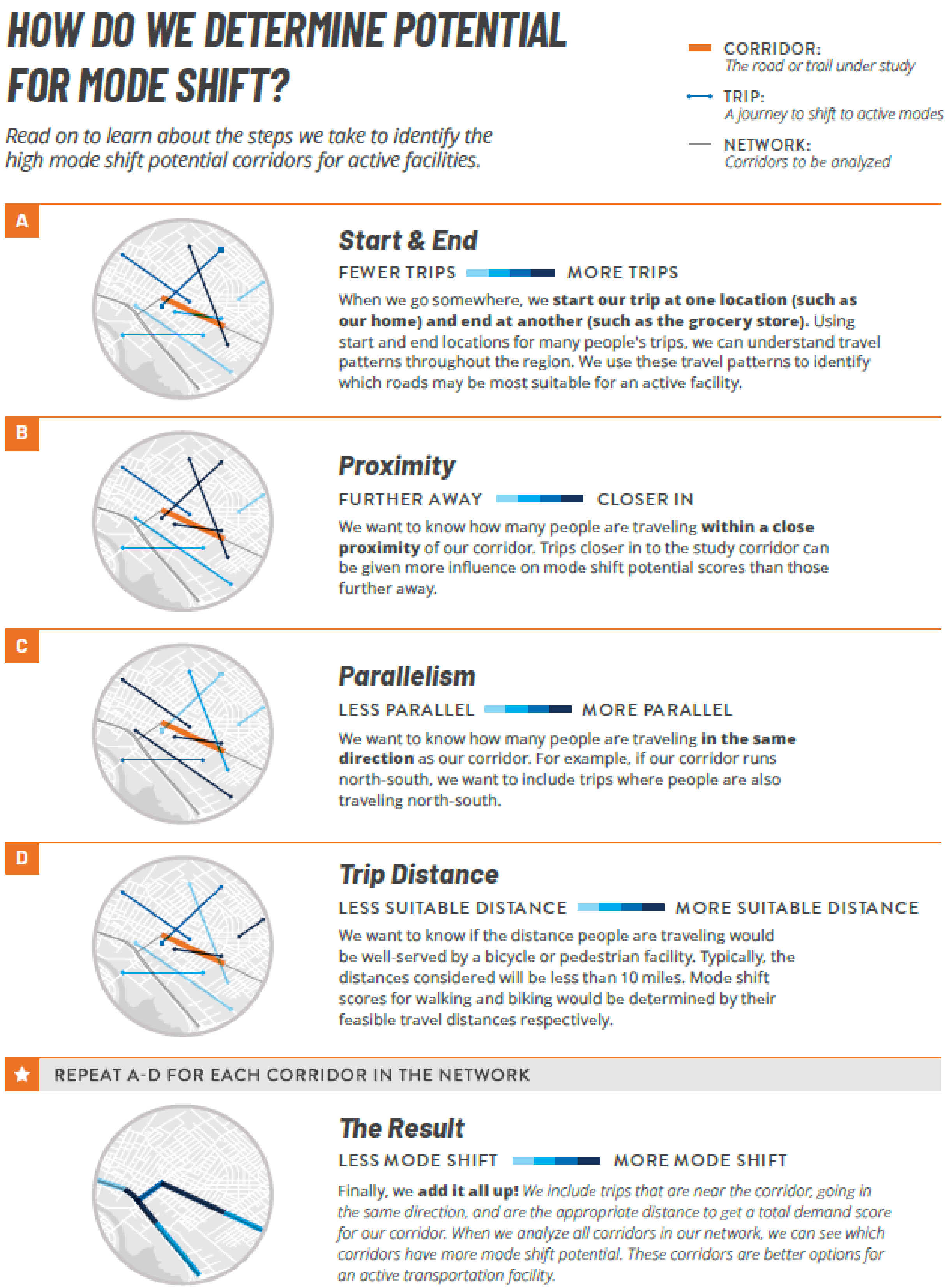


Figure 2.1 Underlying Concepts Behind Traveler Alignment Tool Methodology

2.4 Tool Parameter Selection

Central to estimating mode shift potential is identifying what trips may reasonably be assumed to be converted from vehicle to active transportation modes. This requires a fundamental understanding of the complicated and competing factors at play when a person decides on their mode of travel for any given trip. Researchers have traced mode choice back to a wide variety of underlying characteristics and motivations. Trip purpose seems to play a big role: Social or recreational trips are more likely to be made by walking/bicycling, while escort trips to pick up or drop someone off are more likely to be made by automobile (Kim & Ulfarsson, 2008; de Nazelle et al., 2010; Paul et al., 2014). The need to trip-chain or carry heavy goods has also been mentioned in several studies as a barrier to more active transportation, as has the availability of a car at home (Mackett, 2003; Scheiner, 2010; Paul et al., 2014). Other important factors could include personal characteristics like gender, age, household composition, life cycle stage, lifestyle, and individual attitudes and values (de Nazelle et al., 2010; Scheiner, 2010; Prato et al., 2017). Perhaps most fundamental, however, is trip distance.

2.4.1 Trip Distance

Travel behavior research has long documented the foundational role of distance in the use of active transportation modes. Early research about the influence of the built environment on travel behavior identified trip distances and connectivity (or, more broadly, accessibility) as important factors influencing non-automobile travel. Specifically, shorter trips and travel in places with greater pedestrian access or shorter distances to non-residential destinations were more likely to be made by walking (Cervero & Kockelman, 1997; Badoe & Miller, 2000; Saelens et al., 2003; Saelens & Handy, 2008, McCormack et al., 2004). As these built-environment relationships became formalized into the multiple "D" variables (Cervero & Kockelman, 1997; Ewing & Cervero, 2001, 2010), distance was embedded directly in the "destination accessibility" variable as a measure of proximity and ease of access to destinations, and in "distance to transit" because one can think of public transit as a way to extend a walk trip over a longer distance. Among other D variables, distance is also implicit (Sallis et al., 2003; Ewing & Cervero, 2010): Places with greater job "density" have more nearby destinations for work, shopping, and so on. Greater "diversity" or land use mix allows multiple daily activity needs to be fulfilled in the same area. Areas with rectilinear street network "designs" allow more direct paths than areas with less connected street grids. While most of these built environment and travel behavior relationships were originally applied to walking, more recent research has found that the distance and connectivity relationships do hold for cycling too, especially those related to "destination accessibility" and street network "design," and for transportation (rather than recreational) cycling purposes (Muhs & Clifton, 2016; Le et al., 2018; Yang et al., 2019). In other words, bicycling as a way to get around and meet daily needs is more common for shorter trips and in places with more connected street networks that allow direct travel between destinations.

Using the latest **travel survey data**, the following figures depict the relationships between active transportation mode shares and trip distances for the US (**Figure 2.2**) and Utah (**Figure 2.3**), using the 2017 National Household Travel Survey (ORNL, n.d.) and the 2012 Utah Travel Study (RSG, 2013), respectively. In general, both walking and bicycling mode shares decline with increasing trip distances, but the shapes and thresholds are different for each form of active transportation.

- **Walking** makes up a large share of very short trips: 60% of trips less than 0.5 miles (mi) in the US, and 33–41% of trips less than 0.4 mi in Utah. Walking is still a common and viable mode for trips between roughly 0.5 mi and 1.5 mi: Walk mode shares are 17% in the US, and 12–19% in Utah. After about 1.5 mi, only a small and decreasing share of trips are made by pedestrians.
- **Bicycling** tends to see peak mode shares in the 0.5-mi to 1.5-mi range: 2% of trips in the US, and 3–4% of trips in Utah. Many shorter active transportation trips (less than 0.5 mi) tend to be made by walking instead. After about 1.5 mi, bicycle mode shares start to decrease but are still substantial. After about 5.0 mi, very few trips are made by bicycle.

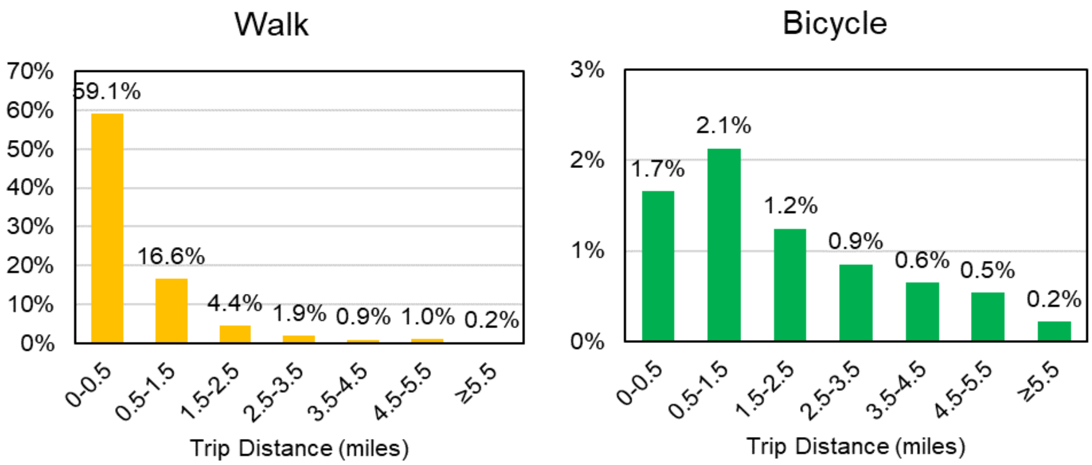


Figure 2.2 US Mode Shares for Walking (left) and Bicycling (right) by Trip Distance, 2017 National Household Travel Survey Estimated Person Trips (ORNL, n.d.)

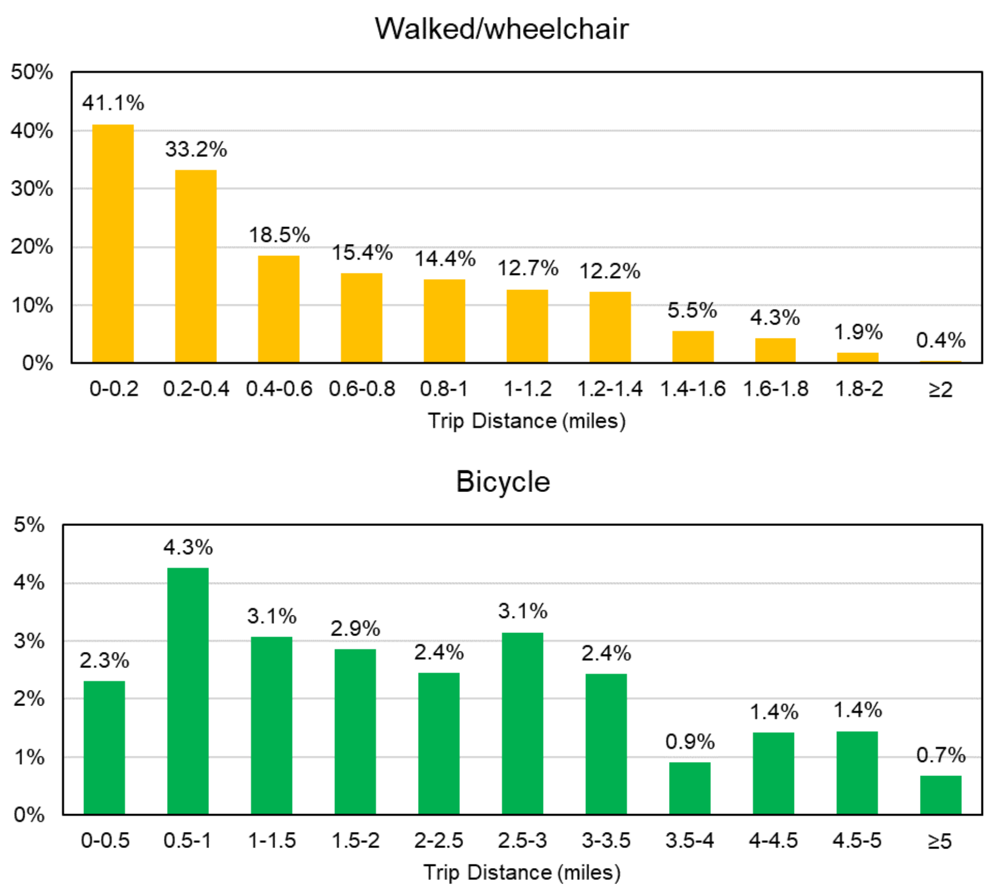


Figure 2.3 Utah Mode Shares for Walking (top) and Bicycling (bottom) by Trip Distance, 2012 Utah Travel Study Main Household Diary Using Weighted Trips (RSG, 2013)

These relationships between walk/bicycle mode shares and trip distances are based on observed trips in the US, and **other countries** may have different thresholds and relationships. In the US, active transportation mode shares are very low compared to other western European and English-speaking countries: for example, 12% in the US versus over 50% in the Netherlands (Buehler & Pucher, 2012). Even within the US, there are wide variations in mode shares state to state and for various cities (Pucher et al., 2011). Yet even in countries with more active transportation use, most walk trips are less than 1 kilometer (km) (0.6 mi), most bike trips are less than 3 km (1.8 mi), and land use policies supporting compact mixed-use developments in northern European countries help to promote walking and cycling by facilitating shorter trips (Buehler & Pucher, 2012). Within high-cycling US cities, the highest bicycle mode shares tend to be seen in more central locations (Pucher et al., 2011), highlighting the importance of distance. A recent study comparing cycling behavior across 17 countries worldwide (Goel et al., 2022) found only modest differences in median bicycle trip distances: for example, 1.9 km (1.18 mi) in the US versus 2.0 km (1.24 mi) in the Netherlands. Notably, the authors also compared bicycle mode shares for various trip distance categories across countries, while controlling for differences in overall mode shares. Their use of "distance distribution ratios"—effectively the mode share for a distance bin divided by the overall mode share—revealed remarkable similarities between countries (Goel et al., 2022). As shown in **Figure 2.4**, results were quite similar and not at all related to overall bicycle mode share: ratios were greater than 1 for trips up to 5 km (3.1 mi), and bicycle mode shares for trips up to 2 km (1.2 mi) tended to be 1.5–2.0 times the all-trip bicycle mode share in each country. Another study looked at mode choice by trip distance in Germany over a 25-year period, 1976 to 2002 (Scheiner, 2010). There, the author found rather stable trends in (if not absolute, then relative) walk and bicycle mode shares over time. For example, more than 80% of trips less than 0.4 km (0.25 mi) were made by walking, and walking dropped below 10% for trips over 2–3 km (1.2–1.9 mi). Peak bicycle mode shares were seen for trips of 1–1.5 km (0.62–0.93 mi), and bicycle modes shares stayed above 10% for trips of 0.4–3 km (0.25–1.9 mi) in all years.

The findings from these two studies (Goel et al., 2022; Scheiner, 2010) suggest two important things. First, as bicycle mode shares increase and other factors change over time, the relative distribution of bicycle mode share by trip distance may largely stay the same; in other words, the shapes of the distributions in **Figure 2.2** and **Figure 2.3** may not change much.

Second, distance is an important determinant of active transportation, and its fundamental role in mode choice (at least for bicycling in "Western" countries) transcends a variety of cultural and (built) environmental differences across countries.

Country	Region	Mode share	0-2 km	2-5 km	5-10 km	10-20 km	20+ km
Netherlands	Europe	26.8	1.40	1.30	0.70	0.30	0.10
Germany	Europe	9.3	1.70	1.30	0.60	0.30	0.10
Finland	Europe	7.8	2.10	1.20	0.60	0.30	0.10
Switzerland	Europe	6.7	1.50	1.30	0.50	0.30	0.20
England	Europe	2.1	1.50	1.30	0.90	0.60	0.20
Australia	Australia	1.8	1.20	1.30	1.20	0.60	0.30
USA	North America	1.1	2.00	1.30	0.70	0.30	0.10

Figure 2.4 Relative Bicycle Mode Shares (Mode Share for Distance Bin Divided by Mode Share Overall) by Trip Distance Category across Countries (Goel et al., 2022)

2.4.2 Alignment of Desire Lines

To tailor mode shift potential estimates to the network link scale, only trips taken along the link of interest should be considered. To avoid the computational costs and complexity of running a full travel demand model to perform a select-link analysis (a regional travel model summary of all OD flows through a single facility link [Travel Forecasting Resource, 2022]), alternative methods are required. As previously mentioned, researchers used desire lines represented by OD pairs to assemble corridors of demand (Bahbouh et al., 2017). Corridors were assembled from desire lines with the goal of capturing maximum demand. Trips taken along a desire line were assigned to a corridor based on the relative directional alignment. The authors postulate a maximum angle between the corridor axis and desire line of 22.5 degrees, illustrated in **Figure 2.5**.

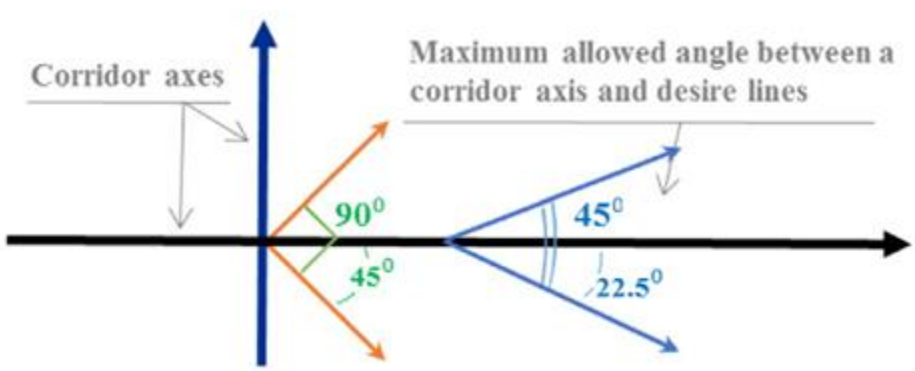


Figure 2.5 Maximum Angle Between Corridor Axis and Desire Lines (Bahbouh et al., 2017)

2.4.3 Proximity of Desire Lines

Not all trips traveling along the same bearing as the corridor should be considered in the link demand. As discussed, active trip mode choice is highly sensitive to trip distance. Trips parallel to, but not proximate to, the corridor are unlikely to use that network link because of the distance costs associated with traveling to and from the corridor. The concept of corridor width, or *influence width*, is considered by Bahbouh et al. (2017) and refers to the zone buffer around a potential demand corridor in which trips taken along a desire line will route to use the corridor. Influence width depends on trip mode, with pedestrian or cycling corridors having estimated widths of up to 100 meters, but some studies suggest using approximate widths, rather than fixed, to maintain flexibility in trip assignment (Reiss et al., 2006). **Figure 2.6** illustrates the concepts of parallelism and proximity of desire lines to a potential demand corridor.

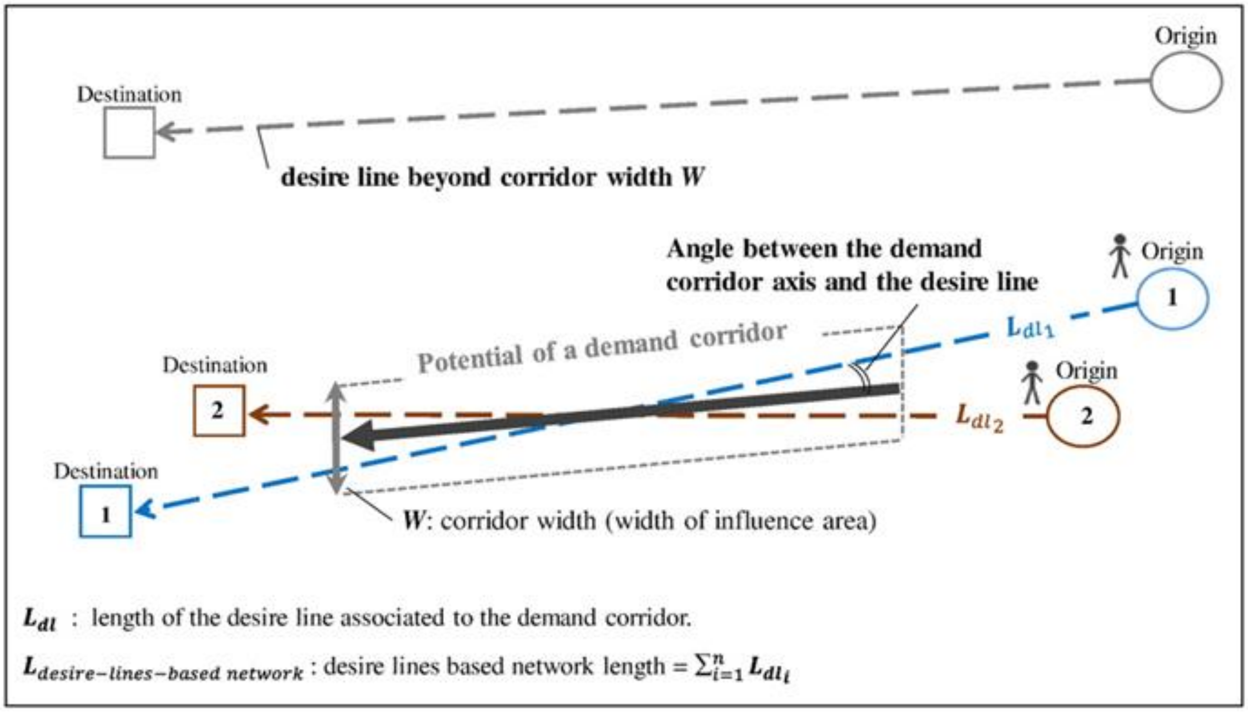


Figure 2.6 Evaluating Desire Lines for Parallelism and Proximity to a Potential Demand Corridor (Bahbouh et al., 2017)

2.5 Selecting Data Sources

Since the 1950s, transportation planners have leaned on surveys to analyze travel patterns at a collective scale (Weiner, 2016). Typically, data is collected at the individual level through travel surveys of reported trip-making behavior for a small subset of the total population. The responses are then generally fed to travel demand models that extrapolate results to estimate travel behavior for the full study geography population. For example, Utah conducted a statewide travel diary survey in 2012 where 9,155 households reported all trips taken on a single weekday (Utah Travel Study, 2013). The resulting data is used to support the five regional travel demand models supported by UDOT.

Travel demand models produce a slew of data outputs ranging from link-level estimates of traffic noise to zonal summaries estimating the number of household vehicles. As previously mentioned, travel demand models are capable of computing link-level demand estimates for proposed projects but require the model to be rerun for each scenario. New methods such as those proposed by Bahbouh et al. (2017) rely on OD pairs that contain summaries of trip characteristics for all trips taken between two aggregate geographies, often traffic analysis zones (TAZ) or census block groups, represented by a straight line connecting the two centroids. Each line represents a single pair and maintains information about average trip distances, travel time, and number of trips by mode. The geographic aggregation simplifies data complexity compared to a full travel demand model run.

The household travel surveys on which these models are built, however, often draw from relatively small sample sizes both in terms of the number of households and the number of days for which data is collected (Travel Forecasting Resource, 2022). As with any complex model, extrapolating estimates from small sample sizes increases the potential error in outputs.

2.5.1 Emerging Transportation Data Sources

Emerging active transportation data sources include OD data obtained from location-based services' data sets and providers like StreetLight Data (2020) and Replica (2020). The relative ease of mass location-based services' data collection allows for far greater sample sizes and more up-to-date information on changes in mobility patterns. Such OD data has been used to analyze trip distances across six US metropolitan areas in a recent report from the Brookings

Institution (Tomer et al., 2020). Using Replica OD data (a national activity-based model [Replica Places] combining geolocation data from mobile devices and proprietary models that generate a synthetic populations' travel patterns) at the level of US census tracts, the authors calculated and compared trip length distributions and estimated regression models linking average trip distances to various neighborhood characteristics. Across all metros, 50% of trips (by all modes) were less than 4 mi (a bikeable distance), while 20% to 30% were less than 1 mi (a walkable distance). Additionally, because these emerging transportation data sources rely on the same travel demand modeling framework as traditional travel demand models, vendors like StreetLight Data can provide detailed select-link analyses for specific existing network links to be used in calibrating and evaluating tool performance.

2.5.2 Origin-Destination Pair Disaggregation

As OD data becomes more widely available, the need for anonymization and spatial aggregation results in challenges using such data for understanding current levels or future potential for active transportation. Post-processing efforts are needed to disaggregate OD data into network volumes on transportation facilities; this process is especially difficult for short walk and bicycle trips, which can be misrepresented as zone sizes increase. One potential solution is through so-called "jittering," which introduces controlled randomness to the disaggregation process. A recent article and tool (Lovelace et al., 2022) demonstrates how jittering can be used to split OD flows and randomly sample multiple OD points from a street network (rather than a single zone centroid) to generate more realistic walk trip flows in a network; see **Figure 2.7**. Such a jittering process could be used to disaggregate OD data for a city, region, or state (and for different time periods) and generate link-specific estimated volumes of short trips that are currently (or could be) made by walking or bicycling.

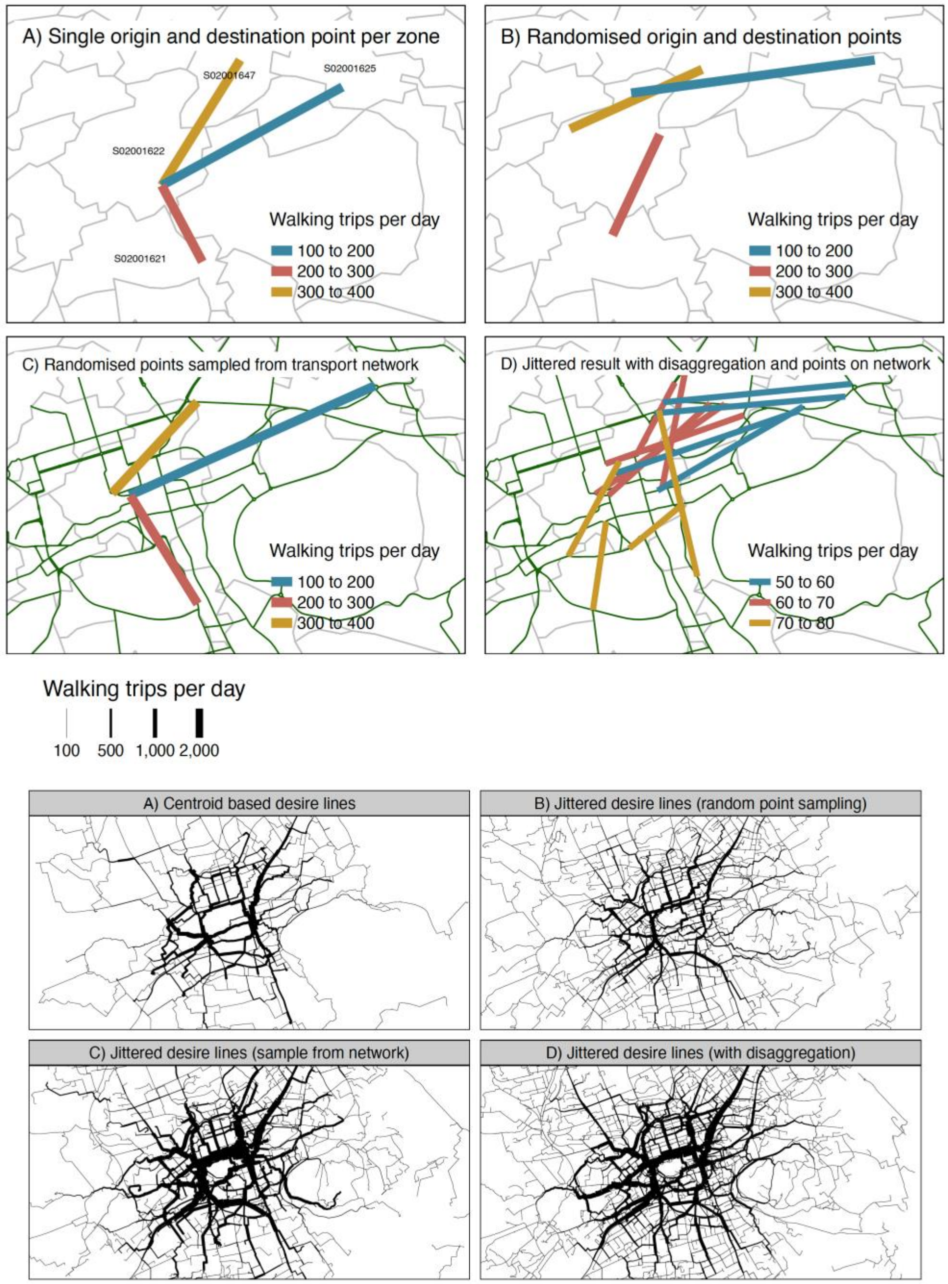


Figure 2.7 Use of Jittering to Translate OD Walk Trip Data to Walk Network Volumes (Lovelace et al., 2022)

2.6 Contextualizing Mode Shift Potential

The output of the tool provides an estimate of the number of car trips taken along the network link that may reasonably be converted to active modes. Naturally, trip volumes differ among network links. Since at least the 1960s, transportation planners in the US have used functional classification systems (FCS) to describe the role of roadways or other transportation facilities in a network. Among the considerations for determining FCS is network usage, meaning the number of trips using that link within a time period. Roads with the largest traffic volumes are typically classified as arterials while local roads move fewer vehicles. FHWA (2013) describes other considerations and travel characteristics related to FCS; see **Table 2.1**.

Table 2.1 Other Considerations and Travel Characteristics Related to Roadway Functional Classifications (FHWA, 2013)

Functional Classification	Distance Served (Length of Route)	Access Points	Speed Limit	Distance Between Routes	Usage (AADT and DVMT)	Significance	Number of Travel Lanes
Arterial	Longest	Few	Highest	Longest	Highest	Statewide	More
Collector	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Local	Shortest	Many	Lowest	Shortest	Lowest	Local	Fewer

The central tenet underlying FCS is that within transportation networks, roadways offer a balance between the competing functions of mobility (transportation; traveling longer distances at higher speeds) and accessibility (origins and destinations; accessing land uses). Arterials provide high mobility, local roads provide high access, and collectors provide a blend of mobility and access (FHWA, 2013). **Figure 2.8** depicts this conceptualization of access versus mobility in FCS.

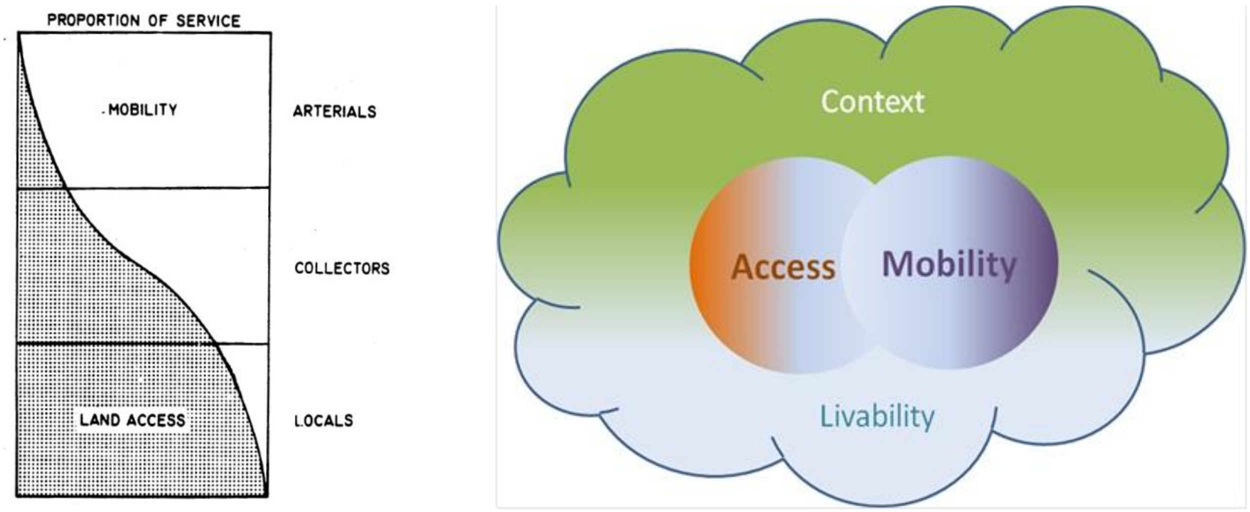


Figure 2.8 Two Depictions of the Trade-Offs Between Access and Mobility in Functional Classification Systems, left (FHWA, 1989) and right (FHWA, 2013)

As a result of these different functions, arterials often have higher speed limits, more travel lanes, and fewer access points (driveways and intersections). Thus, they usually carry a higher share of the length of long-distance trips. Conversely, collectors and local roads are used more for shorter trips and may have lower speeds due to greater expected turns and entry/exit points.

2.6.1 Applying Functional Classification to Active Transportation

In general, traditional FCS systems like the ones described in this section are not necessarily entirely well-suited for adaptation to active transportation modes like walking and bicycling. Many FCS distinctions are based on the highly varied speeds that motor vehicles can travel (10 to 80 miles per hour [mph]), the resulting amount of time it takes to accelerate or decelerate (for turns or stopping for turning vehicles), the implications of differential speeds on flow and safety, and concerns over capacity and congestion. These concerns may not be shared for pedestrian or bicycle traffic.

For pedestrian networks, many of these arguments about the inherent conflict between mobility and accessibility (related to flow, speed, volume, and limiting access) are mostly moot points. Walking speeds exhibit very low variability (2 to 4 mph), acceleration and deceleration happen quickly, conflicts between pedestrians usually do not lead to injuries, trips are usually short, and (except in a few places) sidewalk or pathway capacity is almost always sufficient to avoid congestion and delay. In other words, mobility and access are usually not in conflict for walking, so any FCS applicable to pedestrian travel would need to be defined by different parameters. For example, Stamatiadis et al. (2018) defined pedestrian network FCS based mostly on facility width, with additional consideration to pedestrian volumes, separation from motor vehicle traffic, directness, and so on.

For bicycle networks, some of the same mobility versus access considerations still apply as with motor vehicles, but their importance is diminished. Bicycling speeds do vary but within a much smaller range (10 to 20 mph), acceleration and deceleration are concerns (but more from an energy expenditure perspective), conflicts between bicyclists can lead to (mostly minor) injuries, trips are often short but can be taken over longer distances, and congestion is usually not a concern but can be in some high-use corridors. In other words, mobility and access are somewhat in conflict for bicycling but less so than for driving, so any bicycle FCS might want to consider additional parameters. For example, research has found that traffic safety-related concerns affect bicycle behaviors like route choice and mode choice (Broach et al., 2012; Singleton & Wang, 2014), which suggests that separation from motor vehicles may be an important criterion for bicycle FCS. In their expanded FCS, Stamatiadis et al. (2018) defined bicycle network FCS based mostly on the amount of network connectivity provided (citywide versus neighborhood versus local) and bicycle volumes, as well as separation from motorized traffic.

Local planning efforts sometimes use distance guidelines for laying out bicycle, pedestrian, or active transportation networks. The basic idea here is to provide coverage so that everyone can access a low-stress active transportation network, with (especially for bicycling but sometimes for walking too) higher-quality (wider, more separated) facilities at increasing distances to provide faster and more comfortable options for longer trips. For instance, Minneapolis' bicycle master plan (Minneapolis, 2011) contains a functional classification system in which arterial bikeways are spaced approximately 1 mi apart, with collector bikeways feeding to arterials with around 0.5-mi spacing. The Madison region's bicycle transportation plan (MATPB, 2015) includes similar spacing guidelines for urban areas: 0.5 to 1 mi for primary bikeways and 0.5 to 0.25 mi for secondary bikeways. Many plans such as these align major walkways and bikeways to provide more direct access to major and important destinations, including major employers and job centers, universities and K–12 schools, major transit stations, grocery stores, parks, and other urban amenities (SDOT, 2014, 2017; Pittsburgh, 2020, Portland, 2020). By filling gaps and creating complete hierarchical networks, the ultimate objective is to allow anyone who wants to walk or bicycle (such as for short trips) the opportunity to do so.

Other planning efforts use existing travel behavior and transportation modeling data sources. An interesting application of trip distance to network planning is from Alameda County's multimodal arterial plan (Fehr & Peers, 2016). The concept of functional classification relates directly to trip distance: Higher-class transportation facilities provide greater mobility (traveling longer distances at higher speeds), while lower-class facilities offer greater accessibility (accessing land uses). The work in Alameda County made this connection explicit and directly linked it to active transportation. The plan developed four street types based in part on trip distances, ranging from throughways (at least 50 to 55% of trips are 8 mi or more) to neighborhood/district connectors (at least 50% of trips are 4 mi or less). Trip distances by route were determined from a countywide travel demand model. Along with land use contexts (which are also related to supporting shorter trips by active transportation), these street types were used to help prioritize walking and bicycling on routes with higher shares of short trips most likely to be shifted toward active modes (Fehr & Peers, 2016).

Considering the estimated active transportation mode shift potential from the tool output within a functional classification framework may help contextualize a proposed facility within the larger transportation network. The type of proposed facility should be suitable for serving active transportation trips from a volume and trip characteristic standpoint.

2.7 Summary

The Traveler Alignment tool developed and evaluated in this report uses foundational understandings of the relationship between trip distance and active mode choice and novel methods for evaluating corridor suitability using OD desire line proximity and parallelism. The output of the Traveler Alignment tool is a link-level estimate of mode shift potential, cross validated with the results from a select-link analysis from StreetLight Data, an established source of mobile trace insights in transportation planning practice. The work also evaluates the impact of jittering, a novel OD disaggregation technique, on tool performance. The tool outputs allow for analysis and prioritization of proposed active transportation facility implementation within a functional classification framework for appropriate network volumes.

3.0 DATA COLLECTION

3.1 Overview

This analysis relied on two key data sources to test and validate the performance of the developed tool. The methodology requires OD pair desire lines, which are available as an intermediate output from travel demand models, and produces a link-level trip estimate, similar to a select-link analysis. Recently, an increasing number of big data vendors have released travel model results calibrated from location-based services. The project team elected to derive OD data from Replica's activity-based travel demand model and validate tool performance by cross-checking with select-link analysis performed on 25 segments within the StreetLight Data platform.

3.2 Data Collection

3.2.1 Origin-Destination Lines – Replica Data Review

Replica is a data vendor that produces travel data analytics using mobile location, census, and land use data fed into an activity-based travel demand model (Replica Places) to create a synthetic population and simulate trip-taking behavior. Model results are calibrated with ground truth data to produce a micro-simulation of all movement in the region. Additional methodology details are described in APPENDIX B. Data is available to download from the Replica online platform (**Figure 3.1)**.

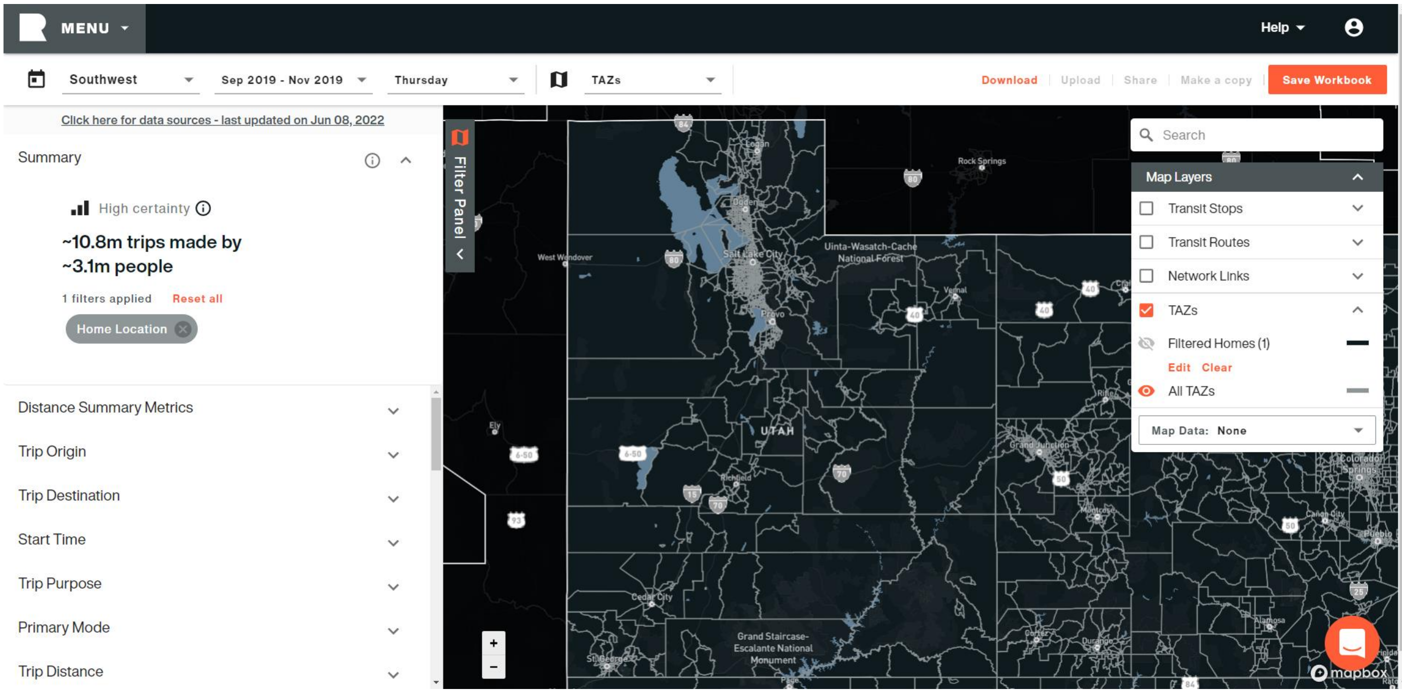


Figure 3.1 Replica Web Data Dashboard Interface

Data is simulated for a representative travel weekday during Fall 2019 and filtered to include trips with destinations in the state of Utah. Replica produces a trip table with an individual record for each modeled trip containing information such as the TAZ in which the trip originated and terminated, mode, duration, distance, and purpose. An example travel day for two simulated people is shown in **Table 3.1**.

Table 3.1 Example Travel Day for Two Simulated People from the Replica Trip Table

Person ID	Distance (mi)	Mode	Travel Purpose	Start Time	End Time
1	1	Private Auto	Work	7:15 AM	7:20 AM
1	0.25	Private Auto	Social	5:00 PM	5:02 PM
1	1.1	Private Auto	Home	5:10 PM	5:15 PM
2	0.25	Walking	Shop	7:00 AM	7:10 AM
2	1.25	Walking	Work	7:30 AM	8:00 AM
2	1.4	Walking	Home	5:00 PM	5:30 PM

3.2.1.1 Replica Post-Processing to OD Lines

The raw trip table from Replica was processed in Python to convert it to an OD matrix with columns shown in **Table 3.2**. Trips with common origin and destination TAZs were aggregated into OD pairs with the count of associated trips taken by each mode and the average distance of all associated trips. The OD matrix was then joined to Utah TAZs, represented spatially in ArcGIS Pro. Each record in the OD matrix was represented by a straight line connecting the geographic centroid of the origin TAZ to the geographic centroid of the destination TAZ. Trips with origins outside Utah were excluded.

Table 3.2 Example OD Matrix from Processed Replica Trip Data

Origin GEOID	Destination GEOID	Average Trip Distance (mi)	Private Auto Trips
4900101001001	4900101001001	4.3	268
4900101001001	4900101001002	6.7	321
4903535001573	4903535001280	10.3	36
4903535001573	4903535001422	2.2	29
4904900001874	4904900001933	4.9	10

3.2.1.2 Jittering

Microsoft Maps provides country-wide building footprint data sets derived from satellite imagery using computer vision algorithms (Microsoft Maps, 2022). For the purposes of this research, this data is used to identify potential trip generations and attractions for implementation of OD line disaggregation via jittering. Building footprint data for the state of Utah was downloaded from the open-source data set and converted to building centroid points in ArcGIS Pro. For use with the odjitter package (Lovelace et al., 2022), each TAZ was required to have at least two points within for trip origin and destination assignment. Thirty one of the 2,731 TAZs had one or fewer buildings reported and were supplemented by building points assigned to the geographic centroid of the TAZ. All buildings were weighted evenly, meaning they had an equally likely chance of being randomly selected as an origin or destination point in the jittering disaggregation process. Jittering allows for intrazonal trips to be treated in the same manner as interzonal trips by assigning a random building within the TAZ to each origin and destination and representing the OD pair as a straight line between the two. **Figure 3.2** shows an example of jittering applied to a small subset of TAZs in Utah.

The original OD lines were jittered with three different thresholds, providing increasing levels of disaggregation. The disaggregation threshold indicates the maximum number of trips that will be represented by a single line, so higher thresholds indicate lower levels of disaggregation. This research investigates OD lines jittered with thresholds of 100, 50, and 10 trips.

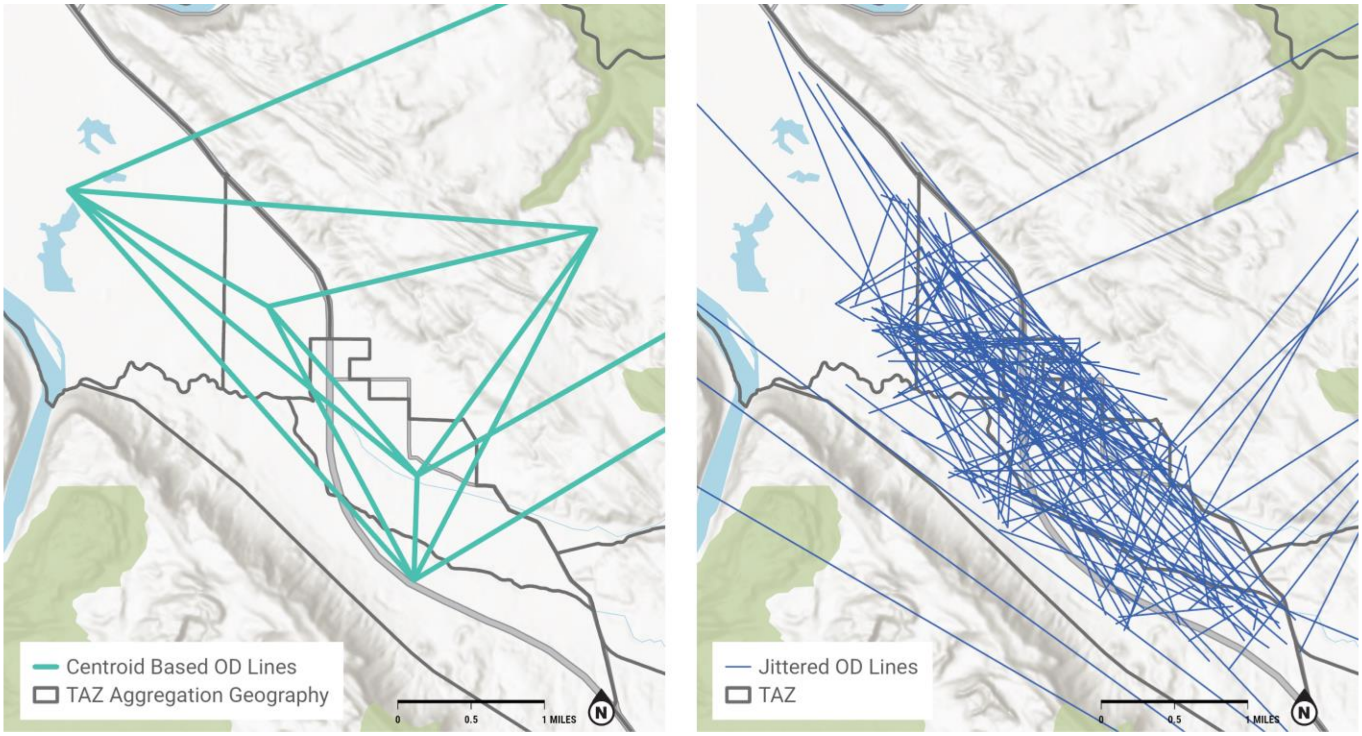


Figure 3.2 Demonstration of Jittering to Disaggregate OD Lines as Applied in Moab, UT

3.2.2 Select-Link Analysis – StreetLight Data Review

Similar to Replica, StreetLight Data processes anonymized smart phone and navigation device location data to produce transportation analytics, particularly at the link level. For more information on the StreetLight Data methodology and data sources, see APPENDIX C. This research used select-link analysis performed by StreetLight Data to determine summary metrics about all vehicle trips taken that pass through the network link during an average travel weekday in Fall 2019. The individual links and analysis settings are set in the StreetLight Data online interface, shown in **Figure 3.3**. Analysis results may be viewed and downloaded from the online interface as well (**Figure 3.3**). The raw output provided by StreetLight Data contains information like the total volume of trips on the link, average travel time, average trip distance, and percentage of total trips in various distance bins.

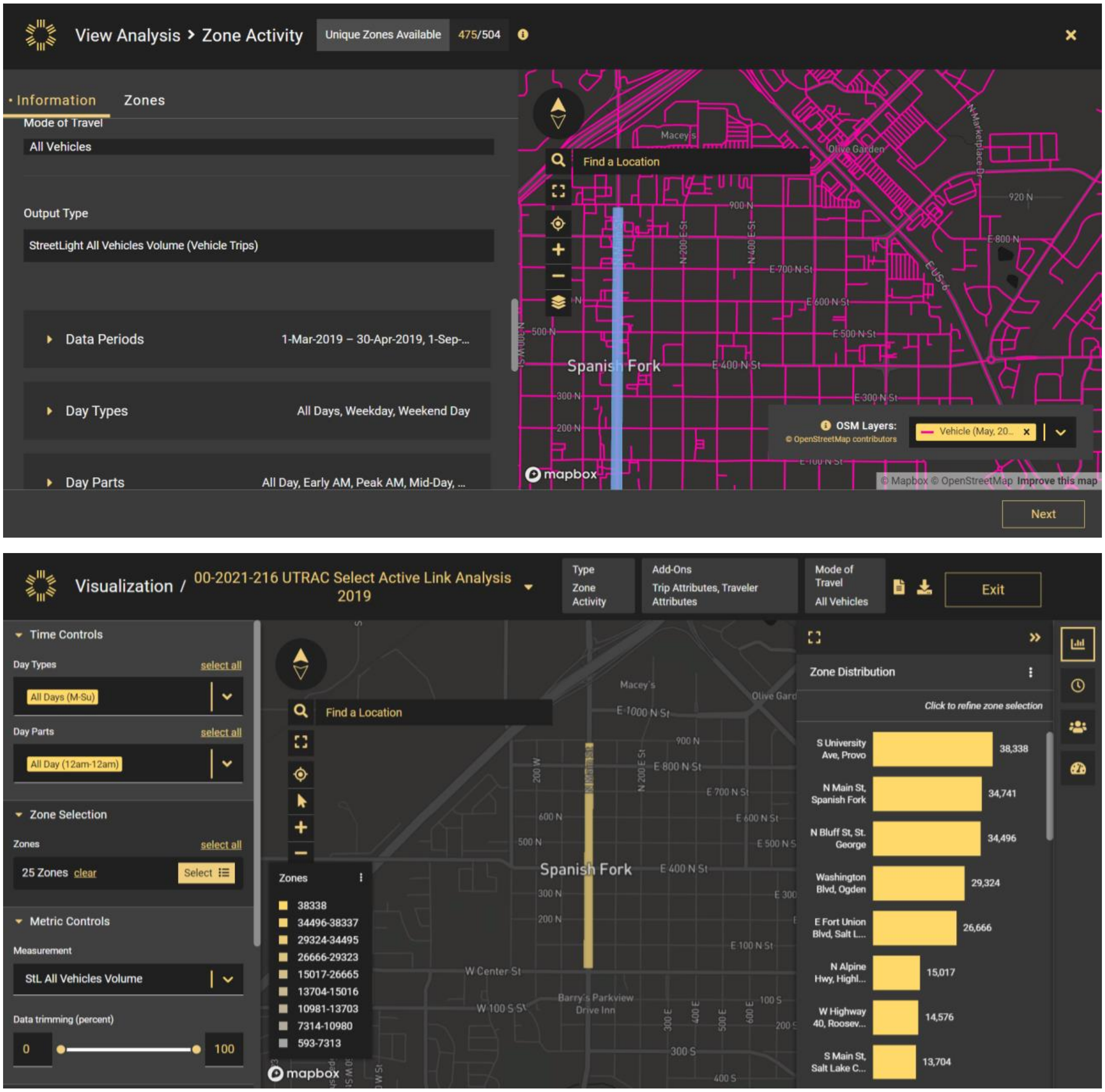


Figure 3.3 StreetLight Data Platform and Analysis Settings

3.2.2.1 Case Study Area Selection Criteria

Select-link analysis was performed on 25 links, each about 1 mi long, spanning urban, suburban, and rural land-use types across the state of Utah. Links were selected from road segments with planned active transportation facilities as part of the statewide bike plan to ensure a diversity of functional classification, land use context, and geographic coverage. The roadway functional classification and land use context were recorded for each link using roadway data provided by UDOT, points of interest from OpenStreetMap, and aerial imagery, respectively. A summary of the 25 links is presented in **Table 3.3**.

Table 3.3 Select-Link Analysis Summary for 25 StreetLight Data Zones

Street Name, City	Land Use Context	Total Vehicle Trips	Baseline Trips*	Expanded Trips**
N Bluff St, St. George	Suburban	35,500	7,000	7,200
W 3650 S, St. George	Suburban	8,000	1,300	1,400
N 2260 W, Hurricane	Suburban	4,800	1,500	1,400
W Powell Dr, Kanab	Rural	4,500	2,600	2,300
N Main St, Moab	Urban	12,400	5,400	4,900
Spanish Valley Dr, Moab	Rural	1,400	370	360
W Center St, Huntington	Suburban	1,300	600	540
S 300 W, Nephi	Rural	500	50	46
Main St, Richfield	Urban	13,900	6,400	5,600
E 600 S, St. George	Suburban	4,500	1,900	1,800
S Carbon Ave, Price	Suburban	12,100	2,800	2,600
N Alpine Hwy, Highland	Suburban	15,900	2,600	2,700
State Rd, Payson	Rural	14,200	1,800	2,000
Washington Blvd, Ogden	Urban	29,700	6,600	6,600
N Main St, Spanish Fork	Urban	36,400	7,400	6,900
Kilby Rd, Park City	Rural	9,700	1,700	1,600
S University Ave, Provo	Suburban	40,100	7,600	7,000
E 400 S, Orem	Suburban	5,400	2,100	1,900
S Cottonwood St, Midvale	Suburban	10,300	950	900
S 3600 W, West Valley City	Suburban	7,900	1,900	1,800
S Main St, Salt Lake City	Urban	14,200	4,400	4,000
N American Beauty Dr, Salt Lake City	Suburban	2,700	600	560
E Fort Union Blvd, Salt Lake City	Suburban	26,700	8,000	7,400
E 700 N, Logan	Suburban	15,800	11,200	10,000
W Highway 40, Roosevelt	Suburban	16,000	4,000	3,600

*Number of trips when the Baseline trip distance thresholds and weights are applied.
**Number of trips when the expanded Baseline + Mile Breaks trip distance thresholds and weights are applied.

3.3 Summary

Data for testing and validating tool performance was provided by Replica and StreetLight Data, respectively, which are two big data vendors that train travel demand models on location data from cell phones and other GPS devices. Replica provided a trip table simulating all person activity during a representative travel day in Fall 2019 that was post-processed into an OD matrix of private vehicle trips aggregated at the TAZ level and spatially represented as straight lines connecting the geometric centroid of each origin TAZ to the destination TAZ. Additionally, further post-processing as applied to disaggregate OD lines via jittering and random assignment of origin and destination points to building footprints provided by Microsoft Maps.

To calibrate and validate the tool outputs, 25 links were manually chosen for in-depth select-link analysis through the StreetLight Data platform. This analysis reported the number of trips by total trip distance passing along the link in a typical weekday period during Fall 2019. Links were selected to capture a diversity of functional classes, land use contexts and geographic spread.

4.0 DATA ANALYSIS

4.1 Overview

The Traveler Alignment tool is designed to identify the number of vehicle trips taken along a link that have the potential to be shifted to active modes. A select-link analysis of 25 StreetLight Data zones provided calibration data to compare model results to and refine input parameters. Parameter settings were adjusted using a qualitative gradient descent method to optimize weighted thresholds for OD line proximity and parallelism and trip distance. Once calibrated to unaltered OD lines, the desire lines were disaggregated via jittering at three different levels to assess potential improvements in tool performance. Estimated potential conversion trips identified by the Traveler Alignment tool and through select-link analysis from StreetLight Data were compared to calculate estimation error using root mean square error (RMSE) and mean absolute error (MAE) metrics, and checked for correlation using Pearson and Spearman tests.

4.2 Replica Statewide Flow Results

Statewide trip characteristic summaries were derived from the Replica Trip Table for all modeled trips within the state of Utah for a typical Thursday during the Fall of 2019. Analysis of short trip-making behavior confirms the potential for active trip conversion at a statewide level. **Figure 4.1** shows the percentage of all trips taken by walking modes as compared to the percentage of all trips that are less than 1 mi in distance, summarized by UDOT transportation district. In all districts, over half of trips less than 1 mi are currently made by walking. District 4 in the southernmost part of the state has the greatest percentage of total trips less than 1 mi, but the lowest percentage of total trips made by walking. District 2, home to Salt Lake City, has the smallest percentage of trips less than 1 mi, but nearly double the number of total trips of any other UDOT district (**Table 4.1**).

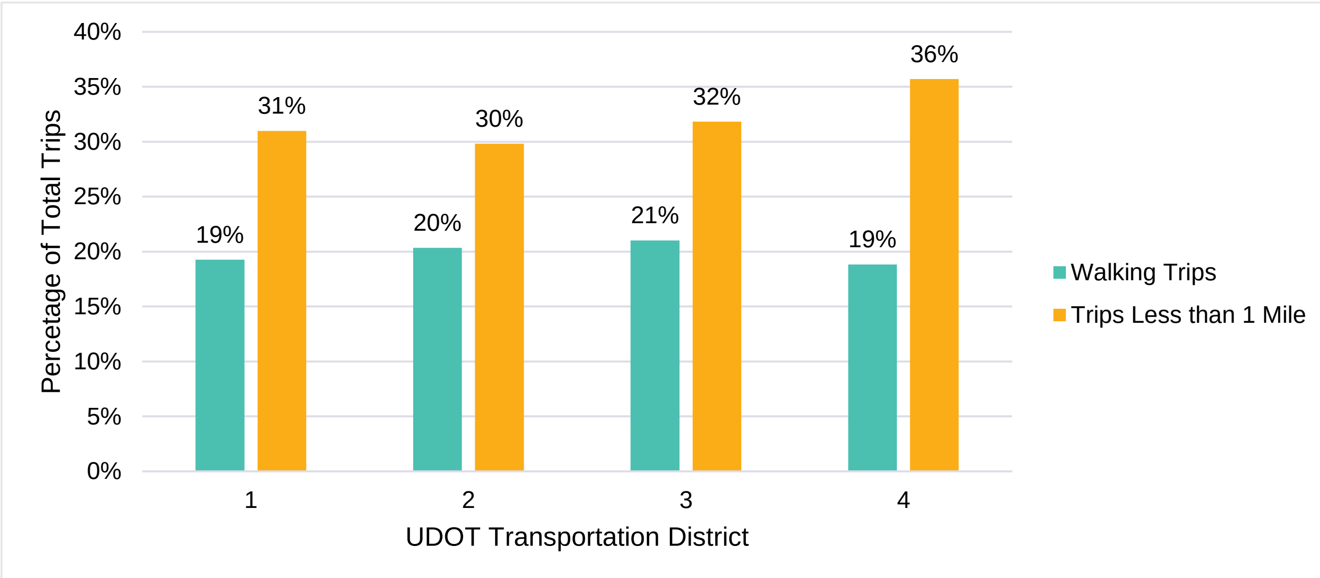


Figure 4.1 Percentage of All Trips Made by Walking Compared to Those Less Than 1 Mi in Distance, Aggregated by UDOT District

Examining the percentage of trips made by bike compared to trips less than 3 mi and 5 mi reveals a massive opportunity for converting short trips to active modes. Specifically, trips less than 3 mi are considered to have ATP, meaning the possibility of being taken by walking or biking. Statewide, less than 5% of trips less than 3 mi are made by biking, and no district has a bike mode share greater than 2% (**Figure 4.2**). The map presented in **Figure 4.3** shows ATP at the TAZ-level statewide.

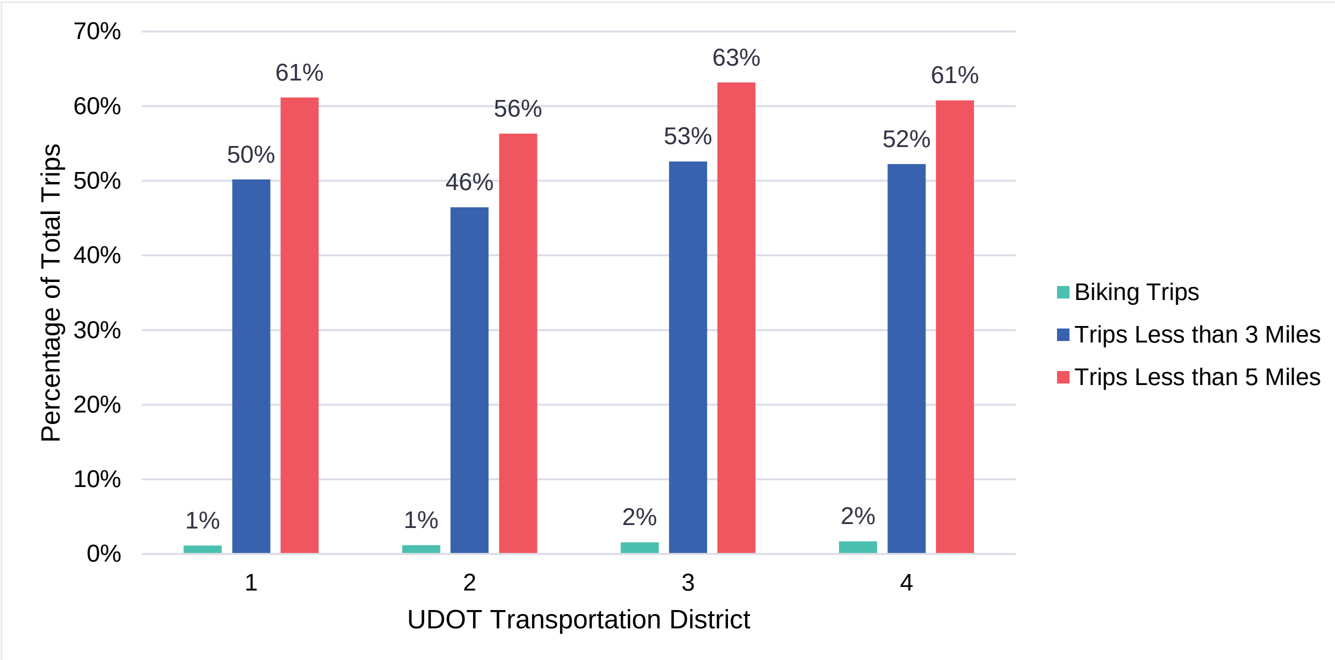


Figure 4.2 Percentage of All Trips Made by Biking Compared to Those Less Than 3 Mi and 5 Mi in Distance, Aggregated by UDOT District

Table 4.1 Short Trips and Active Mode Trips Summarized by UDOT District

UDOT District	**Total Trip Ends**	**Walking Trips**		**Biking Trips**		**Trips Less Than 1 Mi**		**Trips Less Than 3 Mi**		**Trips Less Than 5 Mi**	
	Trips are reported in thousands										
1	2,549	491	19%	29	1%	790	31%	1,279	50%	1,559	61%
2	4,512	919	20%	54	1%	1,345	30%	2,096	46%	2,540	56%
3	2,299	483	21%	36	2%	731	32%	1,209	53%	1,452	63%
4	1,428	269	19%	24	2%	510	36%	746	52%	868	61%
Total	**10,788**	**2,161**		**144**		**3,376**		**5,328**		**6,419**	

Note: Totals may not add up due to rounding.

Pockets near city centers tend to have higher ATP than suburban or rural land uses, though the size of the city does not appear to matter. Between 55% and 65% of trips ending in TAZs at the heart of the smaller cities of Junction and Fillmore are less than 3 mi, consistent with downtown Salt Lake City and Ogden.

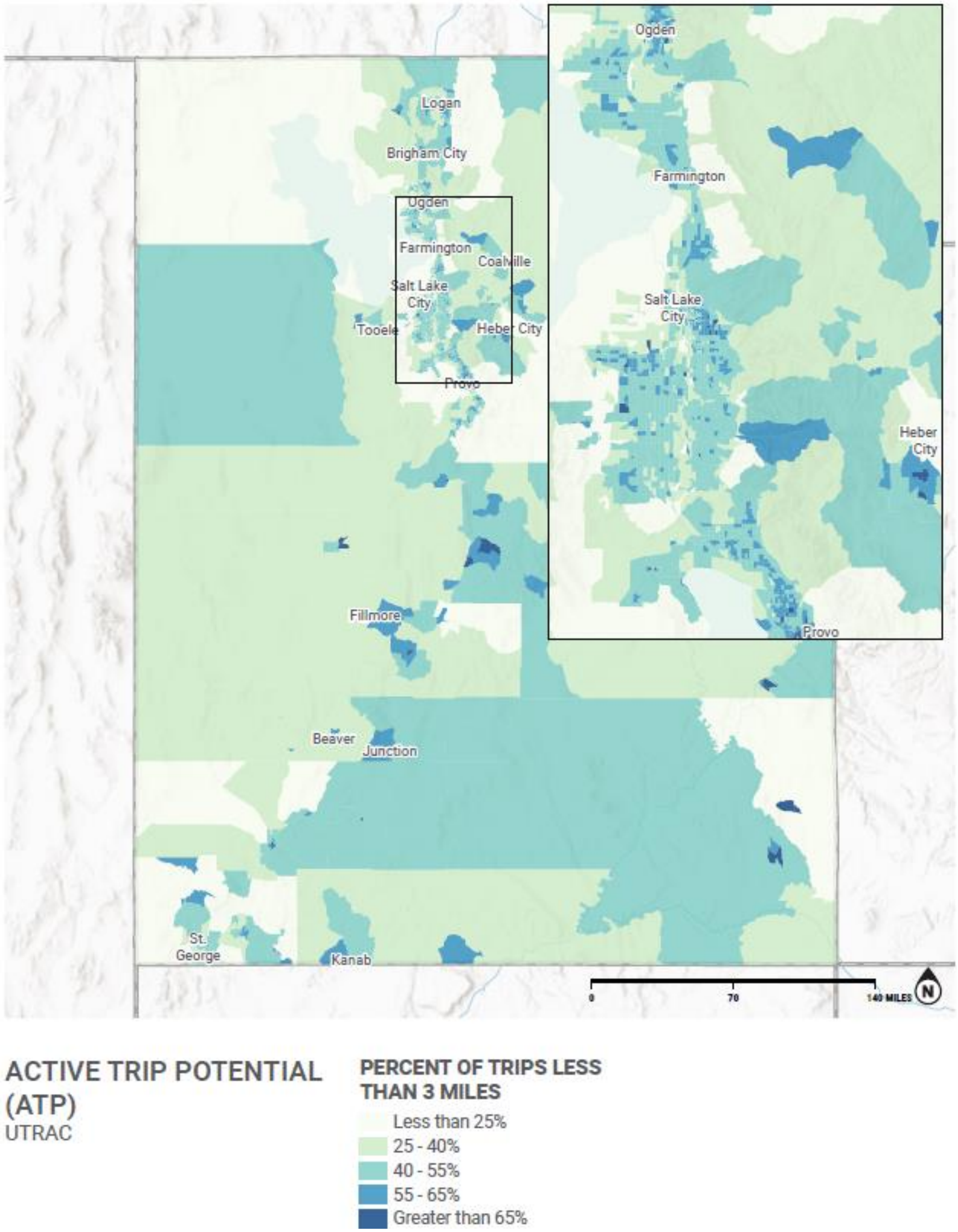


Figure 4.3 Percentage of Trips Less than 3 Mi, Reported at the TAZ Level

When considering the density of ATP trips per square mile, however, bigger cities have dramatically higher trip densities, which tracks with the presence of more trip takers in areas with increased population density. The map presented in **Figure 4.4** shows the density of ATP trips per square mile, which is the highest near high-density urban cores.

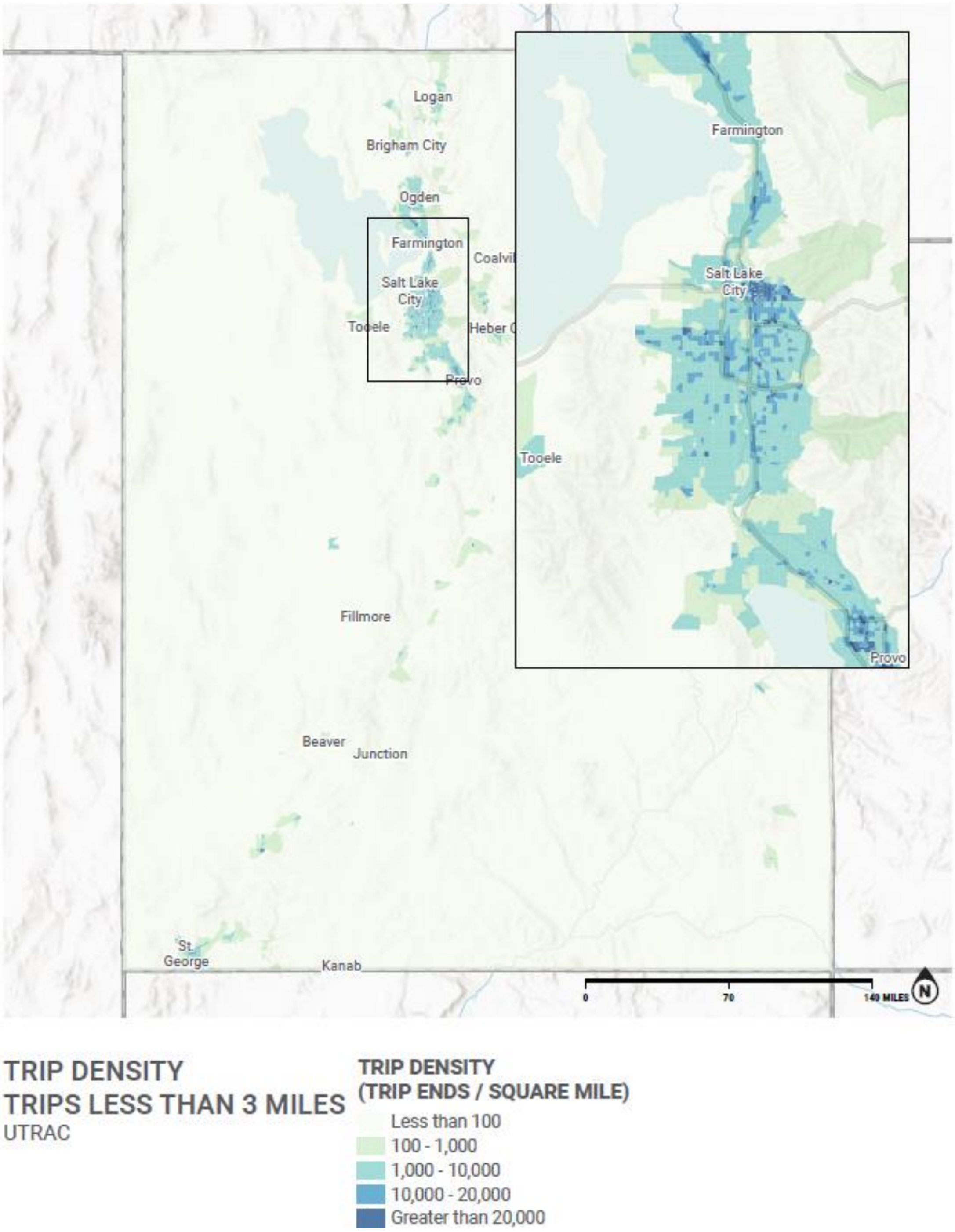


Figure 4.4 Density of Trips Less Than 3 Mi, Reported at the TAZ Level

4.2.1 Dynamic Flow Mapping

State- and district-wide summaries highlight an overall potential for shifting short car trips to active modes, but stop short of identifying where those trips occur. While static maps and tables serve a purpose for communicating quantitative trip behavior summaries, dynamic visualizations can provide greater detail by allowing viewers to zoom in and see both the origin and destination of trips, rather than a TAZ-level aggregation of only trip ends. The flow map, as screen-captured in **Figure 4.5**, shows individual OD pairs connecting TAZ centroids with filters available to visualize short trips and trips taken by active modes.

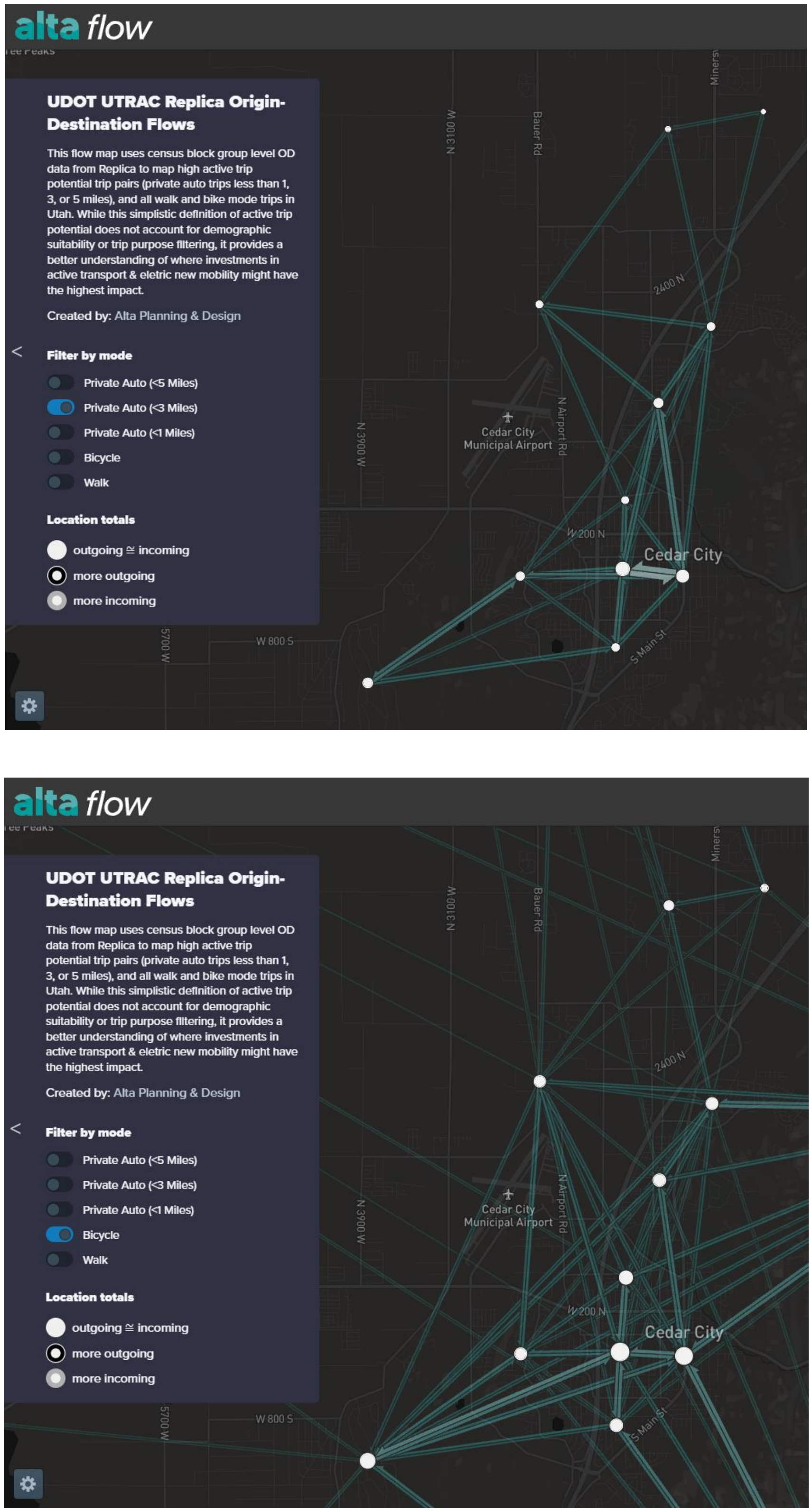


Figure 4.5 Screen Capture of Dynamic Visualizations of Vehicle Trips Less than 3 Mi (top) and Bicycle Trips (bottom) in Cedar City, UT

4.3 Validation Results

Given the relationship between short trips and active trip mode choices as outlined in the literature, vehicle trips identified in the StreetLight Data select-link analysis were determined to have active mode conversion potential by applying the same distance thresholds and weights as the parameter set being evaluated. This number was compared to the number of active mode conversion potential trips as identified by the developed Traveler Alignment tool to assess tool performance. A sensitivity analysis employed a qualitative gradient descent method to alter tool parameters and assess the impact on tool performance.

4.3.1 Sensitivity Analysis

Tool performance may be directly evaluated by comparing the number of trips identified by the Traveler Alignment tool to the comparable trips identified by the select-link analysis. To understand how tuning the parameters impacted tool performance, each parameter was varied individually relative to a Baseline parameter set to produce a qualitative gradient descent process designed to identify the optimal tool parameter settings (**Table 4.2**). This sensitivity analysis was performed and evaluated on the original, non-jittered OD lines to determine the best performing parameter set, and then those parameters were applied to jittered OD lines to assess how disaggregation impacts tool performance.

Table 4.2 Tool Parameter Specifications for the Sensitivity Analysis

Tool Parameter Set	Proximity		Parallelism		Trip Distance		Intrazonal Buffer Distance*
	Upper Threshold	**Weight**	**Upper Threshold**	**Weight**	**Upper Threshold**	**Weight**	
Baseline	0.1 mi 0.25 mi 0.5 mi 1 mi >1 mi	1 0.75 0.5 0.25 0	5° 10° 15° 20° 30° >30°	1 0.9 0.6 0.2 0.1 0	3 mi 5 mi 10 mi >10 mi	1 0.3 0.1 0	0.1 mi
Baseline + Intrazonal	0.1 mi 0.25 mi 0.5 mi 1 mi >1 mi	1 0.75 0.5 0.25 0	5° 10° 15° 20° 30° >30°	1 0.9 0.6 0.2 0.1 0	3 mi 5 mi 10 mi >10 mi	1 0.3 0.1 0	**0.25 mi**
Baseline + Angles	0.1 mi 0.25 mi 0.5 mi 1 mi >1 mi	1 0.75 0.5 0.25 0	**10°** **20°** **25°** **20°** **45°** **>45°**	**1** **0.9** **0.6** **0.2** **0.1** **0**	3 mi 5 mi 10 mi >10 mi	1 0.3 0.1 0	0.1 mi
Baseline + Mile Breaks	0.1 mi 0.25 mi 0.5 mi 1 mi >1 mi	1 0.75 0.5 0.25 0	5° 10° 15° 20° 30° >30°	1 0.9 0.6 0.2 0.1 0	**1 mi** **3 mi** **4 mi** **5 mi** 10 mi >10 mi	**1** **0.8** **0.5** **0.3** 0.1 0	0.1 mi
Baseline + Proximity	0.1 mi 0.25 mi 0.5 mi **0.75 mi** **>0.75 mi**	1 0.75 0.5 **0.25** **0**	5° 10° 15° 20° 30° >30°	1 0.9 0.6 0.2 0.1 0	3 mi 5 mi 10 mi >10 mi	1 0.3 0.1 0	0.1 mi
Baseline + P + M	0.1 mi 0.25 mi 0.5 mi **0.75 mi** **>0.75 mi**	1 0.75 0.5 **0.25** **0**	5° 10° 15° 20° 30° >30°	1 0.9 0.6 0.2 0.1 0	**1 mi** **3 mi** **4 mi** **5 mi** 10 mi >10 mi	**1** **0.8** **0.5** **0.3** 0.1 0	0.1 mi
Baseline + P + M + I**	0.1 mi 0.25 mi 0.5 mi **0.75 mi** **>0.75 mi**	1 0.75 0.5 **0.25** **0**	5° 10° 15° 20° 30° >30°	1 0.9 0.6 0.2 0.1 0	**1 mi** **3 mi** **4 mi** **5 mi** 10 mi >10 mi	**1** **0.8** **0.5** **0.3** 0.1 0	**0.25 mi**

*When tested on jittered data, the tool treats intrazonal pairs like other OD pairs, ignoring the buffer distance.
**The Baseline + P + M + I parameter set is referred to as "Enhanced" in the text for simplicity.

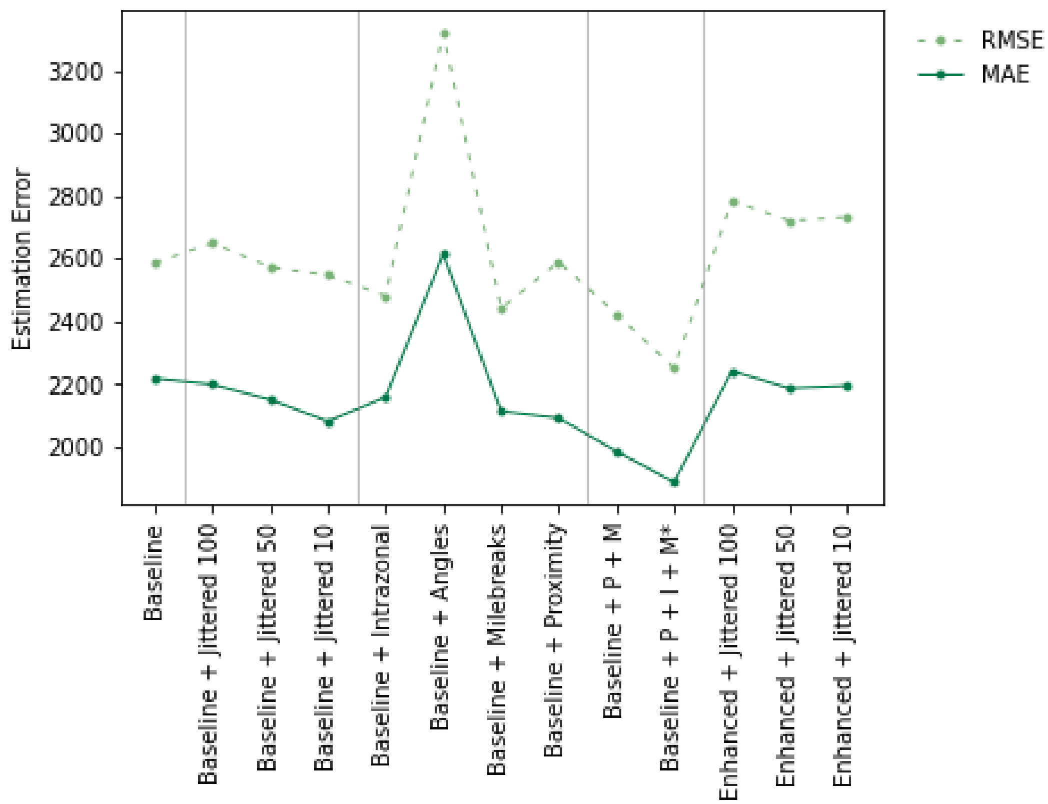
4.3.2 Tool Evaluation

Each tool run produced a segment level estimation of the number of trips with active mode conversion potential based on the applied parameters described previously. The results were compared with the number of trips on the segment as identified through the StreetLight Data select-link analysis with the appropriate trip distance thresholds and weights applied. For example, in the Baseline parameter set, the number of trips identified through the select-link analysis includes 100% of trips less than 3 mi, 30% of trips between 3 mi and 5 mi, and 10% of trips between 5 mi and 10 mi. This would compare each set of mode shift potential trip distance thresholds from the alignment analysis tool to its corresponding index derived from StreetLight Data's pass-through zone analysis.

4.3.2.1 Estimation Error

The difference in trip counts identified by the tool and the select-link analysis as potential active mode conversion trips was evaluated using RMSE and MAE estimation error metrics. Both RMSE and MAE measure the average magnitude of error in the estimated value, treating trip volumes from the select-link analysis as ground truth. RMSE is more sensitive to outliers because the errors are squared before they are averaged, whereas MAE treats the magnitude of error linearly. **Figure 4.6** shows the RMSE and MAE of estimated active mode conversion trips as compared to select-link volumes for all parameter sets.

Figure 4.6 Evaluation of Estimated Active Mode Conversion Potential Trips Compared to Select-Link Volume Results Using RMSE and MAE Metrics



*Baseline + P + I + M is the 'Enhanced' parameter set.

Of the four parameter sets that alter a single variable from the baseline conditions, Baseline + Proximity resulted in the largest reduction in RMSE and MAE compared to the Baseline. Baseline + Intrazonal and Baseline + Mile Breaks showed minor improvement in estimation error. Based on this result, additional tests were conducted on combinations of parameter changes to see if further performance improvement was achievable. Ultimately, the Enhanced parameter set produced the lowest RMSE and MAE of all parameter sets tested by varying proximity, intrazonal buffer distance, and trip distance mile breaks, with values of 2,250 and 1,886, respectively. Across all zones, the average number of trips with active mode shift potential identified via select-link analysis was 3,641 trips per day.

The application of jittering on OD lines when tested on the same Baseline parameter set reduced estimation error, with larger reductions for OD lines with greater degrees of disaggregation. However, when applied in conjunction with the Enhanced parameter set, jittering resulted in higher estimation errors, compared to the same parameter set applied to non-jittered lines. Ultimately, additional analysis is required to understand the impact of jittering on tool performance.

4.3.2.2 Joint Plots

Estimated trips with active mode conversion potential are compared to the number of trips identified via select-link analysis in a joint plot in **Figure 4.7** for the Baseline and Enhanced parameter sets applied to the original OD lines and those that have been jittered to a disaggregation threshold of 10. The histograms on each axis show the distribution of estimated and actual trips by land use context.

Select links in rural land use contexts generally have lower volumes of trips than suburban and urban links. In both the Baseline and Enhanced tests, the tool identifies the fewest number of trips with active mode conversion potential on links in rural areas, but the distributions of estimated trips are nearly evenly spread with no obvious peaks for segments in suburban or urban land use contexts.

Jittering tends to increase the number of trips identified in rural areas. This is likely due to the difference in how the tool treats intrazonal trips when implemented on jittered and non-jittered data. Non-jittered intrazonal trips are considered to have the same trip density across the entire TAZ and are associated to network links based on a buffered area around the segment. For rural TAZs with large geographic areas, this results in low trip densities and few trips allocated to the segment. Jittered data represents intrazonal trips like any other OD pair, connecting building footprints as trip origins and destinations and creating localized pockets of higher trip densities near these trip generators. In a state like Utah, which has vast uninhabited natural areas where no trips would reasonably occur, the jittered representation of trip density in rural areas is likely more representative of reality. The small sample size of rural links limits the ability to assess estimation error improvements on this subset of the data, but a qualitative review suggests moderate improvements in tool performance on rural segments when jittering is implemented. Jittering had no consistent effect on segments in urban or suburban land use contexts. Because TAZs are generally much smaller in suburban and urban areas than rural contexts, the difference in intrazonal trip allocation is likely much smaller.

Both the Baseline and Enhanced parameter sets tend to result in Traveler Alignment tool results with fewer trips than identified in the select-link analysis, particularly on links with higher trip volumes.

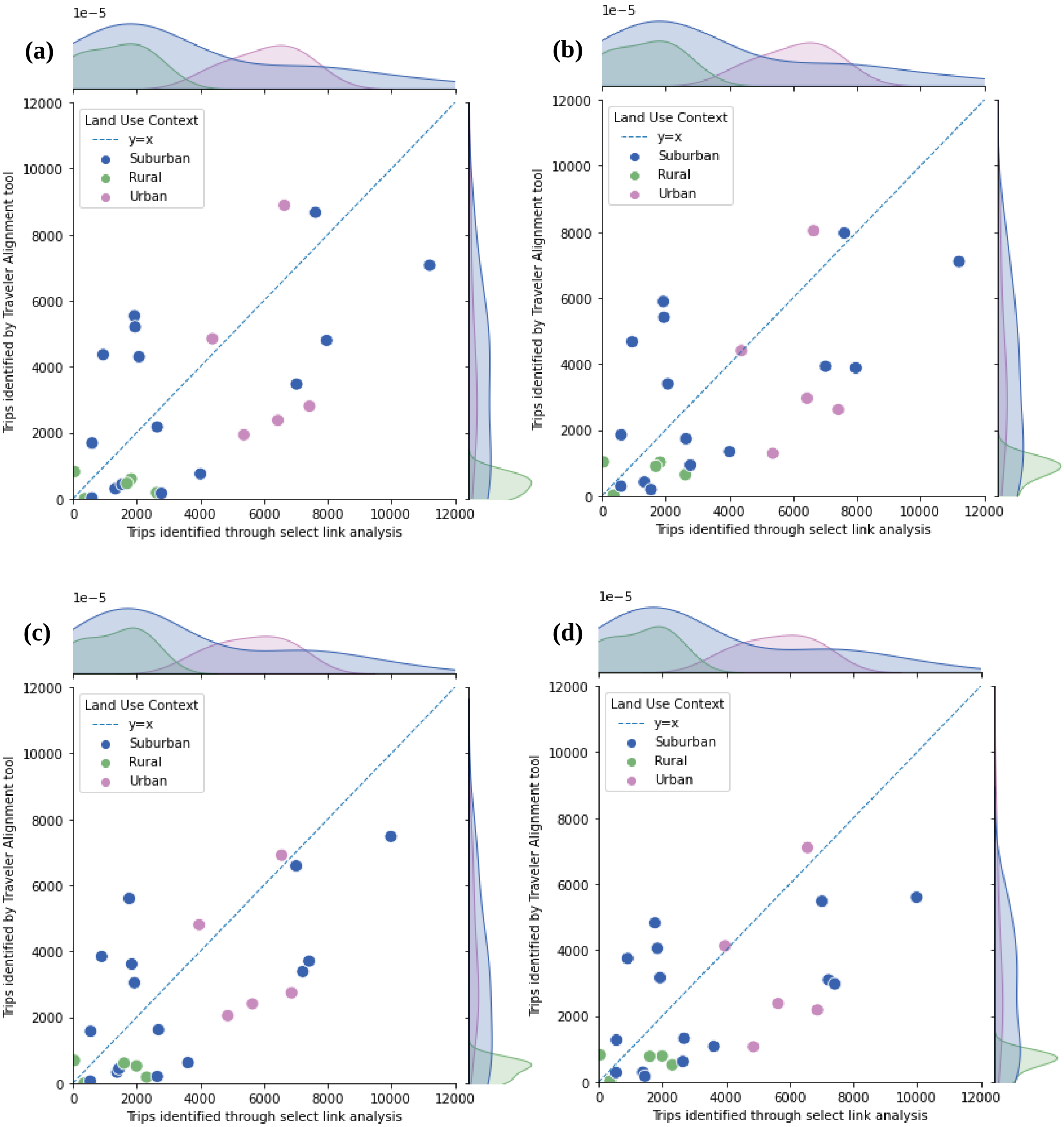


Figure 4.7 Comparison of Active Trip Conversion Potential as Identified Through Select-Link Analysis and as Estimated by the Traveler Alignment Tool for the Baseline Parameter Set Applied to (a) the Original OD Lines and (b) OD Lines Jittered to a Disaggregation Threshold of 10, and the Enhanced Parameter Set Applied to (c) the Original OD Lines and (d) OD Lines Jittered to a Disaggregation Threshold of 10

4.3.2.3 Correlation

Results from each tool parameter set were also assessed against StreetLight Data select-link analysis results using Pearson and Spearman correlation. Pearson correlation checks for a linear relationship between two variables and Spearman correlation detects non-linear monotonic relationships between them by investigating the relationship between the rank of variables, rather than their raw value. The results of these correlation tests are presented in **Table 4.3**.

Table 4.3 Correlation Between Active Mode Conversion Potential Trips as Identified by StreetLight Data Select-Link Analysis and the Traveler Alignment Tool

Tool Parameter Set	Correlation of Tool Results with Select-Link Trips	
	Pearson	Spearman
Baseline	0.62	0.60
Baseline + Intrazonal	0.65	0.62
Baseline + Angles	0.63	0.60
Baseline + Mile Breaks	0.60	0.56
Baseline + Proximity	0.65	0.58
Baseline + P + M	0.64	0.55
Baseline + P + M + I*	0.67	0.58
Baseline Jittered 100	0.56	0.57
Baseline Jittered 50	0.59	0.59
Baseline Jittered 10	0.60	0.59
Enhanced Jittered 100	0.57	0.55
Enhanced Jittered 50	0.60	0.58
Enhanced Jittered 10	0.59	0.57

*Referred to as the “Enhanced” parameter set.

In all parameter sets, there are moderately strong positive correlations between the estimated number of active mode conversion potential trips as identified by the Traveler Alignment tool and the StreetLight Data select-link analysis. Modifying the Baseline parameter set resulted in marginal increases in the Pearson correlation for all parameters except when altering the mile break thresholds and weights. Spearman correlation coefficients are generally lower than the Pearson coefficients, and tend to vary less between parameter sets. When compared to the respective unjittered parameter set, jittering modestly decreases the correlation values for both the Baseline parameter set and Enhanced parameter set. All parameter sets tested showed moderately strong positive Pearson correlations of 0.56 and 0.67 between the Traveler

Alignment tool and select-link analysis results ($p<0.01$). At minimum, the Traveler Alignment tool may be used to understand the relative active mode conversion potential across many proposed projects.

Pearson correlation relies on each variable being roughly normally distributed with no extreme outliers but these assumptions are relaxed in Spearman correlation. As observed in the distribution of link trip volumes in **Figure 4.7**, both the Traveler Alignment tool results and select-link analysis results are slightly skewed to the right, indicating that the Spearman coefficient may be better for evaluation. Additionally, smaller sample sizes like this data set tend to overinflate correlation coefficients. Correlation coefficients are useful in understanding the general moderately strong positive linear relationship between the tool results and select-link analysis results, and indicate the possible usefulness of the Traveler Alignment tool in assessing relative active mode conversion potential for project prioritization purposes.

4.4 Summary

Evaluation of statewide trip-making behavior from trips modeled by Replica for a typical weekday in the Fall of 2019 demonstrates high potential for the conversion of short vehicle trips to active modes by highlighting the discrepancy between walking and biking mode shares and trips less than 1 mi and 3 mi, respectively. The Traveler Alignment tool developed in this research was calibrated to results from 25 select-link analyses provided by StreetLight Data and approximates the number of trips on any existing or new facility that may reasonably be converted to active modes.

Tool performance in approximating the number of trips along a select-link with active mode trip conversion potential was calibrated using RMSE and MAE metrics. Starting from a Baseline parameter set, each tool parameter was varied individually to produce a qualitative gradient descent to minimize estimation error when comparing tool performance to the select-link analysis. Ultimately, the Baseline + P + M + I (or Enhanced) parameter set produced the lowest estimation errors. However, even the lowest MAE achieved (1,886 by the Enhanced parameter set) is about half the average number of potential mode shift trips identified by the select-link analysis across all zones.

Jittering showed marginal improvements in estimation error when applied with the Baseline parameter set, but significantly increased error when applied with the Enhanced parameter set. Examining the joint plot and distribution of trip estimations by land use context reveals that jittering had the largest impact on estimates for links in rural contexts by generally increasing the number of trips identified to have active mode conversion potential.

The final tool parameter settings produced results with a strong Pearson correlation score of 0.67, indicating a statistically significant positive correlation between the number of active mode conversion trips identified by the tool and by the select-link analysis ($p<0.01$).

5.0 CONCLUSIONS

This research develops and evaluates a quick-response Traveler Alignment tool that provides estimates of short trips aligned with on-street or off-street facilities for the purposes of identifying mode shift potential. The tool functionality allows for it to operate on new and existing connections, essentially replicating a select-link analysis while avoiding the high resource costs of traditional travel demand model runs. The proposed tool operates on OD desire lines, which are a more readily available intermediate output of travel demand models that represent trip-making behavior via geographic aggregation. These desire lines are evaluated for their relative parallelism and proximity to the provided corridors, and trips are filtered based on literature-guided values of active mode trip distances. The section that follows discusses aspects of the findings relevant to its applications and performance, limitations of this research, and future areas of exploration based on this research.

5.1 Discussion of Findings and Applicable Limitations

By individually varying each tool parameter, the authors produced a qualitative gradient descent procedure designed to identify the parameter set that minimizes estimation error when compared to calibration results from a select-link analysis conducted by StreetLight Data on 25 zones across Utah. Of the parameter calibration settings tested, the authors found that tighter spatial bandwidths (proximity) and tighter angle thresholds (parallelism) both improved the Traveler Alignment tool performance. This is consistent with previous researchers limiting their angle thresholds to 22.5 degrees to identify assembled corridors of demand (Bahbouh et al., 2017).

The analysis conducted to tune the parameters that influence the Traveler Alignment analysis tool's outputs have a few limitations. The first is that the sample size for this analysis was relatively small at 25 zones. While this is a larger number of zones to use for an analysis tool calibration using mobile data, it is very small relative to the extent of Utah's road network. Additionally, this small sample size required a non-random selection of street segments to vary the distribution of data points across different facility types and land use contexts.

Additionally, the comparability of Replica Places data to StreetLight Data is not entirely understood. To the greatest extent possible, this analysis attempted to create a comparable analysis between the two data sets by limiting the analysis to vehicle trips and comparable trip distance bands. However, the data sets are derived from different sources with one being sourced from a model and another being a mobile data derivative. The comparison provides rough indicators into which parameters are suitable as part of the calibration rather than exact measurements. For this reason, while RMSE and MAE metrics were useful for calibration, the inherent differences in the data sets means that it is unreasonable to expect the tool and select-link results to entirely align.

Following parameter optimization, the authors selected an Enhanced parameter set that minimized estimation error, as measured by RMSE and MAE metrics. This parameter set achieved an MAE of 1,886, about half the average number of trips identified through the select-link analysis. The tool tended to underestimate the number of trips when compared to the select-link analysis results.

However, conservative estimates are better in this case because while short trips are indicators of trips that can be made using active modes, it is unrealistic to expect all short trips to be possible to convert to active transportation (TfLa, 2017; Mackett, 2003). Even if supportive infrastructure is provided, there are a number of reasons why a trip would still be made by non-active modes:

- **Heavy Loads**. In many cases, cargo bikes can support many types of grocery or shopping trips, but some heavy loads are often bulky or heavy enough to warrant the use of a vehicle.
- **Travel Trip Type**. Some shared trips are chained in ways where using active transportation for the entire trip is difficult. For example, if one leg of a tour that is part of a chain of trips is too long to consider using an active mode, the entire tour may be better made using a vehicle.
- **Personal Preference.** Some members of the community may elect to never bike or walk even if an all-ages-and-abilities network is provided in a community. Demographic filtering or weighting based on traveler survey data could be one method to weight the analysis toward demographics more likely to walk and bike.
- **Physical Impairment**. Some members of the community may have an impairment that prevents them from comfortably using active transportation.

- **Seasonal Weather**. Active trips become more difficult to accomplish in difficult weather conditions. While walking and biking trips may still be viable in many instances, there may be some times where it is inadvisable, such as a heat wave or unhealthy air conditions.

The complexity of these variables is far beyond what may be represented in an OD desire line data set, and thus these factors are not considered in this analysis.

5.1.1 Impact of OD Line Disaggregation

The application of a jittering technique for disaggregating OD desire lines by randomly assigning trip origins and destinations to building footprints within the aggregation geography produced mixed results. Jittering improved the performance of parameter sets that used smaller intrazonal buffer distances with wider angle and proximity bands, but reduced performance on the Enhanced parameter set that minimized estimation error on the non-jittered OD desire lines. The key difference between applying the tool to jittered and non-jittered data is how intrazonal trips are handled. Jittering the data allows for intrazonal trips to be treated in the same manner as all other OD pairs, whereas there is no spatial line representation of intrazonal trips in the original desire line format, and trips are instead allocated based on the proportional coverage of the aggregation geography by a buffered area surrounding the segment. In rural areas where TAZs are larger and often filled with significant natural areas where no trips would reasonably happen. Intrazonal trips in rural locations are thus much less likely to have a constant trip density than in more dense urban areas where trip generators are more evenly distributed across the TAZ.

5.2 Areas of Future Research

This mode shift potential tool and its corresponding calibration process opened many questions during the course of research that are potential areas for further research. For example, future research may consider implementing weighted jittering of the OD flow data so that destinations with greater trip generation or attraction potential are selected more frequently than random choice. Buildings or street network segments could be weighted by area, height, land use, or local job or population density.

Another area for future exploration is a more in-depth examination of extending the concepts behind this tool to weight or filter OD desire lines to trips that have suitable demographics or trip purposes for conversion. Similar analysis was conducted as part of Transport for London's evaluation of bicycle and pedestrian trips (TfL, 2017a; TfL, 2017b). This could take the form of an additional weight assignment used to adjust the importance of an aligned trip. This would enable a score that evaluates trip flows based on the proportion of suitable demographics and trip purposes within each

5.3 Summary

This analysis methodology can help provide quick-response understanding of which facilities are likely to align with existing short trips, but it does not replace the fidelity and utility provided by an actual select-link analysis from a travel demand model. Select-link analysis is more likely to capture aggregate network effects and route choice dynamics that this tool would not capture (Castiglione et al., 2015; Brustlin et al., 2012). This tool's key advantage is that it can provide comparable assessments between on-street and off-street facilities without the network editing required to reflect those changes in a travel demand model approach. However, this comes with the drawback that the results from this tool are effectively an index rather than a measurement of trips that might be possible with a model or use of mobile data–derived metrics.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

This chapter includes recommendations for UDOT about how this research and tool can be applied as part of their work and the work of partner agencies. Our recommendations include exploring the integration of this tool into UDOT's TIF active funding process. The authors provide map-based comparisons to existing latent demand scores and the mode shift potential results as a point of comparison to demonstrate the tool's ability to serve as a complement to existing criteria. Additionally, we identify recommendations to explore the integration of statewide or regional travel demand models to evaluate if the tool could function to identify which facilities will see increases in mode shift potential as a result of planned facilities or land use change. Finally, we recommend more nuanced applications of this tool, such as helping to inform modal priorities or developing a robust measure of mode shift potential that includes detailed information about trip purposes and traveler demographics.

6.1.1 Explore Integration into TIF Active Funding Application Process

UDOT takes submissions from jurisdictions for which active transportation projects should be funded and then leverages data related to criteria approved by the Utah Transportation Commission to prioritize their funding (UDOT, 2021). The criteria used for prioritization draw from the UVision Framework to provide, Good Health (Safety, Public Health, and Environment), a Strong Economy (Accessibility, Transport Costs, Economic Development), Better Mobility (Travel Time, Throughput, Risk and Resiliency), and enable Connected Communities (Connectivity, Land Use and Community, Integrated Systems) (UDOT, 2021). All TIF-funded projects, including highway, transit, first last mile, and active projects, are funded along these criteria. The types of criteria and their weighting used for the TIF Active Prioritization Model are depicted in **Figure 6.1**.

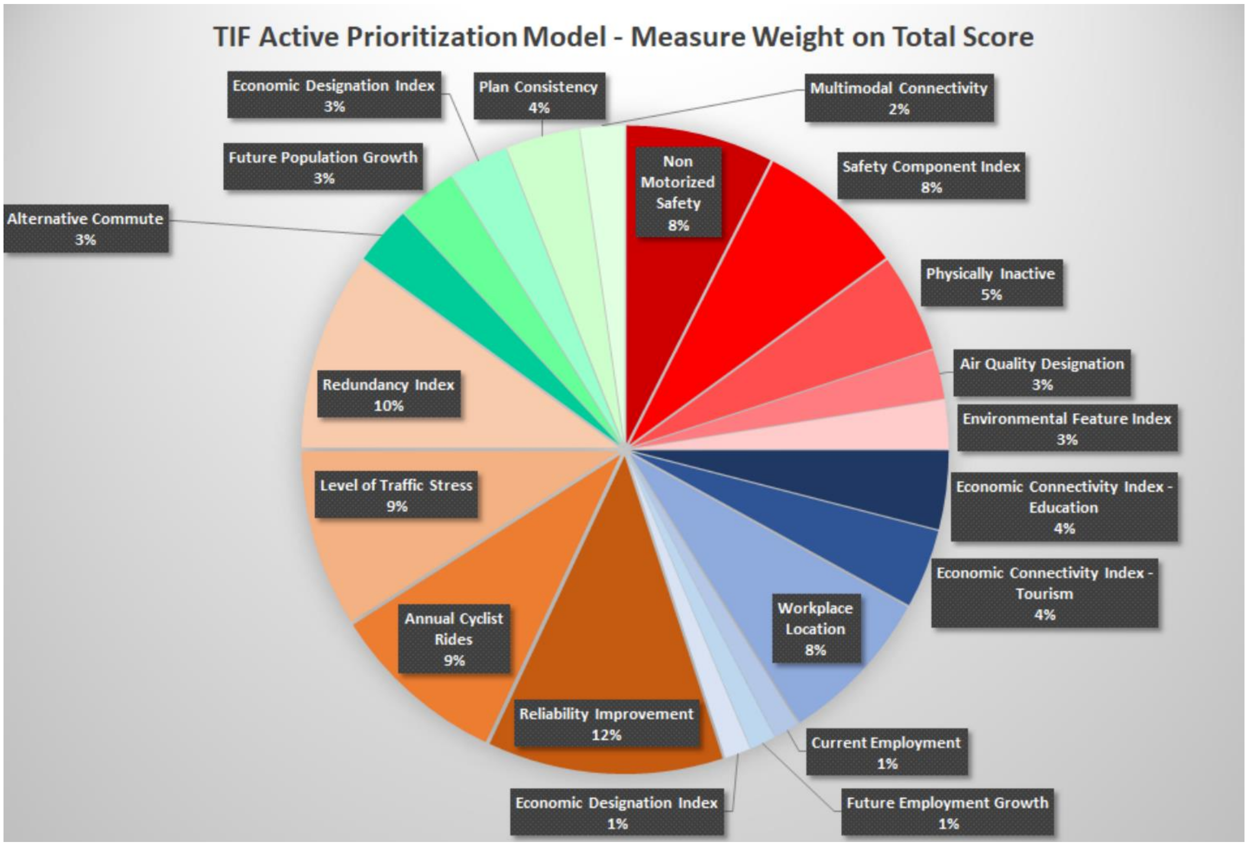


Figure 6.1 TIF Active Prioritization Model Weighting

The range of existing active prioritization criteria is extensive and robust, ranging from improving level of traffic stress to aligning with latent travel demand and future population growth. To understand how this evaluation tool may contribute to UDOT's process, the tool was run on TIF active projects submitted to UDOT in 2021. When projects were longer than 1 mi, they were split into approximately 1-mi segments as a preprocessing step to provide a segmentation similar to that of tested facilities. To be used in prioritization, these segmented scores would need to be aggregated in some form. For example, an average score can be derived via a geospatial dissolve to assemble an average score per TIF active project under consideration.

The results of this application of the tool are show in **Figure 6.2**. The results generally align with the active demand prioritization score calculated by UDOT (**Figure 6.3**), with many TIF active facilities near universities or urbanized areas showing higher scores than more remote facilities. These scores, however, will vary within urbanized areas depending on their alignment and orientation relative to the rest of the region.

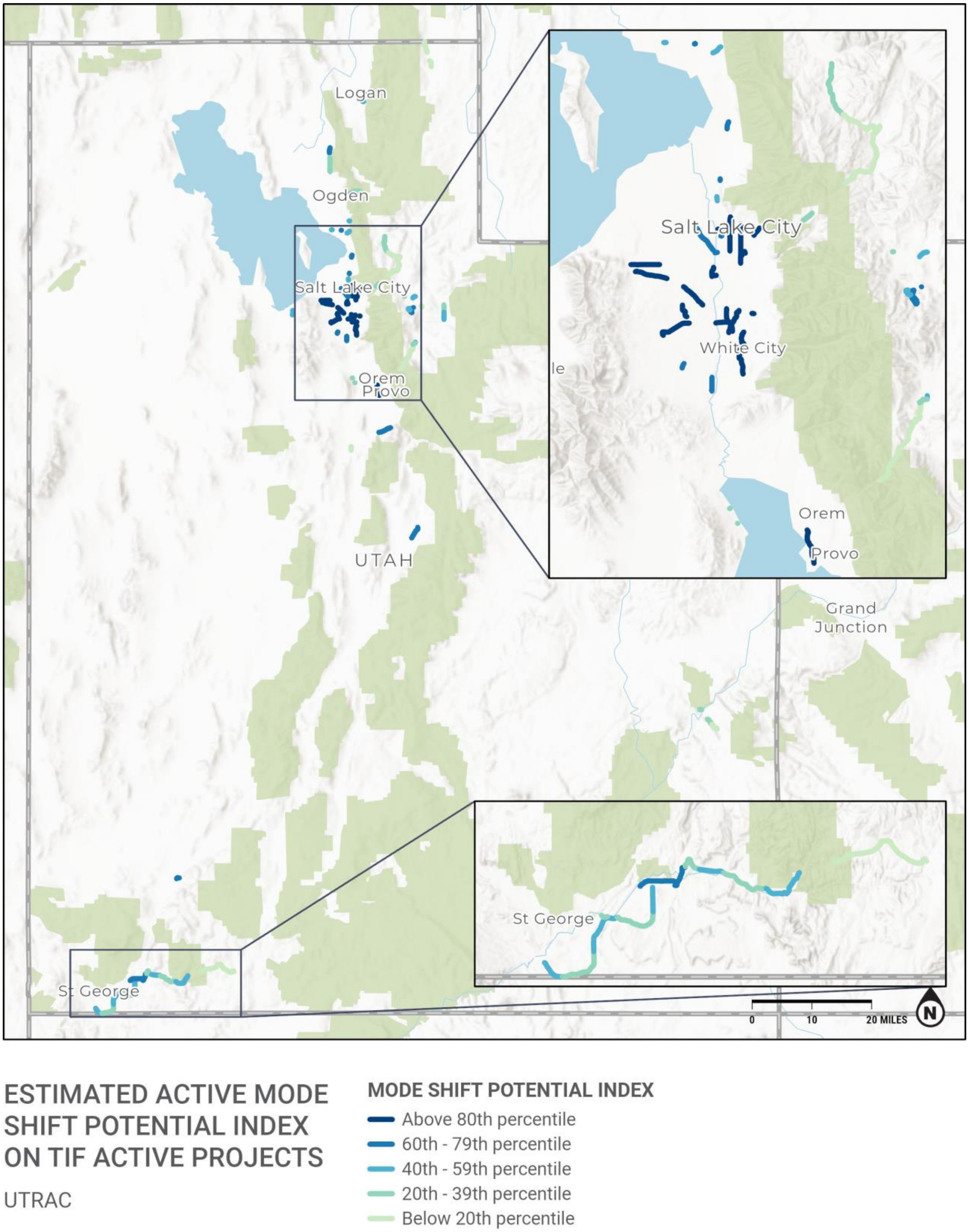


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Figure 6.2 TIF Active Projects Mode Shift Potential Scores

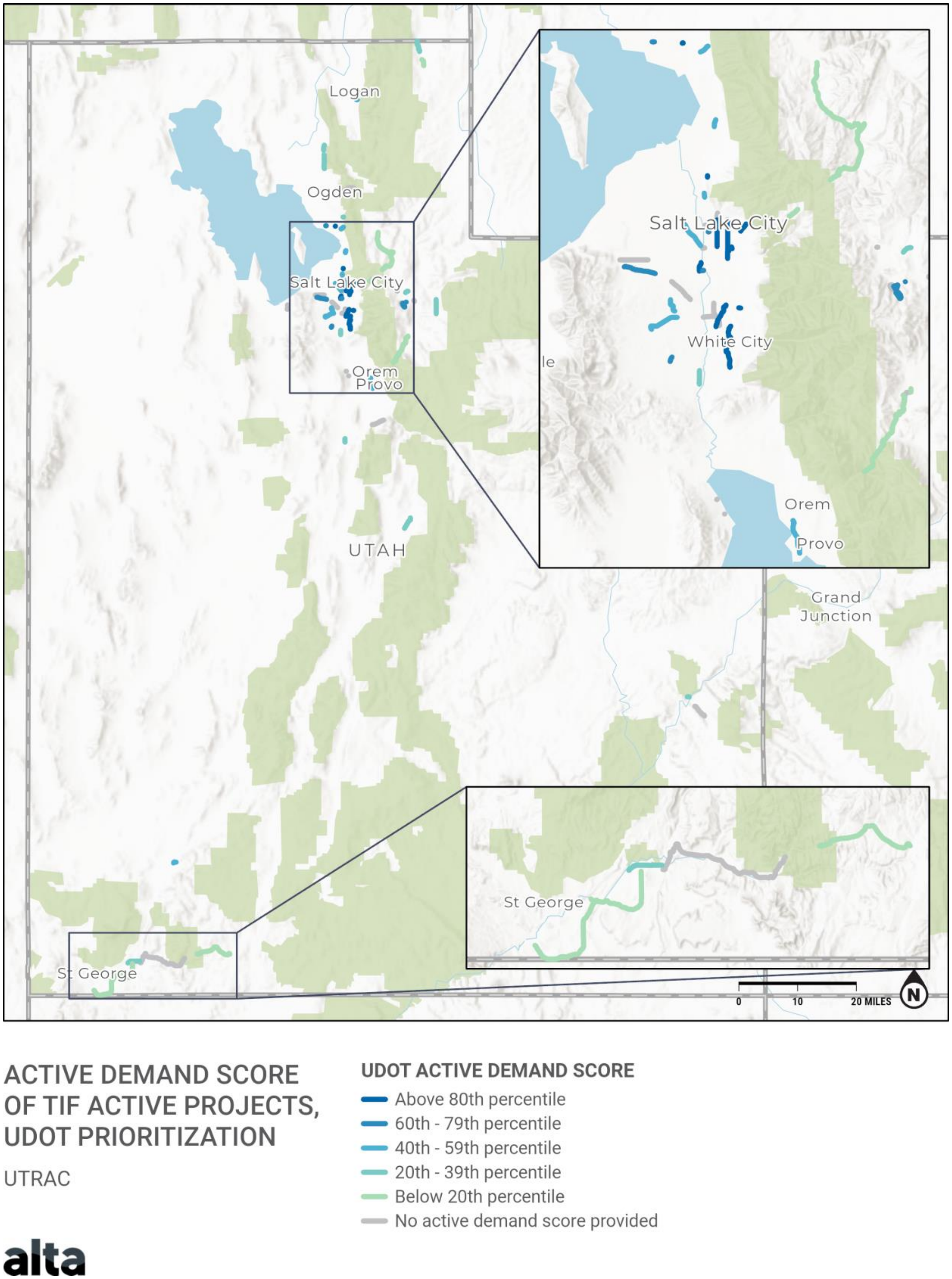

Figure 6.3 Active Demand Score of TIF Active Projects, per UDOT Prioritization

While there are similarities in some of the results produced between the existing active demand scores and the mode shift potential evaluation, there are important differences in result that might suggest the Traveler Alignment tool could be a useful complement for analysis, especially if future, as well as existing, OD matrices from regional or statewide travel demand models are integrated into the analysis, or post-pandemic calibrated models are used to explore how facility investments might react to changes in traveler behavior due to land use change or trends such as increasing propensities for remote work.

6.1.2 Investigate Travel Model Integration

This approach to evaluating mode shift potential has an additional strength in that it can work with any arbitrary OD matrices' desire lines. This means that if a statewide or regional model provides two scenarios for desire lines, this tool could potentially be used to evaluate how long-term land use change or planned facilities might influence which facilities will align with convertible short trips. This could provide insights into how projected changes in land use or development intensity would influence which facilities might align with future needs.

6.1.3 Explore Other Applications and Further Research

The authors final recommendation is to identify and explore other applications of this tool and invest in further research in related topics. For example, an area we think has potential for additional exploration is evaluating how to incorporate trip purpose and traveler demographics into the identification of which trips are candidates for mode shift. This could be informed by an analysis of updated traveler survey data that is expected upon completion of Utah's 2022 Travel Survey. By examining the trip purposes and demographics of travelers who make short, active, and vehicle trips, a basis for some type of propensity weighting could be developed for a more robust mode shift potential evaluation score. This research could be complemented by a review of similar work done by Transport for London, the Brookings Institution, or other organizations examining this topic further.

Additionally, we feel this tool could potentially be used to develop preliminary typologies for proposed and existing facilities based on the distributions of different trip distance bands they are associated with. For example, the tool enables different trip distance bands to be evaluated between runs. This could evaluate whether the distribution of aligned trips between very short (less than 1 mi), short (less than 3 mi), and moderately short trips (less than 5 mi) for different facilities in different runs. This could be used to indicate the types of high-level design needs an active facility may have based on the relative intensities of different short trip categories within each facility. For example, bike plans by cities such as Minneapolis and Madison have identified bike corridor types that influence the spacing of corridors and identify design components related to them (Minneapolis, 2011; MATPB, 2015). Such an analysis could be a component that informs such classifications based on latent demand as well as existing active travel demand (counts).

6.2 Implementation Plan

The goal of this section is to provide direction and guidance on the implementation needs of UDOT and other partner agencies to apply the Traveler Alignment tool developed as part of this research, and to identify staffing and organizational roles that will relate to its successful deployment. To that end, the major components of implementation success will depend on a thoughtful approach to GIS management and identifying key steps to integrate the tool into UDOT processes.

6.2.1 GIS Management and Outreach

Given that the tool created as part of this research is a GIS-based tool, the authors believe it should be stored and maintained by, and live with, UDOT's GIS Manager and related staff. To enable a smooth transition, this tool was provided alongside a user guide that identifies the steps and required inputs to operate the tool (see APPENDIX D: User Guide for Mode Shift Potential Tool). It shows key aspects of the geoprocessing interface, which is illustrated in **Figure 6.4Error! Reference source not found.**, and identifies how to run the tool step by step. Additionally, a training video was provided to UDOT alongside the data used to operate the tool as part of this project. To better educate UDOT staff or partner agencies interested in active transportation or applications of OD data, we recommend considering some type of hour-long lunch-and-learn session in which the GIS Manager can share the training video and some commentary about applications of the tool.

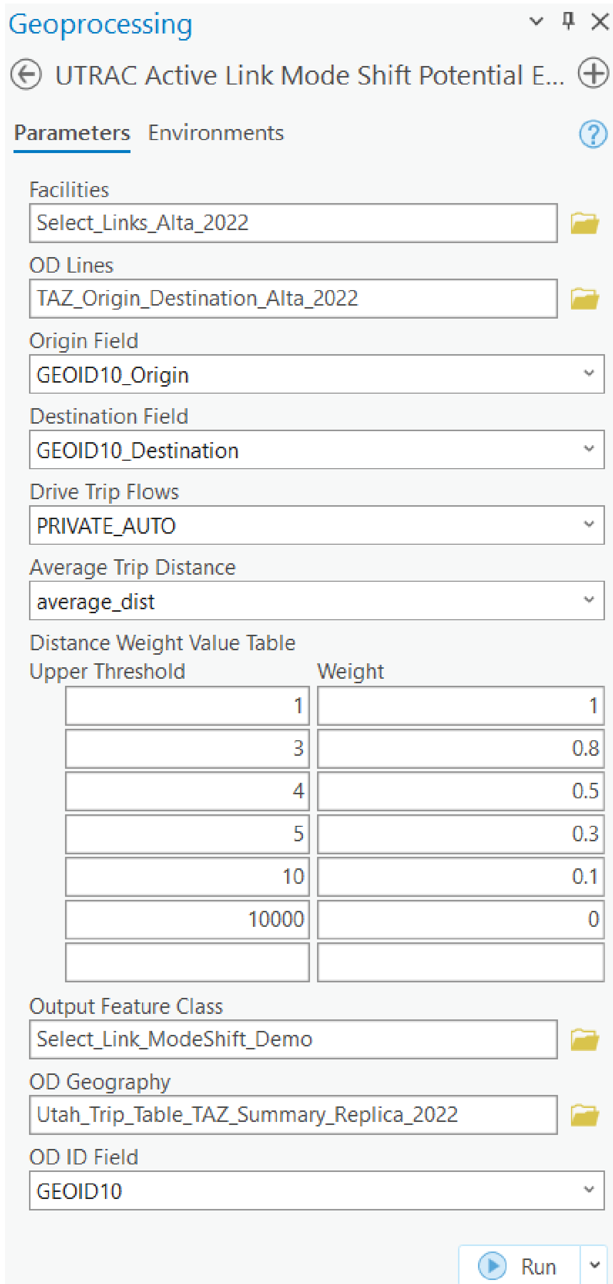

Figure 6.4 Mode Shift Potential Tool Interface and Input Parameters

<u>6.2.2 Integration into UDOT Processes</u>

Finally, the authors recommend exploring other applications this tool could have—either internal to UDOT or with partner agencies. The main area to explore would be whether the tool's results could be integrated into the TIF active funding prioritization and application process. It may provide a valuable complement to existing prioritization criteria, and enable jurisdictions to think more critically about what types of trips they are trying to connect with new facilities. Beyond integration into TIF active funding prioritization, this tool could potentially be provided to partner agencies to evaluate their own prospective facilities in their member jurisdictions.

For example, the Wasatch Front Regional Council (WFRC) in partnership with other agencies recently updated their bicycle model to incorporate updated microzone structures, better measures of network quality, and other improvements to better simulate bicyclist response to changes in available infrastructure. This tool could potentially be paired with the trip distribution matrix from the bike model outputs to avoid the running-an-assignment step to identify which facilities might align with existing or future bicycle demand. These types of applications should be evaluated to see if they merit further exploration as methods to lowering the effort required to apply these detailed models on projects or prioritization processes.

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APPENDIX A: Literature Review Active Functional Classification

This appendix documents a literature review of active transportation's relationship to functional classification, and examples of explicit active transportation-focused functional classification systems.

To: Utah Department of Transportation

From: Patrick Singleton, Utah State University

Date: 20 January 2022

Re: Literature Review for "Active Transportation Functional Classification for Utah"

Introduction

The Utah Department of Transportation (UDOT) seeks a functional classification system applicable to active transportation modes and statewide networks. As a widely-used system encapsulating the tradeoffs between mobility and accessibility, functional classifications (e.g., arterials, collectors) inform the design and operation of transportation facilities, but they focus on roadways and motor vehicle traffic. There is a need to extend and adapt the tenets of functional classification in the context of active transportation modes (e.g., walking, bicycling). Such a system could help UDOT and partner agencies inform and guide the planning, design, operation, and management of active transportation networks statewide and at the regional level. In order to develop an active transportation functional classification system for Utah, it is first necessary to review the literature, including understanding the key concepts—functional classification, layered networks, modal network planning, contextual factors—and considering examples at different levels (local, region, state) from around the U.S.

The objectives of this literature review are to: (1) critically review concepts and tenets related to functional classification (including layered networks, modal network planning, and contextual factors), especially in the context of active transportation modes; and (2) summarize examples of active transportation network planning and structure at local, regional, and statewide levels in the U.S. The following sections present these reviews of concepts and summaries of examples, concluding with the identification of potential opportunities—the use of emerging data and models, and applications to project prioritization—for developing an active transportation functional classification system for Utah.

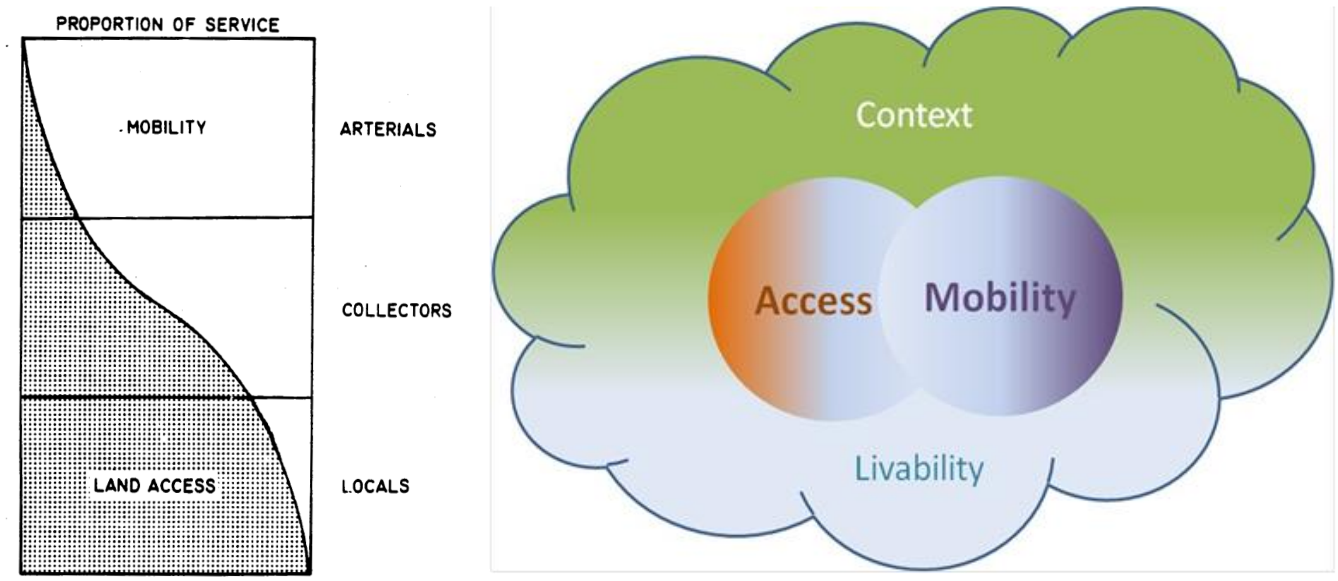
Concepts

Functional classification

A **functional classification** (FC) system is a way to describe the existing or desired role of roadways or other transportation facilities in a network. In the U.S., FC systems for highways have been defined at the state and national levels since at least the 1960s (AASHTO, 1964): e.g., principal arterials, minor arterials, collectors, and local roadways. According to the most recent guidance from the Federal Highway Administration (FHWA), the primary purpose of a FC system is as "a framework for identifying the particular role of a roadway in moving vehicles through a network of highways" (FHWA, 2013, p.1). Over time, FC has come to influence and play a central role in many transportation aspects beyond simply role-definition, including roadway design, transportation planning, maintenance of traffic during construction, federal and/or state funding, performance measurement, operations, and maintenance (Stamatiadis, King, et al., 2018).

The central tenet underlying FC is that within transportation networks, roadways offer a balance between the competing functions of **mobility** (transportation; traveling longer distances at higher speeds) and **accessibility** (origins and destinations; accessing land uses). *Arterials* provide high mobility, *local roads* provide high access, and *collectors* provide a blend of mobility and access (FHWA, 2013). Figure 1 depicts this conceptualization of access vs. mobility in FC systems.

Figure 1: Two depictions of the tradeoffs between access and mobility in functional classification systems, left (FHWA, 1989) and right (FHWA, 2013).



As a result of these different functions, arterials often have higher speed limits, more travel lanes, and fewer access points (driveways and intersections). Thus, they usually carry a higher share of the length of long-distance trips. Conversely, collectors and local roads are used more for shorter trips and may have lower speeds due to greater expected turns and entry/exit points. FHWA (2013) describes other considerations and travel characteristics related to FC; see Table 1.

Table 1: Other considerations and travel characteristics related to roadways functional classifications (FHWA, 2013).

Functional Classification	Distance Served (and Length of Route)	Access Points	Speed Limit	Distance between Routes	Usage (AADT and DVMT)	Significance	Number of Travel Lanes
Arterial	Longest	Few	Highest	Longest	Highest	Statewide	More
Collector	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Local	Shortest	Many	Lowest	Shortest	Lowest	Local	Fewer

Criticisms in the literature

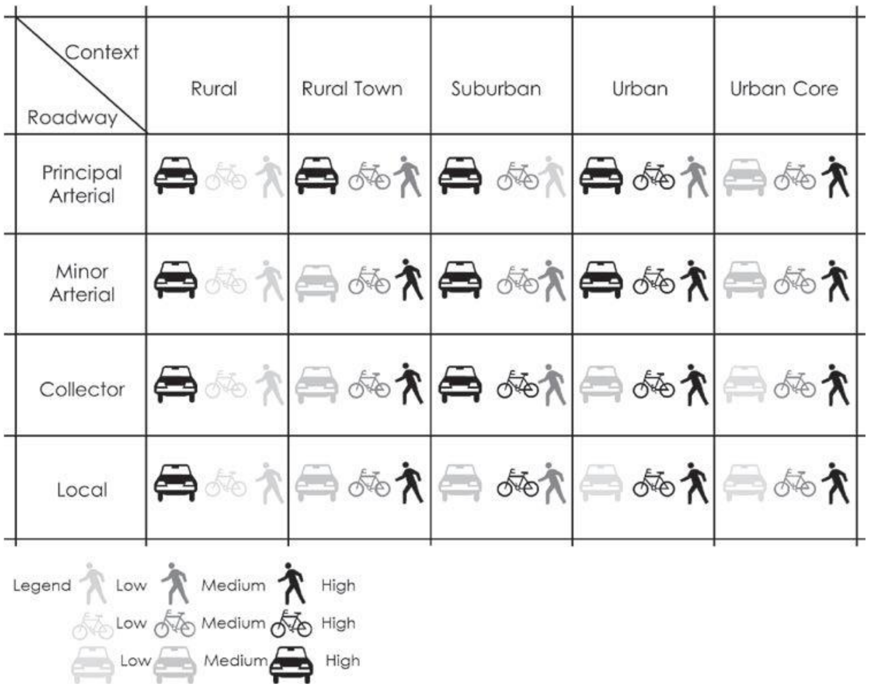
FC systems like this have been criticized on several fronts. First, the FHWA roadway FC system is **not multimodal**: it "is focused on the needs of vehicle drivers and does not help in serving the needs of other types of users (e.g., transit riders, pedestrians, bicyclists)" (Stamatiadis, Kirk, et al., 2018, p.i). In many places, application of FC to roadway and network design has created disconnected active transportation networks (Mekuria et al., 2012) where arterials are barriers to walking and bicycling. Safety concerns motivate many aspects of active transportation behavior, and arterial roadways with higher volumes and more lanes of traffic are more stressful and less comfortable for active transportation (Furth, 2017). Figure 2 illustrates how arterial networks create barriers to comfortable walking and bicycling.

Figure 2: A bicycle level of traffic stress (LTS) analysis of all roads (left) in San Jose, California, reveals disconnected islands of low-stress streets (right), often broken and bounded by high-stress arterials (Furth, 2014).

Second, the federal FC system is **not contextual enough**: while it distinguishes urban and rural areas within all FC categories, it does not adequately address more specific contexts such as suburban areas, rural towns, or the urban core. Also, it is focused solely on the transportation roles (mobility and accessibility) of roads and highways; streets and roadways are also places where people live, work, play, do business, and socialize. As a result, the traditional FC system does not adequately accommodate local or community goals about neighborhood livability and quality of life. We will return to these criticisms about modes and contexts in later sections of this literature review.

In response to some of these criticisms, alternative FC systems have been proposed. A recent National Cooperative Highway Research Program (NCHRP) report reviewed different state-level FC systems and came up with a new Expanded Functional Classification System (Expanded FCS) (Stamatiadis, Kirk, et al., 2018). Central to the Expanded FCS is that roadways with different FCs may look and operate differently in different contexts, including rural, rural town, suburban, urban, and urban core areas. Also, depending on the FC and the context, different modes may be prioritized, including drivers, bicyclists, and pedestrians; see Figure 3. Finally, while mobility, access, and speed may be important criteria for drivers, separation from traffic may be the most important criteria for bicyclists (Stamatiadis, King, et al., 2018). States have begun to adopt similar modifications to the federal FC system, as noted later in the “Statewide” examples section.

Figure 3: The Expanded FCS includes a prioritization of different modes within a variety of contexts (Stamatiadis, Kirk, et al., 2018).



Additional limitations and implicit values

We see additional limitations of FC systems that frame their categorizations and implications based on tradeoffs between mobility and accessibility, resulting in different guidelines for speed, capacity, access points, modal prioritization, etc. for roadways of different classes. First, the traditional FC system ignores the **temporal dependencies of travel behavior** and corresponding operational results. One justification for the mobility vs. access distinction is that fewer access points yields "low travel friction" and higher mobility function (FHWA, 2013, p.4). However, under low-volume conditions (i.e., at night, during some weekend days and holidays), speed and capacity reductions due to traffic flow are negligible on all streets, no matter their FC (arterials, collectors, and local streets), thus diminishing one of the fundamental objectives of a FC system. Of course, roadway designs and operational characteristics have a limited ability to change hour-by-hour or day-by-day based on traffic conditions—some exceptions are changeable lanes, traffic signal timing, and parking restrictions—so this temporal limitation may be fundamental to any sort of FC system.

Second, it is important to note that traditional FC systems imply certain **underlying principles and values** that are not explicitly noted or emphasized. The specification that (primary) arterials serve longer-distance trips between cities and major activity centers at higher speeds *implies* that reducing travel time for such trips is more important than other objectives (e.g., multimodal safety) or than reducing travel time for shorter, more local trips. The access limitations of arterials also imply that origins/destinations on land adjacent to arterials should have poorer initial access to the network than places adjacent to collectors and local streets. These values implicit to the FC system result in specific impacts to land use and development, land valuation, and traveler behaviors. For instance, a residence along an arterial may be valued less than a similar residence on a local street or the property may be more likely to be redeveloped into a commercial use. Also, arterials often operate to support regional auto trips, to the potential detriment of non-auto travel made within the adjacent community.

Third, the real benefits of developing a FC system are hidden or deemphasized. In an urban area with uniform distributions of people, jobs, destinations, roadways, and travel demands, all roadways (except maybe those on the periphery) would likely experience similar demands and a FC system may not be necessary. In real-world communities with transportation and land use systems that have developed more organically and through both central planning and market forces, travel demands are not uniformly distributed. Thus, the real benefit of a FC system lies in taking advantage of **efficiencies in spatially-distributed travel patterns**. If many people are traveling in the same direction between two places, it can be more efficient from a system perspective (faster travel times, or less infrastructure) to route them along one arterial than along several collectors or many local roads. Thus, in a planning sense, an ideal FC system may be the result of a data-driven approach that considers existing/future travel demands and identifies locations where an arterial could provide greater efficiency for traffic flow and mobility. Of course, in reality it may not be possible to significantly change the design of a roadway to accommodate a different FC. However, if coming up with a brand-new FC system (such as for active transportation), such a data-driven approach may be quite effective.

Considerations for adapting FC to active transportation

In general, traditional FC systems like the ones described in this section are not necessarily entirely well-suited for adaptation to active transportation modes like walking and bicycling. Many FC distinctions are based on the highly-varied speeds that motor vehicles can travel (10–80 mph), the resulting amount of time it takes to accelerate or decelerate (for turns or stopping for turning vehicles), the implications of differential speeds on flow and safety, and concern over capacity and congestion. These concerns may not be shared for pedestrian or bicycle traffic.

For **pedestrian** networks, many of these arguments about the inherent conflict between mobility and accessibility (related to flow, speed, volume, and limiting access) are mostly moot points. Walking speeds exhibit very low variability (2–4 mph); acceleration and deceleration happen quickly; conflicts between pedestrians usually do not lead to injuries; trips are usually short; and (except in a few places) sidewalk or pathway capacity is almost always sufficient to avoid congestion and delay. In other words, mobility and access are usually not in conflict for walking, so any FC system applicable to pedestrian travel would need to be defined by different parameters. For example, Stamatiadis, Kirk, et al. (2018) defined pedestrian network FC based mostly on facility width, with additional consideration to pedestrian volumes, separation from motor vehicle traffic, directness, etc.

For **bicycle** networks, some of the same mobility vs. access considerations still apply as with motor vehicles, but their importance is diminished. Bicycling speeds do vary but within a much smaller range (10–20 mph); acceleration and deceleration are concerns (but more from an energy expenditure perspective); conflicts between bicyclists can lead to (mostly minor) injuries; trips are often short but can be taken over longer distances; and congestion is usually not a concern but can be in some high-use corridors. In other words, mobility and access are somewhat in conflict for bicycling but less so than for driving, so any bicycle FC system might want to consider additional parameters. For example, research has found that traffic safety-related concerns affect bicycle behaviors like route choice and mode choice (Broach et al., 2011; Singleton & Wang, 2014), which suggests that separation from motor vehicles may be an important criterion for bicycle FC. In their Extended FCS, Stamatiadis, Kirk, et al. (2018) defined bicycle network FC based mostly on the amount of network connectivity provided (citywide vs. neighborhood vs. local) and bicycle volumes, as well as separation from motorized traffic.

Additional FC considerations are more specific to active transportation. **Types of users and user capabilities** become more important in facility performance for active transportation, because they greatly define performance criteria, especially speed: Almost anyone can drive a car 60 mph, but not everyone can walk 4 mph or bicycle 20 mph. Active transportation facilities are often designed or required to serve multiple users and modes on the same network. On a shared-use path, there may be people walking, jogging/running, rollerblading, skateboarding, with strollers, with dogs, in wheelchairs, just to name some traditional pedestrian modes. Add to that people bicycling (causal, fast exercise, tandem, tricycle, cargo, kids), using e-scooters, or other new forms of active mobility (one-wheel, Segway, etc.), and the facility needs to accommodate many different users with different abilities and performance. Lane markings (walk and bicycle pavement markings) can help to separate users on the same paved surface, but sometimes completely separate facilities may be required; see Figure 4.

Figure 4: Paths in Stanley Park (Vancouver, British Columbia) include lane markings, separate paths, and one-way bicycle traffic to manage high active transportation volumes (photo by author).

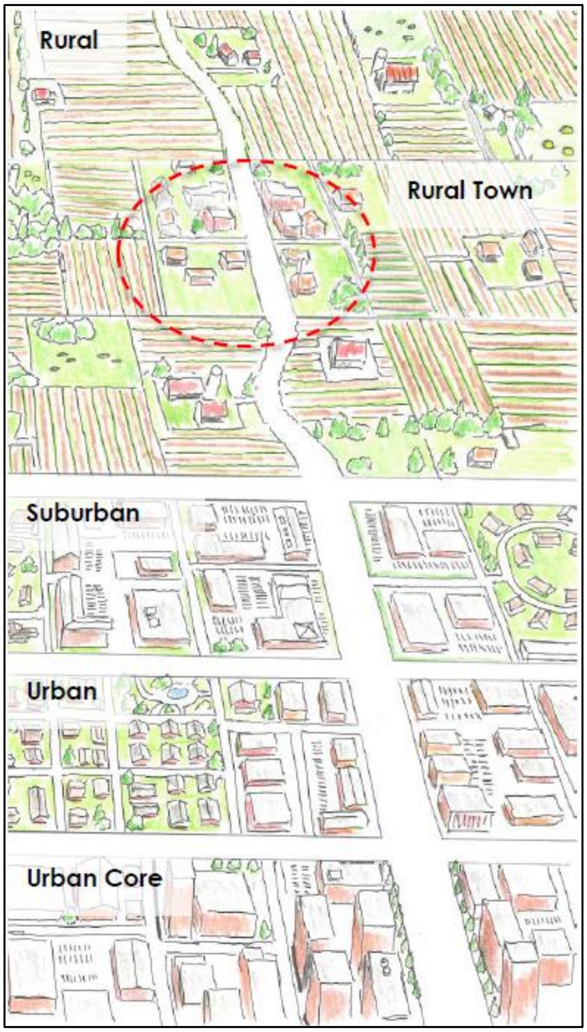
In parts of northern Europe, bike freeways or cycle superhighways have been proposed and even developed. For example, the region around Copenhagen, Denmark, has planned more than 45 routes covering 750+ km (467+ mi) of cycle superhighways (OCS, 2019). The goal is to promote longer-distance bicycle commuting that can compete with car and train travel, and rebuild bicycle mode shares in suburban/rural areas. While design characteristics of cycle superhighways may differ, they often include limited stops, green waves of signals, and clear wayfinding. They also prioritize accessibility, directness, comfort, and safety. By connecting towns and cities and explicitly faster and longer-distance trips, cycle superhighways act as principal arterials for bicycling.

Contextual factors

When crafting definitions of FC systems, **contextual factors** are important to consider. Context provides the setting through which the transportation facility passes, and facilities should address community/neighborhood goals and visions in addition to their transportation purpose. For example, FHWA recommends that "Arterials should avoid neighborhoods [because] they often serve as buffers between incompatible land uses…" (FHWA, 2013, p.27). The prioritization of mobility along arterials often results in barriers to active transportation use, which may be in conflict with local goals for more walkable and bikeable communities and main streets.

As previously mentioned, the federal FC system (FHWA, 2013) includes just two contexts: urban and rural. In response to the limitations of this dichotomy, the Expanded FCS (Stamatiadis, Kirk, et al., 2018) includes additional contexts: rural, rural town, suburban, urban, and urban core. Such contexts were defined using three primary criteria: density (of structures), land uses (residential, commercial, industrial, and/or agricultural), and building setbacks (distance of structures to roadway). Figure 5 depicts the range of contexts included in the Expanded FCS.

Figure 5: The Expanded FCS includes several additional contexts beyond a rural/urban dichotomy (Stamatiadis, King, et al., 2018).



Context can also play an important role in the design and operation of active transportation facilities of different FCs. For example, the FHWA Bikeway Selection Guide (Schultheiss et al., 2019) provides separate matrices for selecting different preferred bikeway types (shared use path, separated bike lane, bike lane, shared lane, shoulder etc.) for rural roadways compared to streets in urban, urban core, suburban, and rural town contexts. Bicycling within rural contexts is often undertaken for more long-distance travel or recreational purposes, and recreational cyclists may be more comfortable on a wide shoulder. Rural active transportation facilities usually have fewer access points to begin with, and are also even less likely to experience congestion, so the access vs. mobility distinction is even less relevant in these contexts.

This work on contextual factors and functional classifications links to earlier work on context sensitive solutions. For example, the Institute of Transportation Engineers published a guidebook for designing walkable urban thoroughfares (ITE & CNU, 2010) that includes similar natural-to-urban context classifications and relationships between context, functional class, and street design. It also links to work on integrating performance-based processes and analysis into roadway geometric design (Ray et al., 2014). Together, these considerations of performance-based design processes and contextual classifications are being proposed to be integrated into the next edition of AASHTO's Green Book (Ray et al., 2019).

Layered networks

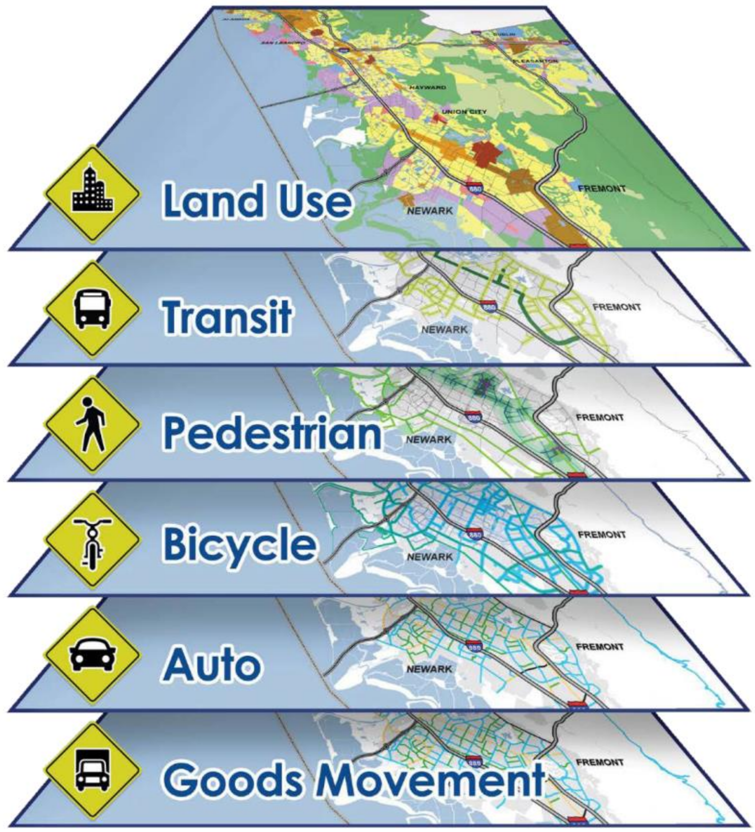
The concept of **layered networks** (or overlays) recognizes that roadways and other transportation facilities can serve multiple functions and modes. A roadway that prioritizes motor vehicles may not be the best street for a bicycle facility, while a bicycle boulevard may not be the best street for emergency vehicles to use to access a neighborhood. FHWA's FC system emphasizes motor vehicle traffic solely, leading to the conceptualization of the mobility vs. access tradeoff. However, other considerations may appear when focusing on different modes, each with different needs and accommodations. Layered networks help to make these multimodal needs explicit.

Transit networks succeed when they serve many users traveling in the same direction along a direct route, accessed by walking or other modes. As a result, transit networks may be focused along corridors that connect major destinations. Freight transportation and goods movement often involves large vehicles that more frequently serve commercial establishments. Therefore, freight networks should avoid residential neighborhoods except to access specific business. Certain routes could also be prioritized for specific short-term uses, such as for emergency services or for snow removal.

Bicycle networks often prioritize direct, low-stress routes that provide separation from major streets or crossings with high-speed, high-volume motor vehicle traffic. Sometimes this can be best accommodated through bicycle boulevards placed nearby but parallel to major commercial streets that may prioritize transit or freight. Pedestrian access is needed everywhere, especially in conjunction with transit, schools, parks, and commercial areas with many destinations.

Layered networks should also begin with context, which often means the land use context of the communities through which the roadway segments pass. Context can provide a framework for identifying which modes or functions should be prioritized; for instance, pedestrians in urban core areas. Additionally, travel behavior data can be used to help identify modal priorities for different facilities. For instance, routes carrying more short trips could be prioritized for modes that thrive over short distances, like walking and bicycling. An example of the layered networks concept from Alameda County, CA, is shown in Figure 6.

Figure 6: Example of a layered networks approach (Fehr & Peers, 2016).



Modal network planning

The concept of **modal network planning** involves developing network plans for specific modes or mode users. This can be thought of as an important step within the broader process of developing layered networks. The principle behind multimodal networks is that there are accessible, interconnected facilities to allow all users to safely and conveniently get to where they want to go by using the mode of their choice (Twaddell et al., 2018). In other words, multimodal networks provide freedom: to travel as one chooses.

Historically, early transportation planning in the U.S. was modal network planning: planning only for networks of roadways serving motor vehicle traffic. Around the same time that the first FC systems were being developed (AASHTO, 1964), U.S. metropolitan transportation planning was focused on planning the interstate highway system and other urban transportation projects to accommodate increasing automobile ownership and use among the general population (Weiner, 2016). As private mass transportation companies folded and public transit agencies began operating urban systems, transit network planning began to be conducted and integrated into metropolitan planning organizations' work. Nowadays, transit network planning is often premised on the conflicting goals of ridership (maximizing use) vs. coverage (reaching the most people/places) (Walker, 2019).

Active transportation planning often involves the creation of proposed networks for walking and bicycling. This process usually requires a detailed assessment of existing facilities (and gaps), land uses, major destinations, existing (or modeled future) travel patterns, safety outcomes, other plans, and community feedback. For bicycle network planning, a level of traffic stress (LTS) analysis (Mekuria et al., 2012) can help to classify streets based on their level of comfort for bicycling. Key considerations when crafting active transportation networks include: network completeness, network density, route directness, access to destinations, and network quality (Twaddell et al., 2018). Similarly, FHWA's bikeway selection guide (Schultheiss et al., 2019) identifies seven principles of bicycle network design, where safety, comfort, and connectivity are particularly important. For small town and rural networks (Dickman, et al., 2016), similar criteria are important: cohesion, directness, accessibility, alternatives, safety and security, and comfort.

Active transportation examples

This section discusses examples of active transportation planning documents that deal with the issues discussed in the previous section, including functional classification, layered networks, modal network planning, and contextual factors. Plans are discussed at different governmental levels: municipal, regional, and statewide.

Municipal

Many cities and municipalities have developed bicycle, pedestrian, and/or active transportation plans that apply some of the concepts of modal networks, layered networks, and contextual factors.

Minneapolis, Minnesota

Minneapolis' bicycle master plan (Minneapolis, 2011) includes a bicycle functional classification system, based on the roadway FC system. *Principal arterial bikeways* are along grade separated corridors and allow for faster speeds. *Minor arterial bikeways* form the bikeway network spine, spaced around 1-mile apart. *Collector bikeways* feed to arterials, with a ½-mile spacing. *Neighborhood bikeways* provide more local connections and lead bicycle traffic to collectors. The plan recommends using the bicycle FC system as a way to prioritize bikeway projects. For example, arterial bikeways would be prioritized, while neighborhood bikeways would not be eligible for regional funding.

Seattle, Washington

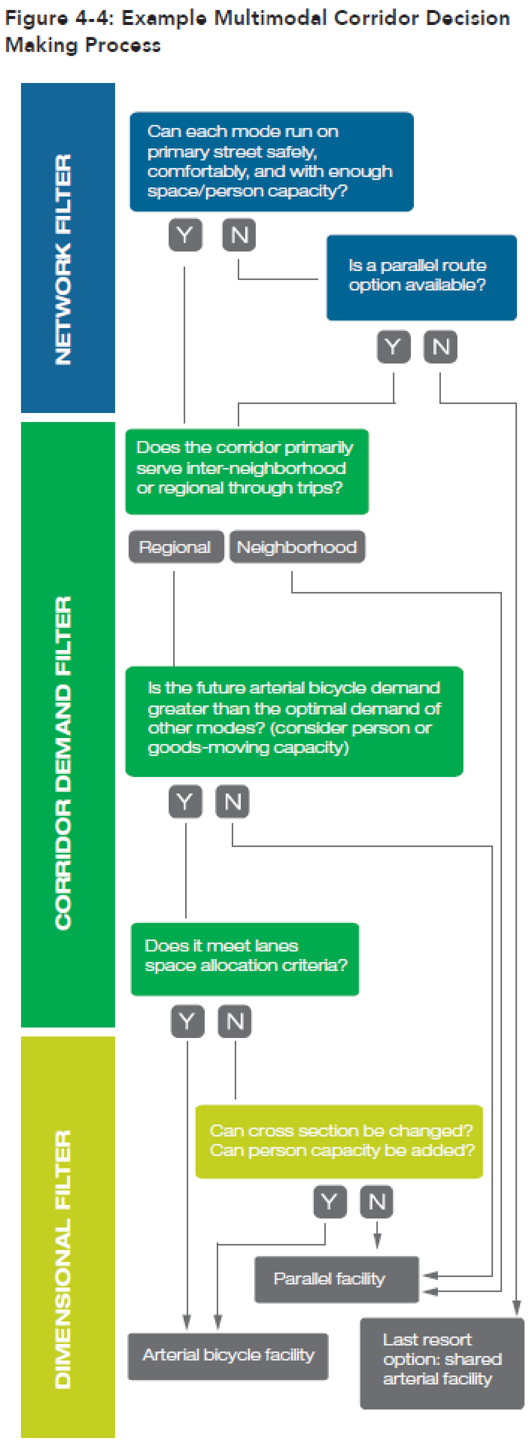
Three plans from Seattle are relevant: the bicycle master plan, pedestrian master plan, and comprehensive plan. These plans are discussed in the following paragraphs.

Seattle's bicycle master plan (SDOT, 2014) includes a bicycle network containing two complementary networks. A *citywide network* focuses on connections to destinations throughout the city, along with short-distance connections to neighborhood destinations. In comparison, a network of *local connectors* provides access to the citywide network, as well as serving destinations and (in some cases) providing parallel routes. A major distinction is that the citywide network should be comfortable for "all ages and abilities" including off-street trails, protected bicycle lanes (cycle tracks), bicycle boulevards (neighborhood greenways), and safe intersections, whereas the local connectors may contain more conventional bicycle lanes and shared streets.

These complementary networks were developed through a planning process involving both public input and technical analysis. The public indicated a need to provide safe bicycle networks for all users. The technical analysis relied on the identification and ranking of key citywide destinations and clusters of destinations. For example, universities, major employers, major transit stations, and neighborhood businesses, schools, and parks were ranked "high;" transit hubs, libraries, large parks, and food providers were ranked "medium;" and major retail and other entertainment destinations were ranked "low." Other considerations included existing bicycle facilities and gaps, street characteristics, topography, and other modal networks.

Regarding other modes, Seattle's bicycle master plan is fairly unique in that it notes and describes strategies for dealing with competing needs within "multimodal corridors," where the bicycle network overlaps with transit priority corridors and major truck streets. As depicted in Figure 7, the plan describes potential considerations when deciding whether to accommodate all modes on the same (arterial) facility or locate bicycle facilities along a parallel route. This guidance allows for a deliberative process that considers primary/secondary modal priorities and the corridor's role within the greater bicycle, transit, and truck networks.

Figure 7: Example decision-making process for multimodal corridors (SDOT, 2014).



Another key element of Seattle's bicycle master plan is that it integrates the citywide and local connections networks directly into a project prioritization framework. It notes that completing key elements of the citywide network may be a near-term priority, while funding allocations between the two networks can be adjusted in the future based on changing needs. Projects on the two networks could be quantitatively or qualitatively evaluated on similar or different criteria to meet plan goals (especially safety and criteria, but also equity, ridership, and livability), and separate project lists could be created.

For pedestrians, an update to Seattle's original 2009 pedestrian master plan (SDOT, 2017) contains a "priority investment network" through an explicit prioritization framework, grounded in the plan's goals. Specifically, the priority investment network includes streets connecting to K-12 public schools and frequent transit stops, using network-distance walksheds (⅛- to ½-mile) to define proximity. Choosing these key pedestrian generators (schools, transit stops) reflects the plan's vibrancy goal of connecting areas of high current or potential future pedestrian demand. The prioritization framework uses this network—along with whether a planned project is along or crossing an arterial or along a non-arterial street—to evaluate and prioritize projects, considering quantitative criteria (meeting plan goals in the areas of safety, health, and equity) as well as more qualitative considerations.

Another important element to note is that Seattle's comprehensive plan (Seattle, 2020) notes that the street right-of-way accommodates multiple functions. These functions include mobility (moving people and goods), access for people (e.g., bus stops, short-term parking), access for commerce (e.g., truck loading spaces), activation (e.g., parklets), greening (e.g., street trees, green stormwater), and storage (long-term parking). The city's policies prioritize these needs in different areas and urban contexts, all led by the specific modal plan priorities and multiple mentions of safety and pedestrians.

Pittsburgh, Pennsylvania

Pittsburgh's "bike(+)" master plan (Pittsburgh, 2020) is another example of an active transportation modal master plan. One unique characteristic is that it considers not just bicycling but other forms of micromobility, including e-bikes, e-scooters, mobility scooters, and similar lightweight, low-speed vehicles. The plan's bike(+) network was developed through a combination of technical analysis as well as public and stakeholder input. The plans notes how the network includes routes providing both citywide and localized connectivity: a *citywide system* directly connects major job centers to support longer commute trips, while a local system of "*neighborways*" uses low-speed, low-volume streets to connect people to community needs (e.g., groceries, schools, parks, recreation centers); riverfront trails also provide routes for commuting and recreation/fitness. Data used to develop the network included Strava ridership, destination locations (grocery stores, high-frequency transit stops, K-12 schools, and other civic destinations), and roadway characteristics (motor vehicle volume, speed, etc.) to determine which streets had low vs. high level of traffic stress for bicycling. The distinction of bicycle(+) networks for different purposes (commuting vs. daily needs vs. recreation) is one finding to note from Pittsburgh's plan.

Salt Lake City, Utah

Salt Lake City recently engaged in a process to develop 17 street typologies (SLC, 2021), with specific street and intersection design guidelines. The guide recognizes that streets are public spaces and that the right-of-way "should serve many functions." These functions include personal mobility (people walking, bicycling, and using mobility devices), greening (e.g., trees, green stormwater infrastructure), placemaking (e.g., seating, art), curbside uses (e.g., bus stops, pick-up/drop-off zones, bicycle parking, freight delivery), and vehicle mobility. The guide also acknowledges the importance of contextual factors through the differentiation of five generalized place types (destination district, urban village, neighborhood, neighborhood node, and industrial district or business park). The typologies relate loosely to traditional functional classifications, in which larger streets (arterials) have fewer access points (Thoroughfare typologies); medium-sized streets (collectors) serve mobility, accessibility, and placemaking (many different typologies); and smaller (local) streets involve more access and modal mixing (Neighborhood typologies). Many other cities throughout the U.S. have developed similar street typologies as a local alternative to traditional roadway functional classifications.

Portland, Oregon

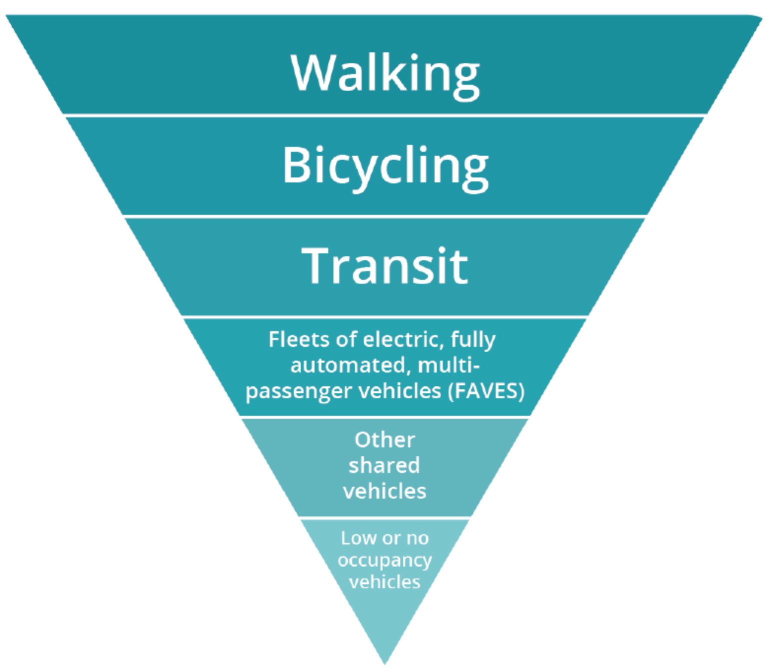
Portland's transportation system plan (Portland, 2020) includes bicycle and pedestrian specific modal plans, as well as key transportation elements of the city's comprehensive plan. Relevant for this work on FC systems is Portland's set of layered/overlaid modal street classifications. There are classifications for bicycle and pedestrian travel, as well as for transit, freight, emergency response, and motor vehicle traffic.

The plan contains three bicycle facility classifications. As the network's backbone, *major city bikeways* "are intended to serve high volumes of bicycle traffic and provide direct, seamless, efficient travel across and between transportation districts." *City bikeways* access major city bikeways, providing "access to significant destinations," and are spaced to be "within three city blocks of any given point." All other streets are *local service bikeways*, serving "local circulation needs" and providing "access to adjacent properties."

For pedestrians, there are four classes. *Major city walkways* "provide safe, convenient, and attractive pedestrian access along major streets and trails with a high level of pedestrian activity," serving the "highest density of mixed-use zoning, major commercial areas, and major destinations," such as streets with frequent transit service or high-demand off-street trails. *City walkways* have "moderate" pedestrian activity and "provide access along major streets to neighborhood commercial areas, or other community destinations." *Neighborhood walkways* connect residential neighborhoods to (major) city walkways and to "nearby destinations such as schools, parks, transit stops, and commercial areas," especially along lower-volume streets. *Local service walkways* "serve local circulation needs" and connect to local destinations.

Portland's transportation system plan uses the classifications to guide land use development standards and recommend street improvements. For instance, major city walkways "should have regularly-spaced marked crossings…, wide sidewalks on both sides, and … accommodate high volumes of pedestrian activity" (Portland, 2020). When different modal classifications conflict, one plan policy prioritizes vulnerable road users who are walking, bicycling, or using public transit, as shown in Figure 8.

Figure 8: Modal priorities in Portland's transportation system plan (Portland, 2020).



Regional

Some bicycle and pedestrian plans at a regional level have developed active transportation networks that include examples of what could be considered modal functional classes. Many of these regional plans have been developed by metropolitan planning organizations (MPOs).

Alameda County, California

A multimodal arterial planning effort in Alameda County (Fehr & Peers, 2016) depicts how many of these concepts related to functional classification—especially layered networks and contextual factors—can come together in a way that is useful for planning active transportation networks. From a traditional FC perspective, arterials provide high levels of mobility but lower levels of access (for motor vehicles). Instead, this plan took a layered networks approach and viewed arterials as multimodal routes that serve different modes simultaneously. It also identified general and specific modal priorities for arterials, depending on the land use context (area type). For example, for arterials in urban-type areas, priority went to transit (if present), then pedestrians, then bicycles, then personal automobile, and finally truck travel (goods movement). Bicycle routes were emphasized based on an earlier countywide bicycle plan. Pedestrian routes were emphasized based on multiple considerations: mixed use areas with high existing or potential development, communities of concern, access to transit, and proximity to schools and parks. Modal priorities and classifications were also determined through the analysis of travel behavior data on trip distances. For instance, routes with higher shares of shorter trips were prioritized for modes that best support short trip-making, such as walking and bicycling. This relates to land use context as well, since walkable land use patterns support shorter active transportation trips.

The Alameda County plan also uses these concepts (layered networks, modal priorities) to identify improvements on multimodal arterials. It lists mode-specific performance measures—including pedestrian comfort and bicycle level of traffic stress—and suggests improvements if objectives (e.g., high or excellent comfort) are not achieved for the top two prioritized modes.

Madison and Dane County, Wisconsin

Bicycle functional classifications are included in the bicycle transportation plan for the MPO for Madison, Wisconsin (MATPB, 2015). As noted in the plan, the traditional FC system does not translate well to bicycling because “bicyclists tend to desire more direct paths and prioritize the comfort… [and] they travel at relative constant speeds and are not as sensitive to capacity constraints.” Instead, the plan uses two classifications. *Primary bikeways* “typically have high bicycle volumes or are comfortable, direct routes for the majority of bicyclists linking neighborhoods and destinations.” *Secondary bikeways* “fill in the gaps between primary bikeways and provide neighborhood access.” Table 2 shows some of the characteristics of Madison’s primary and secondary bikeway FC system.

Table 2: Description of primary and secondary bikeways (MATPB, 2015).

Attributes	Primary Bikeways	Secondary Bikeways
Facilities	Shared-use paths, protected bike lanes on high volume streets, bike lanes on moderate volume streets, and bicycle priority streets.	Shared-use paths, bike lanes on moderate and high volume streets, connected low-volume streets.
Connectivity	Connect regional employment and retail areas as well as central business areas and neighborhood centers.	Connect residential areas and smaller retail and employment areas.
Usage	Moderate to high use for transportation or moderate to high potential for use in developing areas.	Lower to moderate usage.
Typical Spacing	½ to 1 mile in urban areas. As needed in rural areas.	¼ to ½ mile in urban areas. As needed in rural areas.
Other attributes	Primary bikeways often cross barriers like highways and rivers, may feature facilities that attract tourism, and are likely to avoid steep hills.	Secondary bikeways often connect users to primary bikeways, and may in some case offer faster and more direct travel than the primary bikeway systems, but at a lower comfort level.

Portland Metro Area, Oregon

Metro, the MPO for the Portland, Oregon, region, developed a regional active transportation plan (Metro, 2014) that includes specific pedestrian and bicycle functional classification systems. For pedestrians, three functional classifications are provided. First, *pedestrian parkways* are "major urban streets or regional trails that provide comfortable and safe access to transit, urban centers, and many regional destinations and to most employment, industrial land areas, regional parks and natural areas." Second, *regional pedestrian corridors* are "any major or minor arterial street or regional trail" that is not a pedestrian parkway. Third, *local pedestrian corridors* are all other streets or trails.

For bicycling, there are also three levels of FC. First, *bicycle parkways* "form the spine of the bicycle network" and "should provide a comfortable and safe riding experience." Spacing guidelines are provided ("approximately every two miles"), and bicycle parkways provide connections to the same kinds of destinations (transit, urban centers, etc.) as pedestrian parkways. Second, *regional bikeways* "connect to bicycle parkways and complete the regional network of bicycle routes." Third, *local bikeways* are all other streets or trails. Notably, the plan comments that each bicycle FC can be of any type of bicycle facility (trail, bike lane, bicycle boulevard, etc.), thus separating out facility design from functional classification.

These pedestrian and bicycle FCs were determined through public/stakeholder feedback as well as a technical network analysis process. Different analyses were conducted for the pedestrian and bicycle networks, all in support of plan goals (access, equity, safety, and increased activity). For the pedestrian network (Alta, 2013), GIS analysis looked at each of these goals. Access considered walking distance to essential destinations (including high-frequency transit stops, regional parks, and other essential services); equity considered changes in access for specific underserved populations (low-income, minority, non-English-speaking, youth, and older adults). The safety analysis considered improvements to "barrier" streets, with high volumes, speeds, lanes, and pedestrian crashes. Based on the analysis, pedestrian parkways largely followed the regional transit network (with frequent service) or were along or connected regional destinations and pedestrian districts, including some trails and multi-use paths.

For the bicycle network (Metro, 2013), Metro used GIS analysis as well as a regional travel demand forecasting model that included a robust bicycle modeling tool. This tool allowed for forecasts of bicycle volumes, mode shares, miles traveled, and average trip lengths. GIS analysis calculated the density and connectivity of the bicycle network, proximity to severe bicycle crashes, and access for specific demographics. Based on the analysis, bicycle parkways were identified in part in areas with greater projected demand. These facilities also connected regional destinations (with high population and employment), allowed for safe and comfortable separation from motor vehicle traffic, and serviced underserved populations.

Maricopa Association of Governments, Arizona

As the MPO for the Phoenix area, the Maricopa Association of Governments (MAG) created an active transportation plan (MAG, 2020) that includes some network analysis and types. Specifically, an active transportation (AT) grid was developed as "a network of complete corridors" with designs "that emphasizes safety, comfort, connectivity, and equity." This AT grid was developed through technical analysis. First, demand was calculated using various data sources (employment, schools, universities, parks, transit ridership, demographics, Strava data). At the same time, activity centers were identified using the same datasets. Then, gravity scores were calculated between all activity centers (based on demand and distance), identifying corridors. Finally, for the highest scoring corridors were investigated for specific alignments. Supplementing this *AT grid* is a network of *regional conduits* connecting regional cities, towns, and activity centers, often along off-street paths.

Statewide

Few states have developed active transportation networks that include some classification or typology, often because such planning work usually takes place at a local or regional level. Instead, many state DOTs have adopted contextual guidance based on NCHRP Report 855 (Stamatiadis, Kirk, et al., 2018) that informs the application of roadway FC systems in different areas.

Oregon

The Oregon bicycle and pedestrian plan (ODOT, 2016) is an example of a statewide modal plan that incorporates some active transportation network considerations. Several policies embedded in the plan note the need for complete bicycle and pedestrian networks that connect directly to key destinations and allow for multimodal connections, including to transit. The plan also notes that pedestrian and bicycle facilities should be designed to be context-sensitive, considering vehicle speeds, roadway characteristics, land uses, and latent demand. It also acknowledges the unsuitability of the motor vehicle-focused functional classification system, and suggests several potential approaches: a multimodal classification, a single walk/bike classification, separate walk and bike classifications, or context-specific design guidelines. However, no specific solution or active transportation FC system is provided or proposed.

More recently, the Oregon DOT has developed a blueprint for urban road design (ODOT, 2020). The purpose of the publication is to provide greater contextual differentiation in order for state road projects in urban areas to have designs that better fit their context. Building from the land use contexts provided in NCHRP Report 855 (Stamatiadis, Kirk, et al., 2018), ODOT's urban contexts include traditional downtown (central business district), urban mix, commercial corridor, residential corridor, suburban fringe, and rural community. Like the national publication, the Oregon document also includes modal considerations in different contexts, as shown in Table 3. Importantly, ODOT recommends that, during planning and design decisions, urban context should be primary and state highway classification should be secondary. The document goes on to note specific design guidelines and flexibility within each of the urban contexts.

Table 3: Modal considerations in different urban contexts (ODOT, 2020).

Land Use Context	Motorist	Freight	Transit	Bicyclist	Pedestrian
Traditional Downtown/CBD	Low	Low	High	High	High
Urban Mix	Medium	Low	High	High	High
Commercial Corridor	High	High	High	Medium	Medium
Residential Corridor	Medium	Medium	Low	Medium	Medium
Suburban Fringe	High	High	Varies	Low	Low
Rural Community	Medium	Medium	Varies	High	High

Arizona

The Arizona DOT has developed a complete transportation guidebook (ADOT, 2016). While not an active transportation plan or offering modal priorities, it does include context-specific design guidance. Contexts include activity centers (in urban, suburban, and rural areas), suburban areas, rural areas, and special use areas (open spaces, cultural/historical sites). Roads in each of these context areas include design suggestions for bicycle facilities and the pedestrian realm.

Florida

Similarly, the Florida DOT created a context classification guide (FDOT, 2020) that describes how the surrounding context as well as transportation characteristics should influence the design of a state roadway. The guide explicitly notes that it arises from limitations with the traditional roadway FC system, including "a need to better define contexts beyond urban and rural classifications, and to incorporate multimodal needs." FDOT's specific context classifications are: rural, rural town, suburban residential, suburban commercial, urban general, urban center, and urban core. Contexts are defined using various built environment characteristics, including connectivity (intersection density, block perimeter, block length), land use, building (height, placement, frontage), and off-street parking location. The guide describes how "context classification provides an important layer of information that complements functional classification," including examples for how to reconcile specific design criteria such as speed.

Data and models

The examples presented in the sections above offer several insights into ways in which classes or typologies of active transportation facilities and networks could be created. In this subsection, we discuss these approaches, including any data and/or models used.

Central to most definitions of different active transportation FC systems is the idea of connecting important **destinations**. For example, Seattle prioritized major employers (including universities), major transit centers, and neighborhood destinations in their citywide bicycle network, and public schools and frequent transit stops in their pedestrian priority investment network (SDOT, 2014, 2017). Major destinations and transit service were also key in defining Portland's major city bikeways and walkways (Portland, 2020) and regional bicycle/pedestrian parkways (Metro, 2014). Most of these analyses appeared to use GIS analysis and data about population, employment, transit service, neighborhood destinations, and civic amenities. Similar kinds of data and methods were also used or suggested for defining urban contexts and contextual classifications (e.g., FDOT, 2020).

Related to this is the concept of **connectivity**. Many plans noted the need for networks to be direct. In practice, when developing a FC system or network, this could be operationalized by using network buffers for walksheds (Seattle, 2017), identifying impedances including "barrier" streets (Alta, 2013), drawing corridors between activity centers (MAG, 2020), or using GIS analysis to calculate measures of connectivity and density (Metro, 2013). Several plans provided guidance about the desired spacing of facilities of different bicycle FCs, including ½-to-1-mile for primary bikeways in Madison (MATPB, 2015) or every 2-miles for bicycle parkways in Portland (Metro, 2014). Measures of connectivity like these usually require networks to be constructed that can be readily analyzed using GIS.

Implicit in the destination-focused approach is that higher FCs should serve more users overall and/or users making certain types of trips. For example, Pittsburgh's plan implied different bike(+) networks were focused on commuting, daily needs, and recreation. However, most plans did not describe using **bicycle or pedestrian volumes or activity** data. Instead, current or potential demand seemed to be derived from land use and build environment characteristics and general understandings (rather than models) of active transportation usage. A few more recent plans mentioned using Strava data to help develop the network (Pittsburgh, 2020; MAG, 2020), while Metro in Portland used a bicycle modeling component of their regional travel demand forecasting model (Metro, 2013) to analyze the bicycle network. Trip and travel behavior data do not even need to be restricted to walking and bicycling to be useful. For example, short trips by all modes were used to help determine modal priorities for arterials in Alameda County (Fehr & Peers, 2016), as a measure of potential active transportation.

There are significant opportunities to utilize **new and emerging data sources** for measuring or modeling current (and even future) demand or use of active transportation facilities. Active transportation traffic monitoring programs continue to grow, with more instrumented short-term and permanent counters being installed on trails and streets. For pedestrians, data from pedestrian push-buttons at traffic signals are being used to measure pedestrian crossing volumes at more than 1,500 intersections in Utah (Singleton & Runa, 2021), and direct demand models can use empirically-modeled relationships with built environment context to roughly estimate pedestrian volumes at tens of thousands of additional intersections throughout Utah's urban areas (Singleton et al., 2021). For bicycle travel, Strava data can be a useful proxy for bicycling levels, but it is biased towards recreational users and in locations where more recreation than commuting takes place (Nelson et al., 2020). Emerging data sources use continuous information from smartphones and other location-based services to identify walk and bicycle trips made by a substantial share of the population. Companies like StreetLight data analyze and provide this sort of information, allowing analysts to obtain origin-destination flows, volumes on selected links, and even inferred demographics and trip purposes (StreetLight, 2020). From a modeling perspective, improvements continue to be made on how walking and bicycling are considered within regional travel demand forecasting tools (Singleton et al., 2018).

Project prioritization

The examples presented in this section usually do not include descriptions of how active transportation networks or FC systems are used to select or rank potential projects. When discussed (such as in plans from Minneapolis or Seattle), the plans suggest prioritizing improvements on regional over neighborhood bikeways or citywide instead of local networks. However, there are other ways in which an active transportation FC system could inform the project prioritization process. For example:

- *Prioritize higher FC projects*: Projects on routes with higher-level functional classes could receive more points. So, a project on a regional route would receive a higher score than a project on a local route.
- *Separate projects by FC*: Projects could be ranked within each FC category, ensuring funds go towards improving routes of all functional classes. This requires setting aside specific proportions of funds for each FC.
    - *Fund FC projects based on gaps*: A subset of this approach could allocate funding shares based on the percentage of routes of a given FC that do not meet performance (design, operation, use, comfort, safety, etc.) objectives. For example, if the regional network was 67% complete while the local network was only 33% complete, twice as much funding would be allocated to the local network. So, this approach would provide funding to incrementally complete the network as a whole.
- *Prioritize projects using factors affecting FC definitions*: This approach would use more fine-grained information to help prioritize projects. Such data about destinations, connectivity, current/future demand, safety, communities, etc. could be used not just to define FCs and develop the network (see previous subsection), but this information could also be utilized on a project-by-project basis for scoring and ranking. So, a project that might connect communities with more low-income and zero-vehicle households might score higher than a comparable project in a different area.

The Utah Transportation Commission's process for prioritizing transportation capacity projects (UTC, 2021) already includes active transportation project funding criteria that may be related to criteria used to define an active transportation FC system. The Strong Economy vision element (20% of total score) contains multiple criteria related to providing access to key locations like education and tourism destinations (Accessibility), connecting workers' housing and job locations (Transport Costs), and linking current/future employment centers and economic development zones (Economic Development). These criteria are directly related to one purpose of FC systems: connecting important destination with high-FC facilities. The Better Mobility vision element (40% of total score) contains the Throughput criterion (45% of Better Mobility score) that is currently operationalized using demand taken from the Statewide Active Transportation Demand Model—itself based on built/social environment measures of the 5Ds: density, diversity, destinations, demographics, and design—as well as the degree of separation from motor vehicle traffic and the level of traffic stress. These measures are directly related to FC characteristics: facilities of higher-FC efficiently move high active transportation volumes and provide high levels of safety and comfort for users of all ages and abilities. The other vision elements (Good Health = safety, public health, and the environment; Connected Communities = connectivity, land use and community, and integrated systems) relate more towards other goals that could be used in conjunction with defining FC for an active transportation network. Giving priority to projects on routes with higher active transportation FCs could help to replace and/or supplement some of these existing project prioritization criteria.

Conclusion

In the U.S., the federal highway functional classification (FC) system categorizes roadways according to their role in vehicle movement within a network. This FC system focuses on motor vehicle traffic and the competing functions of mobility and accessibility. Beyond their functional role, roadway classifications (arterial, collector, local) influence transportation design, planning, funding, maintenance, operations, and performance. For many reasons, such a FC system is not well-suited for active transportation modes, and an alternative FC system would be more appropriate.

Through a consideration of literature and guidance about FC systems, including critiques, this review identified several key characteristics of traditional roadway FC systems that limit their applicability for active transportation:

- By focusing on motor vehicles, the traditional FC system is not sufficiently multimodal. It ignores and diminishes active transportation modes, and its application creates arterials that are often barriers to walking and bicycling. Arterials prioritize travel time over safety, encourage long-distance travel that is more likely to be undertaken by motor vehicles, and restrict initial access to adjacent properties. This implicit valuation causes impacts on land use, traveler behaviors, and transportation safety, usually negatively for active transportation modes. The use of layered networks can help to address multimodal needs and considerations.
- The traditional FC system also does not sufficiently address context. An arterial may need to look and operate differently when in a small town vs. a suburban or even urban core area. Relatedly, uniform application of FC-based design standards across all contexts can result in roadways that are incompatible with local and community goals. Additional contexts can help to generate more locally-appropriate transportation solutions.
- Tradeoffs between mobility and access, even when considering context, do not represent the full functions of streets and street rights-of-way. Certainly, streets provide for mobility of people (and goods), as well as non-motorized access to destinations through sidewalks, crosswalks, transit stops, bicycle parking, etc. Active transportation access is much more varied than motor vehicle access (driveways and parking spaces). Also, streets fulfill important ecological and placemaking functions: they are also locations for socialization, art, and green space. These additional functions are most appreciated when traveling using active modes of transportation.
- Conflicts between mobility and access goals embedded in the traditional FC system are diminished for bicycle travel and almost non-existent for pedestrians. Most of these conflicts stem from motor vehicle safety implications (of variations in speed, deceleration rates, turning vehicles, etc.) and concerns over capacity and congestion. Instead, for pedestrian and bicycle travel, comfort and safety (and separation from motor vehicle traffic) are often more important criteria. This implies that street and crossing design should play an important role in an active transportation FC system.

By reviewing examples of active transportation planning, network construction, and functional classification, this review also identified some key trends and practices that may be useful when developing an active transportation FC system for Utah:

- Especially at the local level, there is an increasing focus on how streets serve multiple functions. These functions go beyond mobility and accessibility and include activation/placemaking, greening, storage/curbside uses, etc. Importantly, they also go beyond motor vehicle traffic and explicitly recognize the multifaceted needs of different modes, and often emphasize active transportation (especially in more urban areas). An active transportation FC system should also acknowledge how the act of traveling by walking, bicycling, or other micromobility modes is a process involving more than just being mobile. It also includes elements of socialization, exploration, and joy (Singleton, 2019).

- Many cities have adopted street typologies that encompass the concepts of functional classification and context, as well as that acknowledge the multiple functions of the street right-of-way. An active transportation FC system should be sensitive to context; for example, acknowledging that a regional or arterial bikeway may look and operate differently in a suburban area (e.g., a canal trail) vs. in the dense urban core (e.g., on-street protected bike lane).
- Several active transportation facility typologies have noted how it is important to separate functional classification from facility design, especially in different locations. This separation acknowledges that there are multiple ways for a facility to operate effectively. Thus, active transportation facility design should be a function of FC but also context and other factors.
- That said, it may be desirable to include different performance objectives for active transportation facilities of different FCs. For instance, a bikeway of the highest FC may need to be comfortable for users of all ages and abilities (e.g., LTS 4), while lower FCs facilities may tolerate less comfort (e.g., LTS 2) if only for a short distance. Performance relates directly to facility design as well as level of use and user characteristics. So, a busier shared-use path will have to be wider and allow more passing opportunities.
- Consistent with a layered networks approach, many cities have developed classes of active transportation facilities that overlay with street classifications for other modes, including public transit, goods movement, personal vehicle movement, etc. Where modal classifications compete within a multimodal corridor, an explicit process should be described to dictate how to reconcile conflicts and make infrastructure decisions. This could be an explicit modal prioritization (e.g., pedestrians first) or a set of questions to help determine modal priorities and alternative solutions (e.g., bikeway on a parallel street). The active transportation FC system should layer on top of the existing roadway FC system.
- Most active transportation networks differentiate facility classes by trip purpose, either explicitly or implicitly. This could be through purpose-based language: e.g., routes for commuting, accessing places needed for daily life, and recreation. More commonly, this happens through the selection of destinations to connect with different classes of facilities: citywide vs. local destinations, or job centers vs. neighborhood needs. If crafting an active transportation FC system in this way, it may be beneficial to be explicit about the kinds of trips that are being prioritized through the selection of destination types.

Based on this review, there are several opportunities to craft an active transportation FC system for Utah that takes advantage of emerging data sources and is useful not just for design and operation but also for planning and project prioritization:

- The central underlying benefit of using a FC system (based around mobility and accessibility) is actually about taking advantage of efficiencies in spatially-distributed travel patterns. In other words, higher FC facilities should carry higher volumes because they are efficient ways to move lots of people (by walking, bicycling, etc.) between destinations along a common corridor. Therefore, the development of an active transportation FC system should be data-driven, which would eliminate some of the subjectivity of selecting key destinations to connect with facilities.
- In order to measure existing demand and current use, emerging data sources should be considered. For instance, StreetLight or other data providers using location data can provide bicycle and pedestrian flows and volumes for most areas within a region or state. Origin-destination flows may be more valuable for this purpose than selected link volumes, because they identify key destinations and patterns without relying on what may be a poorly-connected set of exiting facilities. Other short motorized trips with a high potential for shifting towards active transportation could also be included in the analysis.
- In order to measure future demand and potential use, modeling methods should be considered. Even O-D flows may be restricted by poor infrastructure, and an active transportation network should be planned with future land uses and travel behaviors in mind. Short driving trips may shift to active modes if appropriate supports (including infrastructure) are provided. Therefore, travel models may be useful. For instance, enhancements to the Wasatch

Front Regional Council's travel demand forecasting tools (WFRC, n.d.) could be useful for forecasting future bicycle demand on a fully-build bikeway network. Models of pedestrian demand that are sensitive to local land use and built environment characteristics (Singleton et al., 2021) could be used to predict future pedestrian demand.

- Even within a data-driven process of developing an active transportation FC system and network, analysis of other GIS data will remain useful. Data from the Utah Geospatial Resource Center (UGRC, n.d.) can help to identify key destinations or calculate network connectivity. The U.S. Environmental Protection Agency's recently updated Smart Location Database (EPA, 2021) provides consistent measures of land use, built environment, and neighborhood characteristics that could be used to define contexts. Planning data about the demographic and socioeconomic composition of neighborhoods would be useful if there is a desire to prioritize facilities in certain areas, e.g., transit-dependent areas or places with greater populations of older adults or children.
- An active transportation FC system could play a useful programmatic role in helping to prioritize investments in active transportation infrastructure. See the earlier discussion in the "Project prioritization" section for more specific ideas and ways such a FC could integrate into UDOT's project prioritization process.

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APPENDIX B: Replica Methodology

This appendix documents a Replica's summary of its activity-based modeling methodology including their development of synthetic agents, what the data is calibrated against, and key steps in the modeling process.

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.

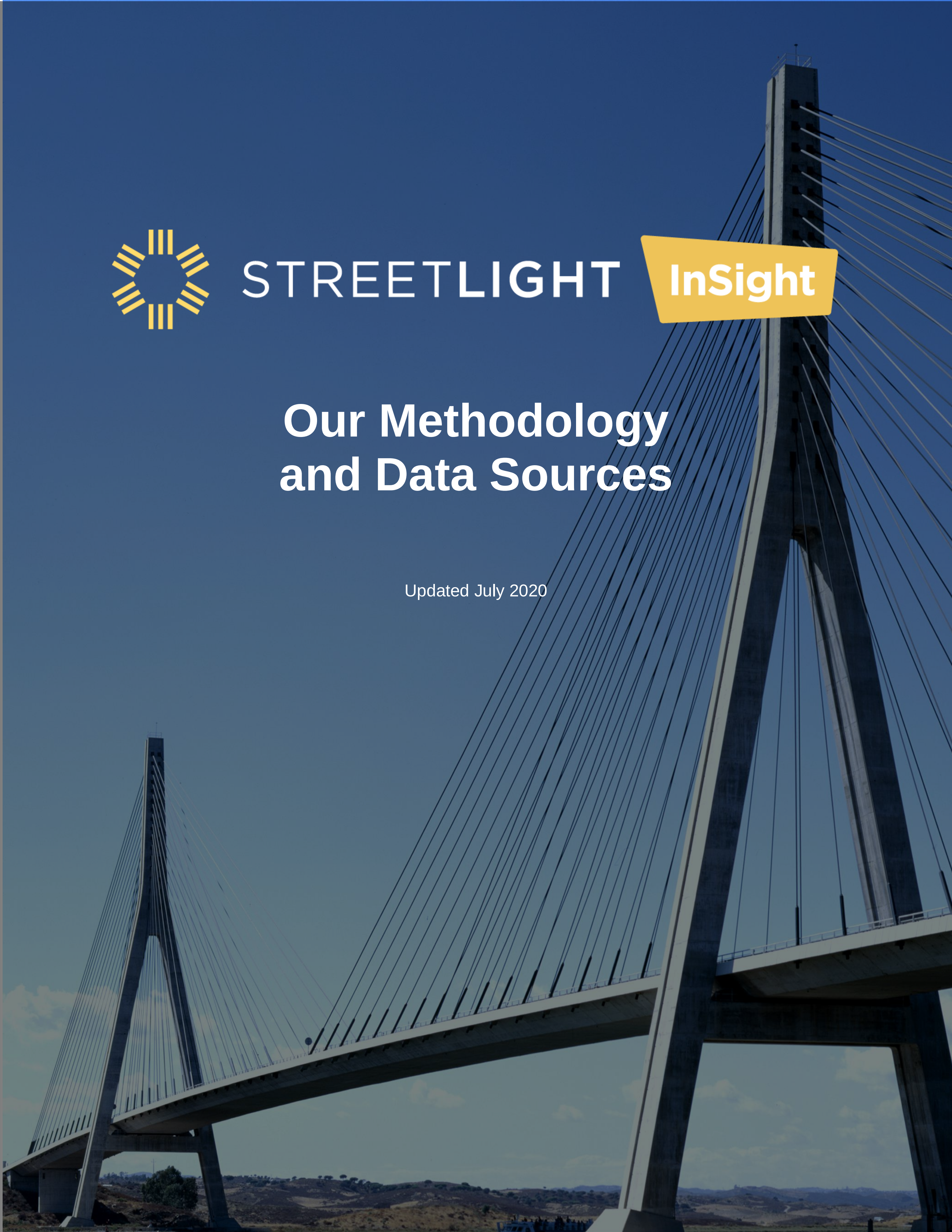
APPENDIX C: StreetLight Data Methodology

This appendix documents a StreetLight Data whitepaper that describes the data sources and methodology employed by StreetLight Data to develop travel pattern metrics. This document is relevant for all StreetLight metrics that are available via the StreetLight InSight platform.

STREETLIGHT InSight

Our Methodology and Data Sources

Updated July 2020



StreetLight InSight® Metrics: Our Methodology and Data Sources

This white paper describes the data sources and methodology employed by StreetLight Data to develop travel pattern metrics. This document is relevant for all StreetLight InSight® metrics, whether they are available via the StreetLight InSight® platform, via data API, or via custom delivery.

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Locational Data Sources and Probe Technologies

StreetLight Data's metrics are currently derived from two types of locational "Big Data:" navigation-GPS data and Location-Based Services (LBS) data. StreetLight has incorporated and evaluated several other types of mobile data supply in the past, including cellular tower and ad-network derived data.

As the mobile data supply landscape has evolved and matured over time, we have determined that a combination of navigation-GPS data and LBS data is best suited to meet the needs of transportation planners. Our team phased out the use of cellular tower data because its low spatial precision and infrequent pinging frequency did not meet our standards for use in corridor studies, routing analyses, and many other Metrics. LBS data is suitable for these studies and offers a comparable sample size to cellular tower data.

StreetLight's Big Data resources include over 110M devices in the US and Canada. This number is about 1/3 of those countries' population. However, clients should not expect a 33% trip penetration rate for all StreetLight InSight® analyses they run. That's because we don't capture every trip on every day for all of our devices. Trip penetration rates for individual analyses can range from as small as 1% to as large as 35%. Trip penetration varies based on data period, geography, mode, and other factors. We integrate our Big Data with data from the census and 10,000+ permanent counters to normalize our sample and accurately represent the full population.

Our data supply grows each month as updated data sets are provided by suppliers. We currently use one major navigation-GPS data supplier, INRIX, and one LBS data supplier, Cuebiq. See Table 1, below, for more details on the different locational data sources StreetLight Data has recently evaluated.

Type	Pros	Cons	Notes
Cellular Tower: Derived from cellular tower "triangulation" and/or "multi-lateration" (100-2000m spatial precision)	Large sample size - Most telecom providers have over 30M devices Ability to infer home and work locations	Very poor spatial precision (average of several hundred meters) Infrequent pings for some suppliers High cost Consumers typically opt-out of data collection (vs. opt-in) No differentiation of personal and commercial trips Poor coverage in rural areas No capture of short trips No ability to reliably infer active modes of transportation	We haven't seen the U.S. cellular industry making investments to improve these weaknesses.
In-Vehicle Navigation-GPS: From connected cars and trucks (3-5m spatial precision)	Excellent spatial precision Very frequent pings Separates personal and commercial trips Opt-in for consumers	Usually lower sample size Difficulties inferring home/work (depending on supplier practices) No non-vehicular modes	This data has been traditionally used for speed products.
Location-Based Services: Mix of navigation-GPS, aGPS, and sensor proximity data from apps that "foreground" and "background" with locational data collection (5-25m spatial precision)	Very good spatial precision Frequent ping rate Superior ability to infer trip purpose and trip chains Ability to infer modes (walk/bike/transit/Gig Driving) accurately Large and growing sample size Opt-in for consumers	Less mature suppliers Variation in sample size and characteristics across suppliers requires more sophisticated data processing	Several players are emerging in this new market with very large sample sizes, opening up the possibility of a healthy, competitive supply base.
Ad-Network Derived Data: When user sees an ad on their phone, their location is recorded by the ad-network	Large sample size of individuals	Few pings per month mean inference of travel patterns is not feasible	This source should not be used until significant changes are made.

Table 1 – Overview of Big Data supply options for transportation analytics. StreetLight recommends and uses a mix-and-match approach currently focused on navigation-GPS and LBS data types.*

Our Navigation-GPS and LBS Data Sources

In this section, we will explain why access to two different Big Data sources is uniquely beneficial for transportation professionals. First, it is important to note that StreetLight InSight® is:

- The first and only on-demand platform for planners to process Big Data into customized transportation analytics to their unique specifications, including the type of Big Data they would like to use.
- The first and only online platform that automatically provides comprehensive sample size information for analyses. (See more information on sample size on page 8 of this report.)

We selected navigation-GPS and LBS data because they are complementary resources that provide unique and valuable travel pattern information for transportation planning. See Figure 1 below for a visualization of these data sources.

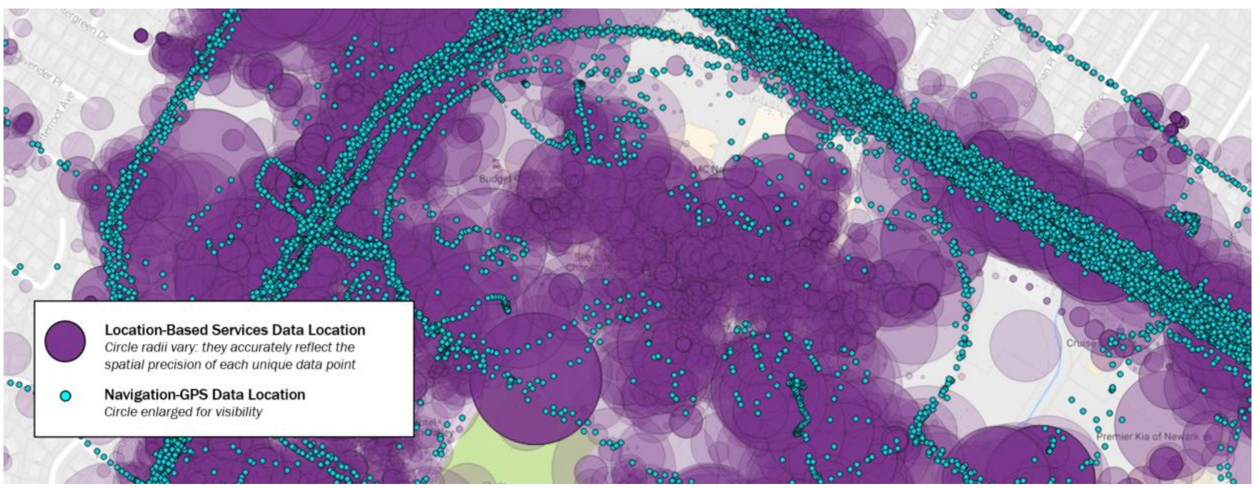


Figure 1 – Filtered visualization of a subset of unprocessed navigation-GPS and LBS data near a mall in Fremont, California.

Location-Based Services (LBS) Data

LBS data can be processed into personal travel patterns at a comprehensive scale. Its fairly high spatial precision and regular ping rate allow for capturing trips as well as activity patterns (i.e., home and work locations), trip purpose, and demographics. This makes it an ideal alternative to data derived from cellular towers, which also has a large sample size but unfortunately lacks spatial precision and pings infrequently.

Cuebiq, our LBS data supplier, provides pieces of software (called SDKs) to developers of mobile apps to facilitate LBS. These smartphone apps include couponing, dating, weather, tourism, productivity, locating nearby services (i.e., finding the closest restaurants, banks, or gas stations), and many more apps, all of which utilize their users' location in the physical world as part of their value. The apps collect anonymous user locations when they are operating in the foreground. In addition, these apps may collect anonymous user locations when operating in the background. This "background" data collection occurs when the device is moving. LBS software collects data with WiFi proximity, a-GPS and several other technologies. In fact, locations may be collected when devices are without cell coverage or in airplane mode. Additionally, all the data that StreetLight uses has better than 20-meter spatial precision. (Similarly, our partner INRIX collects some LBS data from navigation-oriented smart phone apps).

Navigation-GPS Data

Navigation-GPS data has a smaller sample size than LBS data, but it does differentiate commercial truck trips from personal vehicle trips. This makes navigation-GPS data ideal for commercial travel pattern analyses. Navigation-GPS data is also suitable for very fine resolution personal vehicle travel analyses (e.g.: speed along a very short road segment) because of its extremely high spatial precision and very frequent ping rate.

INRIX, our navigation-GPS data supplier, provides data that comes from commercial fleet navigation systems, navigation-GPS devices in personal vehicles, and turn-by-turn navigation smartphone apps. (These apps produce data that are like the LBS data described above). Segmented analytics for medium-duty and heavy-duty commercial trucks are available. For commercial trucks, if the vehicle's on-board fleet management system is within INRIX's partner system, INRIX (and thus StreetLight) will collect a ping every one to three minutes whenever the vehicle is on, even if the driver is not actively using navigation.

For personal vehicles, if the vehicle is in INRIX's partner system and has a navigation console, INRIX (and thus StreetLight) will collect a "ping" every few seconds whenever the vehicle is on, even if the driver is not actively using the navigation system. This provides a very complete picture of vehicles' travel patterns and certainty that the trips are in vehicles.

Data Processing Methodology

The following section contains an overview of the fundamental methodology that StreetLight Data uses to develop all metrics. Each StreetLight InSight® metric has specific methodological details which can be shared with clients as needed by request.

Step 1 – ETL (Extract Transform and Load)

First, we pull data in bulk batches from our suppliers' secure cloud environments. This can occur daily, weekly, or monthly, depending on the supplier. The data do not contain any personally identifying information. They have been de-identified by suppliers before they are obtained by StreetLight. StreetLight Data does not possess data that contains any personally identifying information.

The ETL process not only pulls the data from one environment securely to another, but also eliminates corrupted or spurious points, reorganizes data, and indexes it for faster retrieval and more efficient storage.

Step 2 – Data Cleaning and Quality Assurance

After the ETL process, we run several automated, rigorous quality assurance tests to establish key parameters of the data. To give a few examples, we conduct tests to:

- Verify that the volume of data has not changed unexpectedly,
- Ensure the data is properly geolocated,
- Confirm the data shares similar patterns to the previous batch of data from that particular supplier.

In addition, StreetLight staff visually and manually reviews key statistics about each data set. If anomalies or flaws are found, the data are reviewed by StreetLight in detail. Any concerns are escalated to our suppliers for further discussion.

Step 3 – Create Trips and Activities

For any type of data supply, the next step is to group the data into key patterns. For example, for navigation-GPS data, a series of data points whose first time-stamp is early in the morning, travels at reasonable speeds for a number of minutes, and then stands still for several minutes, could be grouped into a probable "trip." For LBS data, we follow a similar approach. However, since LBS data continues to ping while the device is at the destination, we see clusters of pings in close proximity at the beginnings and ends of trips.

Step 4 – Contextualize

Next, StreetLight integrates other "contextual" data sets to add richness and improve accuracy of the mobile data. These include road networks and information like speed limits and directionality, land use data, parcel data, and census data, and more.

For example, a "trip" from a navigation-GPS or LBS device is a series of connected dots. If the traveler turns a corner but the device is only pinging every ten seconds, then that intersection might be "missed" when all the device's pings are connected to form a complete trip. StreetLight utilizes road network information including speed limits and directionality, to "lock" the trip to the road network. This "locking" process ensures that the complete route of the vehicle is represented, even though discrepancies in ping frequency may occur. Figure 2, below, illustrates this process.

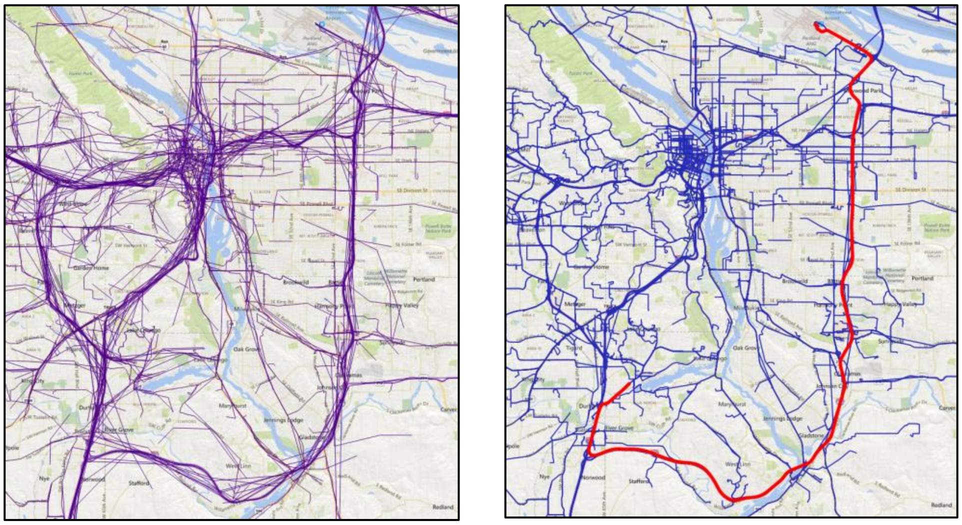


Figure 2: “Unlocked” Trips becoming locked trips.

As another example, if a device that creates LBS data regularly pings on a block with residential land use, and those pings often occur overnight, there is a high probability that the owner of the device owner lives on that block/block group. This allows us to associate “home-based” trips and a “likely home location” to that device. In addition, we can append distribution of income and other demographics for residents of that census block to that device. That device can then “carry” that distribution everywhere else it goes. (Our demographic data sources for the U.S. are the Census and American Community Surveys. In Canada, our source is Manifold Data.) This allows us to normalize the LBS sample to the population, and to add richness to analytics of travelers such as trip purpose and demographics.

Step 5 – More Quality Assurance

After patterns and context are established, additional automatic quality assurance tests are conducted to flag patterns that appear suspicious or unusual. For example, if a trip appears to start at 50 miles per hour in the middle of a four-lane highway, that start is flagged as “bad.” Flagged trips and activities are not deleted from databases altogether, but they are filtered out from StreetLight InSight® queries and metrics.

Step 6 – Normalize

Next, the data is normalized along several different parameters to create the StreetLight Index. As all data suppliers change their sample size regularly (usually increasing it), monthly normalization occurs.

For LBS devices, we perform a population-level normalization for each month of data. For each census block, StreetLight measures the number of devices in that sample that appear to live there, and makes a ratio to the total population that are reported to live there. A device from a census block that has 1,000 residents and 200 StreetLight devices will be scaled differently everywhere in comparison to a device from a census block that has 1,000 residents and 500

StreetLight devices. Thus, the StreetLight Index for LBS data is normalized to adjust for any population sampling bias. It is not yet "expanded" to estimate the actual flow of travel.

For navigation-GPS trips, StreetLight uses a set of public loop counters at certain highway locations to measure the change in trip activity each month. Then it compares this ratio to the ratio of trips at the location, and normalizes appropriately. In addition, StreetLight systemically performs adjustments to best estimate total, normalized trips based on external calibration points. Such calibration points include public, high-quality vehicle count sensors (for example, those in PEMs systems, or the TMAS repository) as well as reports from surveys and other externally validated sources. Thus, the StreetLight Index for GPS data is normalized to adjust for change in our sample size. It is not normalized for population sampling bias (because we cannot infer home blocks for GPS data). This is one of the reasons we recommend LBS data for all personal travel analytics. The StreetLight Index for GPS data is not yet "expanded" to estimate the actual flow of travel.

Step 7 – Store Clean Data in Secure Data Repository

After being made into patterns, checked for quality assurance, normalized, and contextualized, the data is stored in a proprietary format. This enables extremely efficient responses to queries via the StreetLight InSight® platform. By the time the data reaches this step, it takes up less than 5% of the initial space of the data before ETL. However, no information has been lost, and contextual richness has been added.

Step 8 – Aggregate in Response to Queries

Whenever a user runs a metric query via StreetLight InSight®, our platform automatically pulls the relevant trips from the data repository and aggregates the results. For example, if a user wants to know the share of trips from origin zone A to destination zone B vs. destination zone C during September 2017, they specify these parameters in StreetLight InSight®. Trips that originated in origin zone A and ended in either destination zone B or destination C during September 2017 will be pulled from the data repositories, aggregated appropriately, and organized into the desired metrics.

Results always describe aggregate behavior, never the behavior of individuals.

Step 9 – Final Metric Quality Assurance

Before delivering results to the user, final metric quality assurance steps are automatically performed. First, StreetLight InSight® determines if the analysis zones are appropriate. If they are nonviable polygon shapes, outside of the coverage area (for example, in an ocean) or too small (for example, analyzing trips that end at a single household) the zone will be flagged for review. If a metric returns a result with too few trips or activities to be statistically valid or to protect privacy, the result will be flagged. When results are flagged, StreetLight's support team personally reviews the results to determine if they are appropriate to deliver from a statistical/privacy perspective. The support team then personally discusses the best next steps with the user.

In general, StreetLight InSight® response time varies according to the size and complexity of the user's query. Some runs take two seconds. Some take two minutes. Some take several hours. Users receive email notifications when longer projects are complete, and they can also monitor progress within StreetLight InSight®. Results can be viewed as interactive maps and charts within the platform, or downloaded as CSV and shapefiles to be used in other tools.

Measuring Sample Size

StreetLight's Big Data resources include over 110M devices in the US and Canada. This number is about 1/3 of those countries' population. However, clients should not expect a 33% trip penetration rate for all StreetLight InSight® analyses they run. That's because we don't capture every trip on every day for all of our devices. Trip penetration rates for individual analyses can range from as small as 1% to as large as 35%. Trip penetration varies based on data period, geography, mode, and other factors. We integrate our Big Data with data from the census and 10,000+ permanent counters to normalize our sample and accurately represent the full population.

As is the case with any Big Data provider, sample size and penetration rate for a given analysis depend on the specific parameters used in the study. The reason is that some data are useful for certain analyses, but are not useful for others. For example, a device may deliver high-quality, clean location data for one study, but messy, unusable location data – or no data at all – for another. Efficiently identifying the data that are "useful" for a particular analysis is a critical component of the data science value that differentiates StreetLight Data. Because penetration rates vary, sample sizes are automatically provided for almost all StreetLight InSight® analyses[1]. This allows users to calculate penetration rates and to better evaluate the representativeness of the sample. Sample size values also are useful to clients who wish to normalize StreetLight InSight® results through additional statistical analysis.

For LBS analyses, sample size is currently provided as the number of unique devices and/or number of trips for LBS analyses, depending on the type of analysis. These values should be

[1] Sample sizes are not automatically provided for AADT or Traffic Diagnostics Projects. They are available by request. These analyses use a very large volume of location data, so providing sample sizes automatically via StreetLight InSight® would negatively impact data processing speeds.

thought of as most similar to “person trips.” Including both the number of devices and trips for all LBS analyses is in our product roadmap. Sample size is provided as number of trips for navigation-GPS analyses. These should be thought of as “vehicle trips.”

In general, though not always, the trip sample size for commercial navigation-GPS data will be higher than the device (truck) sample size. Commercial trucks that are in active use typically take many trips per week that are often on set routes; thus, they are more likely to have up-to-date fleet management tools, and that means they are more likely to be included in StreetLight’s navigation-GPS data set. Trucks that are more rarely used are less likely to be included in the data set.

In general, though not always, the trip sample size for LBS data will be lower than the device (person) sample size. The reason is that not all devices in StreetLight’s database capture every single trip perfectly. To illustrate, consider this hypothetical example:

- 8:00AM: Device creates location data at expected home location
- 2:00PM: Device creates location data at sports arena

This device has created useful information for analyzing the home locations of visitors to the arena. However, since the device didn’t create any location data on the trip to arena, perhaps because it was off, then the route taken and the travel time cannot be calculated with certainty. As result, it could not be used in an analysis of road activity on an arterial near the arena.

As another example, consider a device that generates regular pings for each trip taken over 10 days. However, the user deletes the smart phone app that created that data, and it stops pinging. That device then disappears for the last 20 days of the month. The device’s data can still be used, but the trip penetration for the month is only 33% of this person’s trips, not 100%.

Typical daily trip penetration rates are between 2 and 5% of all trips on any one specific day. StreetLight’s pricing and data structure encourage looking at many days of data. The costs are the same for analyzing an average day across three months, three years, or analyzing a single day. Thus, we encourage clients to evaluate the total sample across the entire study period instead of focusing on per-day penetration rates.

About StreetLight Data

StreetLight Data pioneered the use of Big Data analytics to help transportation professionals solve their biggest problems. Applying proprietary machine-learning algorithms to over four trillion spatial data points, StreetLight measures diverse travel patterns and makes them available on-demand via the world’s first SaaS platform for mobility, StreetLight InSight®. From identifying sources of congestion to optimizing new infrastructure to planning for autonomous vehicles, StreetLight powers more than 3,000 global projects every month.

STREETLIGHT DATA

APPENDIX D: User Guide for Mode Shift Potential Tool

This appendix documents a user guide that accompanies the mode shift potential tool provided to UDOT. It provides guidance regarding its inputs and operation.

To: UTRAC

From: Alta Planning & Design

Date: May 12, 2022

Re: UTRAC Active Link Mode Shift Potential Tool User Guide

Active Link Mode Shift Potential Tool User Guide

This ArcGIS tool estimates the mode shift potential from auto to active modes along proposed facility segments by assessing the proximity, angle, and trip distances of origin-destination (OD) pair lines with respect to the proposed facility.

Required Inputs

There are three key required inputs for this tool, two of which are provided in the accompanying geodatabase:

- **Origin-destination pair lines** – Polyline feature class of OD pair lines that connect the origin to the destination and contains, at minimum, attributes on the number and average distance of drive trips made between the OD pair, and ID fields for each origin/destination geography.
    - The provided 'TAZ_Origin_Destination_Alta_2022' feature class contains OD pairs generated for travel between TAZs in Utah for a typical travel day in Fall 2019, as estimated by Replica.
- **Origin-destination geography** – Polygon feature class of the aggregating geography for OD pairs, used for handling intrazonal trips. The minimum required attribute is an ID field that joins to the OD pair lines feature class.
    - The provided 'Utah_Trip_Table_TAZ_Summary_Replica_2022' feature class contains the TAZ geography and associated ID, along with trip characteristics non-essential to the function of this tool.
- **Segments/projects for evaluation** – Polyline feature class of network segments or project lines for mode shift potential evaluation. No specific attributes are required other than a valid geometry.
    - There is a provided example 'Select_Links_Alta_2022' which is a feature class of 25 segments that were evaluated against StreetLight data select link analysis results for tool parameter calibration.
    - Any polyline feature class may be evaluated.

Derived Outputs

The tool will output a feature class with the same geometry as the inputted line segments for evaluation, but with two attributes added:

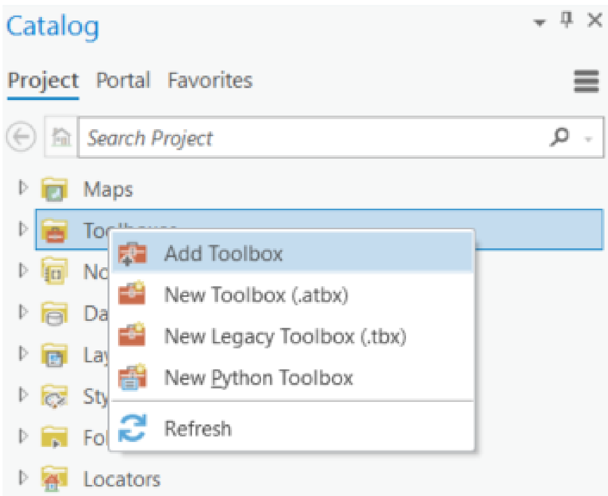
- **Potential_Conversion_Trips** – Estimated number of trips along the line segment with the potential to be shifted from auto to active modes.
- **Trip_Conversion_Index** – Percentile rank of Potential_Conversion_Trips.

Using the tool in ArcGIS

The following instructions describe the process of running the tool with the provided input data.

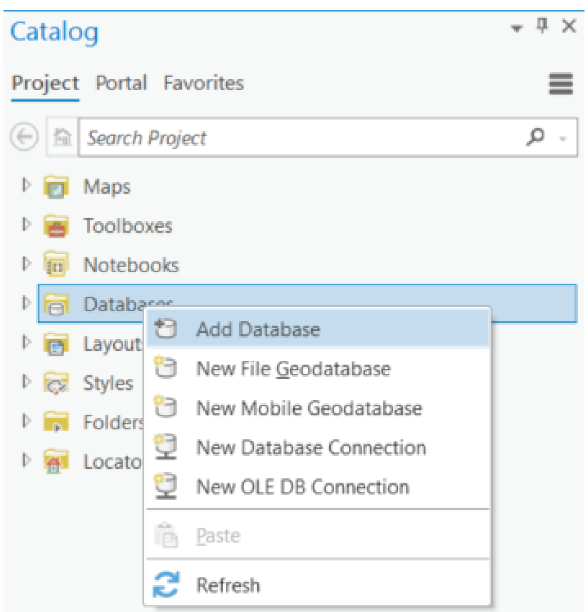
Importing the toolbox

1. In the Catalog window, right click on 'Toolboxes' and select 'Add Toolbox.' Navigate to the location of the toolbox on your computer, select it, and press OK.



Importing the provided database

2. In the catalog window, right click on 'Databases' and select 'Add Database.' Navigate to the location of the database on your computer, select it, and press OK.



Inputting tool parameters

3. Expand the toolbox added in Step 1 and double-click on the tool to open the Geoprocessing window.

4. Select the file icon next to the Facilities input box and navigate to the feature class that contains the proposed facilities for evaluation.

5. Select the file icon next to the OD Lines input box and navigate to the feature class that contains the OD pair lines.

6. From the dropdown menu that appears in the Origin Field input box, select the field from OD Lines that corresponds to the origin ID.

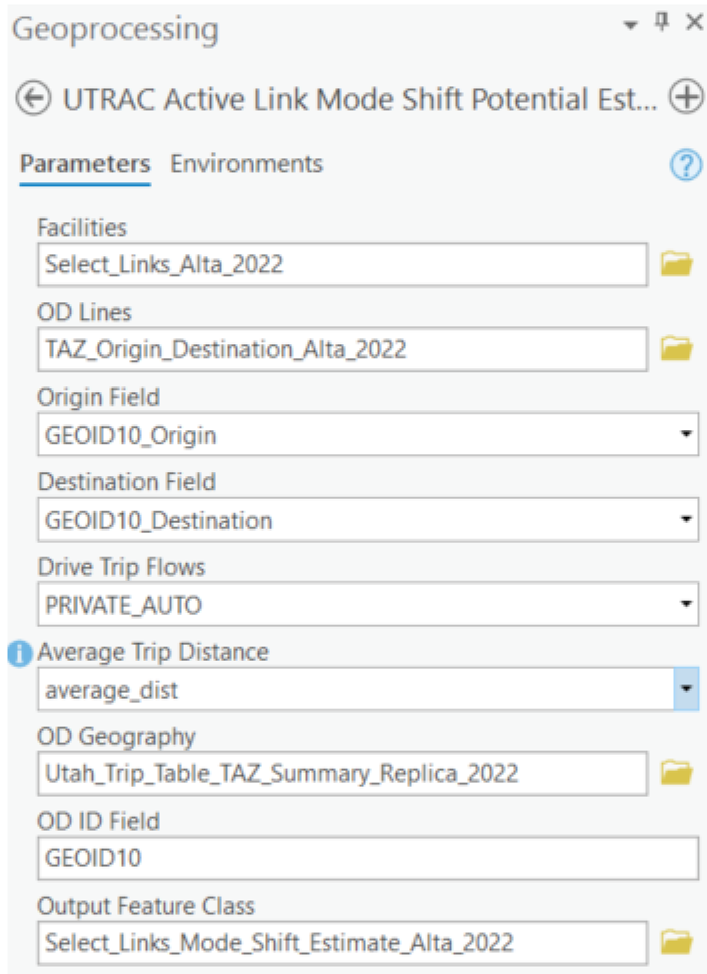
7. Repeat Step 6 to select the corresponding destination ID field.

8. Select the field in OD Lines that indicates the number of drive trips taken between each OD pair.

9. Select the field in OD Lines that indicates the average distance of trips taken between each OD pair.

10. Select the file icon next to the OD Geography input box and navigate to the feature class that contains the OD geography.

11. Select the field in OD Geography with the ID field that links OD Geography with OD Lines.



12. Select the file icon next to the Output Feature Class and navigate to the location where you want to save the outputted feature class.

13. Run the tool!

Questions and troubleshooting guidance may be directed to David Wasserman (davidwasserman@altago.com) or Grace Young, Alta Planning (graceyoung@altago.com).

HOW DO WE DETERMINE POTENTIAL FOR MODE SHIFT?

Read on to learn about the steps we take to identify the high mode shift potential corridors for active facilities.

CORRIDOR: *The road or trail under study*

TRIP: *A journey to shift to active modes*

NETWORK: *Corridors to be analyzed*

A

Start & End

FEWER TRIPS — MORE TRIPS

When we go somewhere, we **start our trip at one location (such as our home) and end at another (such as the grocery store).** Using start and end locations for many people's trips, we can understand travel patterns throughout the region. We use these travel patterns to identify which roads may be most suitable for an active facility.

B

Proximity

FURTHER AWAY — CLOSER IN

We want to know how many people are traveling **within a close proximity** of our corridor. Trips closer in to the study corridor can be given more influence on mode shift potential scores than those further away.

C

Parallelism

LESS PARALLEL — MORE PARALLEL

We want to know how many people are traveling **in the same direction** as our corridor. For example, if our corridor runs north-south, we want to include trips where people are also traveling north-south.

D

Trip Distance

LESS SUITABLE DISTANCE — MORE SUITABLE DISTANCE

We want to know if the distance people are traveling would be well-served by a bicycle or pedestrian facility. Typically, the distances considered will be less than 10 miles. Mode shift scores for walking and biking would be determined by their feasible travel distances respectively.

★ REPEAT A-D FOR EACH CORRIDOR IN THE NETWORK

The Result

LESS MODE SHIFT — MORE MODE SHIFT

Finally, we **add it all up!** *We include trips that are near the corridor, going in the same direction, and are the appropriate distance to get a total demand score for our corridor. When we analyze all corridors in our network, we can see which corridors have more mode shift potential. These corridors are better options for an active transportation facility.*