BOSTON REGION METROPOLITAN PLANNING ORGANIZATION

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TECHNICAL MEMORANDUM

DATE: **December 19, 2019**

TO: **Boston Region Metropolitan Planning Organization**

FROM: **Ryan Hicks and Seth Asante, Central Transportation Planning Staff**

RE: **New and Emerging Metrics for Roadway Usage**

1 INTRODUCTION

The Boston region contains a robust transportation network that encompasses diverse modes of transportation, including vehicular, truck, public transportation, bicycle, and pedestrian movement. Yet, these different modes of transportation are monitored separately as transportation performance monitoring has traditionally focused on moving vehicles rather than people. To better monitor multimodal travel as it relates to the mobility of individual travelers, the Boston Region Metropolitan Planning Organization (MPO) supported the *New and Emerging Metrics for Roadway Usage* study through its federal fiscal year (FFY) 2019 Unified Planning Work Program (UPWP).

The objectives of this study were explicitly stated in the UPWP work program. The objectives were to 1) determine performance measures that can assess multiple modes and quantify the mobility of motorists, transit riders, bicyclists, and pedestrians rather than vehicles, and 2) determine a plan for the selected performance measures to be considered for the Congestion Management Process (CMP), the Long-Range Transportation Plan (LRTP), and other MPO activities. These multimodal monitoring criteria may significantly benefit the programs listed above, but it is not obligatory for any agency or program to adopt the recommended criteria. Though not required, the recommendations from this study will be useful for educating planners, engineers, and the public about multimodal performance monitoring.

The first section of this memorandum focuses on a literature review of studies that focused on multimodal transportation performance monitoring. The memorandum further discusses the selection process for performance metrics based on the goals and objectives that are in the Boston Region MPO's LRTP, *Destination 2040*. Then there is a summary of a test analysis that applied selected performance metrics to conditions at two locations on the transportation network. The memorandum concludes by presenting the selected performance metrics and the adjusted thresholds based on the previously mentioned analysis.

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2 LITERATURE REVIEW

2.1 Background

Over the last few years, there has been ample research on developing nuanced performance metrics that are multimodal and inclusive. As a result, many transportation organizations are evolving traditional level of service (LOS) standards into multimodal LOS standards. Thus, it was imperative for the MPO staff to review existing multimodal studies and guidelines before creating a unique multimodal performance monitoring method for voluntary use in MPO activities, such as corridor and intersection studies. Elements from other MPO studies, such as those that resulted in the development of the Bicycle Report Card and the Pedestrian Report Card Assessment tool, were incorporated into this study.

An ideal multimodal performance monitoring method should include performance metrics and land use elements, and have minimal influence from transportation demand models. For multimodal performance monitoring, it is ideal to have data that represent real conditions on the transportation network rather than modeled data as future projections can be unpredictable due to unforeseen changes to planned transportation developments. This section summarizes several studies that relate to the topic of multimodal performance monitoring and their strengths and weakness.

2.2 Victoria Transport Policy Institute

The *How Should We Measure Traffic Congestion?* study was developed by the Victoria Transport Policy Institute (VTPI), an independent transportation planning organization based in Victoria, British Columbia.[1] The goal of VTPI is to determine new ways to fix transportation-related problems. This study emphasized the interesting point that intensity-related performance measures are good for determining short-term planning but ignore congestion exposure, which is defined as "the amount people must drive under urban-peak conditions."

VTPI was cognizant of newer technologies, such as app-based ride-sharing and autonomous vehicles, which might increase congestion by adding to the number of vehicles on the transportation network. This study analyzed the costs of congestion and presented some alternatives to roadway LOS metrics, such as the following:

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[1] Todd Litman, "Smart Congestion Relief—Comprehensive Evaluation of Traffic Congestion Cost and Congestion Reduction Strategies," Victoria Transport Policy Institute, accessed February 15, 2019, http://www.vtpi.org/cong_relief.pdf; Todd Litman, "Introduction to Multi-Modal Transportation Planning—Principles and Practices," Victoria Transport Policy Institute, accessed February 15, 2019, http://www.vtpi.org/multimodal_planning.pdf.

- multimodal level of service
- quality of service
- trip generation and vehicle travel and fuel consumption models
- multimodal accessibility modeling

This study relates to several goals of the *New and Emerging Metrics for Roadway Usage* study, as the VTPI study encouraged the improvement of overall accessibility and transport system efficiency rather than maximizing vehicle speeds.

Strengths

This study searched for performance measures that were comprehensive and multimodal.

Weaknesses

This study relied heavily on model-based planning.

2.3 National Cooperative Highway Research Program

The National Cooperative Highway Research Program's *Field Test Results of the Multimodal Level of Service Analysis for Urban Streets* study relied upon a few principles, such as measuring congestion exposure rather than congestion intensity as intensity indicates how extreme congestion is at a specific time.[2] Included in this study were cases that analyzed and assessed performance metrics at several locations in the United States. The main goal of this study was "to develop and test a framework and enhanced methods for determining levels of service for automobile, transit, bicycle, and pedestrian modes on urban streets, in particular with respect to the interaction among the modes." Examples of the performance metrics tested include pavement condition and driveway conflicts per mile.

[2] Richard Dowling, Aimee Flannery, Paul Ryus, Theo Petrisch, and Nagui Rouphail, "National Cooperative Highway Research Program Web-Only Document 158: Field Test Results of the Multimodal Level of Service Analysis for Urban Streets," Transportation Research Board, accessed February 15, 2019, http://reconnectingamerica.org/assets/Uploads/nchrp_w158.pdf; Richard Dowling, David Reinke, Aimee Flannery, Paul Ryus, Mark Vandehey, Theo Petritsch, Bruce Landis, Nagui Rouphail and James Bonneson, "National Cooperative Highway Research Program Web-Only Document 616: Multimodal Level of Service Analysis for Urban Streets," Transportation Research Board, accessed February 15, 2019, https://nacto.org/docs/usdg/nchrp_rpt_616_dowling.pdf.

Strengths

- The study made a concerted effort to incorporate several transportation modes into the calculations.
- Refinement of the model takes place after the assessment has concluded, which improves the accuracy of the model.

Weaknesses

This study relied on models, which might not represent real conditions on a transportation facility. To improve accuracy, model calibration is necessary to reflect local conditions.

2.4 Bellevue Transportation Commission

The Bellevue Transportation Commission of the City of Bellevue, Washington, proposed a transportation monitoring system in its *MMLOS Metrics, Standards and Guidelines* report (2017-18) that accommodates all travelers and all trips, regardless of mode.[3] The study was initiated in response to Washington State's Growth Management Act of 1990, which requires local governments to observe LOS on city-owned roadways and transit routes. Strategies and policy revisions are then recommended based on those LOS calculations. The study report states that implementing a multimodal LOS monitoring system can progress the City towards a comprehensive citywide multimodal transportation system. The study recommended using the following LOS metrics for the vehicle, pedestrian, bicycle and transit modes:

- The vehicle LOS measures are based on the Highway Capacity Manual (HCM) standards.
- The pedestrian LOS measures focus on buffers and landscaping, which can affect pedestrian comfort. Crossing opportunities are also analyzed.
- The bicycle LOS measure analyzes the level of stress for bicyclists using bicycle facilities, such as bike lanes and bike paths.
- The transit LOS measures examine factors that affect ridership or the experience of the transit rider.

Strengths

- This study evaluated all modes equally through the recommended performance metrics.
- The recommendations from this study enabled the City of Bellevue to make changes to its transportation policies to evaluate transportation

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[3] Bellevue Transportation Commission, "MMLOS Metrics, Standards and Guidelines," accessed February 15, 2019, https://transportation.bellevuewa.gov/UserFiles/Servers/Server_4779004/File/Transportation/Bellevue_MMLOS%20FINAL.pdf.

corridors and monitor transportation performance using performance targets.

Weaknesses

The metrics for vehicle and transit modes may not be sufficient for large urban areas, which must focus on air quality and climate change issues and are aiming to reduce vehicle-miles traveled (VMT) while increasing transit and nonmotorized mode shares.

2.5 City of Ottawa

The report titled *Multimodal Level of Service (MMLOS) Guidelines* was completed for the City of Ottawa, Ontario, by the IBI Group.[4] This study examined a way to measure congested conditions without exclusively favoring roadways. This study analyzed other modes of transportation, such as the pedestrian, bicycle, public transportation, and truck modes. As a result, the City of Ottawa created the MMLOS tool in 2015. This tool emphasizes evaluating tradeoffs for improving one mode over another mode.

The metrics selected for this tool are measured at both signalized roadway intersections and roadway segments except for vehicular LOS metrics, which can only be measured at intersections. The metrics are as follows:

- The pedestrian LOS criterion focuses on pedestrian comfort, safety, and convenience.
- The bicycle LOS criterion focuses on level of traffic stress (LTS) experienced by bicyclists at specific roadway locations.
- The transit LOS criterion focuses on the transit mode share of a corridor by analyzing transit travel time and transit priority afforded to transit vehicles.
- The truck LOS criterion focuses on the percentage of trucks and buses in a corridor. Buses and trucks are monitored together because they are considered to be heavy vehicles.
- The vehicular LOS criterion focuses on the functionality of intersections according to the Transportation Impact Assessment Guidelines.[5]

[4] IBI Group, “Multi-Modal Level of Service (MMLOS) Guidelines,” accessed February 15, 2019, https://sudburycyclistsunion.ca/wp-content/uploads/2016/04/Ottawa-MMLOS.pdf.

[5] City of Ottawa/Dillon Consulting, “Transportation Impact Assessment Guidelines (2017),” accessed February 15, 2019, https://documents.ottawa.ca/sites/documents/files/tia_guidelines_en.pdf.

Strengths

- Trade-off evaluations are very helpful for determining the best way to solve congestion in a corridor.
- This study uses performance metrics to evaluate all modes of travel.

Weaknesses

- This method of performance monitoring requires a large, varied data collection effort.
- The study emphasized measuring LOS but fell short on measuring quality of service (as measured by mode shares, VMT, and the like). The monitoring of quality of service is useful for tracking policy goals.

2.6 California Senate Bill 743

California Senate Bill 743 was enacted in 2013 and will mandate on July 1, 2020, changes to the guidelines for implementing the California Environmental Quality Act (CEQA) in regards to the analysis of transportation impacts.[6] This bill imposes changes to the way California municipalities will measure the environmental effects of projects by focusing on the relationship between transportation and land use.

This bill requires municipalities to eliminate LOS and vehicle delay measures and begin monitoring VMT to gauge transportation impacts. A reason for this change is that the previous LOS requirements of the CEQA encouraged sprawl in certain locations while discouraging infill development closer to jobs, transit and walkable areas.[7]

As stated in the *Shifting Gears in Transportation Analysis* webinar, issues with LOS as a measure of transportation impact are as follows:[8]

- "Punishes last-in [developments constructed near the central business district] inhibits infill, pushes development outward"

[6] California Governor's Office of Planning and Research, "Transportation Impacts (SB 743), CEQA Guidelines Update and Technical Advisory," accessed February 15, 2019, http://opr.ca.gov/ceqa/updates/sb-743/; California Governor's Office of Planning and Research, "Technical Advisory On Evaluating Transportation Impacts in CEQA," accessed February 15, 2019, http://opr.ca.gov/docs/20171127_Transportation_Analysis_TA_Nov_2017.pdf.

[7] Melanie Curry, "After 4 Years, Key Rule Requiring Development to Account for New Miles Driven Moves Forward," Streets Blog Cal, accessed February 15, 2019, https://cal.streetsblog.org/2017/11/28/after-4-years-key-rule-requiring-development-to-account-for-new-miles-driven-moves-forward/.

[8] Chris Ganson and Christopher Calfee, "Shifting Gears in Transportation Analysis," State of California Governor's Office of Planning and Research, accessed February 15, 2019, http://opr.ca.gov/docs/743_February_2016_Webinar.pdf.

- "Solves [or reduces] local congestion, exacerbates regional congestion"
- "Inhibits transit"
- "Inhibits active transport"
- "Measures mobility, not access; shows failure when we [local and regional governments] succeed [for example, sprawl can increase mobility of travelers, but it reduces the access to locations to the same travelers]"
- "Measures mobility poorly; fails to optimize network even for automobiles"
- "Forces more road construction than we [local and regional governments] can afford to maintain"
- "Hard to calculate and inaccurate"

Strengths

- The bill promotes a more multimodal performance monitoring approach for local communities.
- The bill helps municipalities monitor both land use and transportation.
- Projects that promote sprawl will have to account for the extra traffic that will occur as a result.
- This bill encourages local planners and officials to consider creating their own performance measures.

Weaknesses

It is unknown if VMT will be an adequate metric to monitor congestion as new technologies such as autonomous vehicles emerge.

2.7 Guide to Sustainable Transportation Performance Measures

The Guide to Sustainable Transportation Performance Measures, published by the US Environmental Protection Agency in 2011, benefited from several interviews and information exchanges with staff from several MPOs, the Federal Highway Administration, and the Federal Transit Administration.[9] The document describes opportunities to incorporate environmental, economic, and social sustainability into transportation decision-making through the use of performance measures. Among the several performance measures described in the guide are transit accessibility, transportation affordability, and VMT per capita.

Transit accessibility metrics indicate the relative convenience of transit as a mode choice. Transit accessibility can be measured in terms of the distance people must travel to transit stops or travel time on transit. These metrics

[9] United States Environmental Protection Agency, "Guide to Sustainable Transportation Performance Measures," accessed February 15, 2019, https://www.epa.gov/sites/production/files/2014-01/documents/sustainable_transpo_performance.pdf.

typically emphasize the availability of transit where people live, where people work, and on commuter routes.

Transportation affordability metrics reflect the ability of transportation system users to pay for transportation. Since an affordable transportation system is one that takes a smaller share of a user's total income, typical metrics include annual transportation costs compared to annual income and the proportion of income spent on transportation by people in various income groups.

VMT per capita metrics show the amount of vehicle activity per population in a region. Reducing VMT has been associated with better air quality, congestion reduction, and fewer vehicular crashes.

Strengths:

- The guidebook provides examples of best practices in sustainable transportation performance measurement that are being applied across the country.
- Data for most of the performance metrics are available to most MPOs or can be obtained from other planning agencies.
- The recommended monitoring methods from the guidebook incorporate environmental, economic, and social (equity) sustainability into transportation decision-making.

Weaknesses:

The method is sourced from various MPO regions; therefore, it is not customized for large MPO regions with multimodal transportation systems such as the Boston region.

2.8 SUMMARY

The features of the six studies that are most pertinent to multimodal transportation planning are summarized in Table 1. Based on the research conducted, the two studies that served as models for the *New and Emerging Metrics for Roadway Usage* study were the MMLOS studies in Bellevue, Washington, and Ottawa, Ontario. The guidelines from these studies provide performance metrics for multiple modes, incorporate a land use component, and feature very little influence from a model.

A general trend is that many transportation agencies are minimizing or eliminating the use of automobile LOS and promoting the use of VMT. Most of these studies agree that the best way to accurately measure congestion across multiple modes is to determine ways to measure the movement of people rather than the movement of vehicles.

Table 1
Study Comparisons

	How Should We Measure Traffic Congestion?	Multimodal LOS Analysis for Urban Streets	MMLOS (Bellevue)	MMLOS (Ottawa)	Senate Bill 743	Guide to Sustainable Transportation Performance Measures
Study author/ location	Victoria Transport Policy Institute	NCHRP	Bellevue, Washington	Ottawa, Ontario	California Senate	US Environmental Protection Agency
Purpose	Evaluation/ literature review	Field test results	Guidelines	Guidelines	Legislative bill to change law	Guidelines
Inputs from model	Yes, with criticisms	Yes	No	No	Yes	Yes for some performance measures
Study completion year	2018	2008/2010	2017/2018	2015	2013	2011
Number of performance metrics/ inputs	54	38	16	49	1	12 example measures/34+ example metrics
Cumulative LOS	Yes, recommends MMLOS	Yes for every mode	Yes for every mode	Yes for every mode	No	Bicycle and pedestrian LOS only
Measures VMT	No	No	Yes, in the future	No	Yes	Yes
Network defined	Highways only	No	Yes	Yes	No	No
Land use incorporated	Yes	No	Yes	Yes	Yes	Yes

LOS = level of service. MMLOS = multimodal level of service. NCHRP = National Cooperative Highway Research Program. VMT = vehicle-miles traveled.
Source: Central Transportation Planning Staff.

3 *DESTINATION 2040* GOALS AND OBJECTIVES

For performance monitoring to be effective, goals and objectives must be well-defined to enable the selected metrics to gauge progress towards improving the transportation network. The MPO defined six goal areas and associated objectives in its LRTP, which was completed in August 2019:

- Safety
- System Preservation and Modernization
- Capacity Management and Mobility
- Economic Vitality
- Clean Air/Sustainable Communities
- Transportation Equity

Three of those goal areas—Safety, Capacity Management and Mobility, and System Preservation—are relevant to this study and the selection of performance metrics. Each of these goal areas pertain to moving people safely and effectively across multiple modes. Monitoring the mobility of individual travelers rather than vehicles will show a more accurate depiction of congestion on the transportation network. Person capacities for transportation facilities often are higher when vehicle occupancies are higher. These three goals and 11 associated objectives are discussed further below.

Safety

The MPO's safety goal focuses on the safety of travelers for all modes. Oftentimes, this goal involves analyzing Highway Safety Improvement Program (HSIP) crash cluster locations. The LRTP states that facilities to improve safety for bicyclists and pedestrians are required to improve safety at high crash locations as bicyclists and pedestrians are involved in a growing share of crashes.

The safety objectives include the following:

- Reduce number and severity of crashes and safety incidents for all modes
- Reduce serious injuries and fatalities from transportation
- Make investments and support initiatives that help protect transportation customers, employees, and the public from safety and security threats

Capacity Management and Mobility

The Capacity Management and Mobility goal focuses on the movement of people and goods throughout the transportation network and the connectivity of the transportation network. The goal emphasizes the need to ensure that transportation infrastructure meets the Americans with Disabilities Act (ADA) standards. This goal is consistent with the goals that were presented in the studies from the literature review, with the focus on multiple modes rather than exclusively automobile travel.

The Capacity Management and Mobility objectives include the following:

- Improve reliability of transit
- Support implementation roadway management and operations strategies to improve travel reliability, mitigate congestion, and support non-single-occupant vehicle travel options.
- Fund improvements to bicycle/pedestrian networks aimed at creating a connected network of bicycle and accessible sidewalk facilities (at both regional and neighborhood scale) by expanding existing facilities and closing gaps
- Support strategies to better manage automobile and bicycle parking capacity and usage at transit stations
- Increase percentage of population and places of employment within one-quarter mile access to transit stops
- Improve access to and accessibility of all modes, especially transit and active modes
- Eliminate bottlenecks on the freight network and improve freight reliability

System Preservation

The System Preservation goal focuses on maintaining the existing transportation network. The areas of focus include, but are not limited to, infrastructure located along roadways and at intersections, including sidewalks and pedestrian signals.

The System Preservation objectives include the following: Improve existing pedestrian and bicycling infrastructure.

4 DATA AVAILABLITY

An effective performance monitoring program begins with data collection. Transportation data can be obtained by manual collection or by receiving or purchasing data from a third party. Table 2 shows the prospective performance metrics and data sources that were evaluated in the studies described in Section 2 of this memorandum. The MPO staff already has access to some of these datasets and others would be easily obtained. Some other datasets would be difficult to obtain or contain incomplete data. Some metrics can currently only be collected by doing manual fieldwork, which can be expensive and time-consuming. Only the metrics that rely on data sources readily available to the MPO staff were selected for this study.

Table 2
Data Sources and Prospective Performance Metrics

Data Source	Ability to Obtain	Prospective Performance Metrics
MassDOT roadway inventory	Easy	Pavement condition, number of roadway travel lanes, level of traffic stress, sidewalk presence, bicycle accommodations, annual average daily traffic, and pavement condition
MassDOT crash database	Easy	Bicycle crashes, pedestrian crashes
Travel demand model	Easy	Transit-miles traveled, truck vehicle-miles traveled, vehicle-miles traveled, volume-to-capacity ratio, and percent of typical urban travel time
INRIX *	Easy (MPO granted access)	Vehicle travel speed, average travel speed, duration of congestion, travel time index, speed index, vehicle delay, multimodal travel time per person, and multimodal peak period length
Boston Region MPO signal database	Moderate	Pedestrian signal presence and pedestrian signal type
MassDOT ADA Transition Plan	Easy	Curb ramp presence
Functional design reports	Moderate	Duration of pedestrian change interval
MBTA Back on Track website[†]	Easy	On-time performance
MBTA timepoint dataset	Easy (provided to MPO)	Transit vehicles per hour, hours of service per day, transit vehicle speed, transit time index, person-hours of delay, person-hours of delay per bus trip, delay per bus run, and percent of delay during peak periods
MBTA automatic passenger counter data	Easy	Passenger crowding and pass up standard
Bike parking inventory	Easy	Transit stop bicycle parking
Regional Integrated Transportation Information (RITIS) dashboard	Difficult (state incident dataset is incomplete)	Exposure to incident potential and clearance time for incidents
National Performance Management Research Dataset [‡]	Moderate	Truck travel time reliability index and buffer time index
Field collection	Difficult	Multimodal person throughput, bike lane blockage frequency, bike rack presence, bicycle facility condition, sidewalk condition, encounters per hour, mean walking speed, pedestrian volumes, passenger amenities, transit stop weather protection, transit stop seating, transit stop paved bus door passenger zone, transit stop wayfinding, exposure to congestion, and truck volumes

Data Source	Ability to Obtain	Prospective Performance Metrics
Aerial imagery	Moderate	Proximity to transit, bicyclist operating space, bicycle facility continuity, proximity to bike network, driveway conflicts per mile, safe crosswalks per mile, walkway width, length of crossing, island refuge presence, on street parking, vehicle-pedestrian buffer, crosswalk treatment, intersection treatment, corner radius, street width, and safe crossings opportunities at transit stops
Zoning maps	Moderate	Land use

* INRIX is a private company that collects roadway travel times and origin-destination data for most roadways that are collectors, arterials, limited-access roadways or freeways.

† Data for other local regional tranist authorities and organizations—such as the Brockton Area Transit Authority, Cape Ann Transportation Authority, and MetroWest Regional Transit Authority—may be substituted for local datasets, if necessary.

‡ The National Performance Management Research Data Set (NPMRDS) includes archived INRIX vehicle probe data and freight probe data. The American Transportation Research Institute provides the freight probe data that is included in the NPMRDS. RITIS provides the NPMRDS and incident data to the Boston Region MPO through its web portal.

ADA = Americans with Disabilities Act. MassDOT = Massachusetts Department of Transportation. MPO = Metropolitan Planning Organization.

Source: Central Transportation Planning Staff.

5 SELECTION OF PERFORMANCE METRICS

Prior to implementing a new performance monitoring program, it is important to conduct outreach and receive feedback on the proposed performance metrics from stakeholders. This study included two outreach efforts involving an online survey and interviews. An online survey is best for receiving quantitative feedback from a large number of respondents and interviews are ideal for collecting in-depth feedback from stakeholders.

5.1 Survey

The online survey was distributed between April 23, 2019, and May 10, 2019, to approximately 55 professionals who work in the field of transportation planning and are involved with performance monitoring throughout the New England region. Overall, 17 survey responses were received. A copy of the final survey is located in Appendix C. The survey asked respondents about their

- general background (affiliation);
- preferred mode of travel;
- opinion about the definitions of potential performance metrics that were derived from the studies presented in the literature review and various MPO activities;
- rankings of potential performance metrics by travel mode;
- opinion about multimodal transportation monitoring in areas with certain demographic characteristics; and
- advice about any metrics that should be added or changed.

For an extensive analysis of the survey results, refer to Appendix D. The survey results indicated that transit and pedestrian modes rank the highest in regards to preferred mode of transportation. Several of the respondents stated that they would like to see performance metrics that show connections between different modes. Measuring automobiles and travel speeds are very polarizing as many of the respondents reported that they were strongly for or against including automobile speeds.

The key findings of the survey were as follows:

- The *curb radius* and *pavement condition* metrics received negative feedback. The suitability of these metrics can vary based on the geometric design of an intersection or roadway segment.
- Monitoring of *vehicle travel speeds* is not perceived positively for multimodal transportation performance monitoring.
- Participants suggested adding performance metrics for *intermodal connectivity* and *viability of weather by mode* (comfort of mode of travel during inclement weather). Intermodal connectivity can be measured in part by the presence of bicycle racks and safe crossings at transit stops. Viability of weather is factored in the form of comfort, in regards to various bicycle, pedestrian, and transit metrics.

5.2 Interviews

The MPO staff interviewed several transportation planning professionals in the Boston region to get more extensive feedback on the potential performance metrics. The interviewees recommended that the study focus on both the comfort and movement of people and that five or six metrics per travel mode should be used. The interviewees recommended some modifications to the proposed metrics and suggested some new metrics.

The interviewees recommended including new metrics such as *low-stress bicycling and network connectivity*, *number of bike lane discontinuities*, *crossings at transit stops*, and *number of pedestrian interruptions*. *Crossings at transit stops* was selected as a metric for this study. The other recommended metrics were not selected, but features from the metrics were interwoven into other metrics that were selected.

The interviewees also recommended changing the *crossing opportunities* metric to *safe crossing opportunities* and adding criteria to evaluate if a crosswalk is safe for a pedestrian to cross in the time provided by the traffic signal. Interviewees also recommended that the *transit time index* measure should be based on a free-flow travel or baseline travel time, rather than the transit schedule.

5.3 Selected Performance Metrics

Based on the findings from the literature review and the survey results, MPO staff recommend that 24 performance metrics to be used for evaluating multimodal transportation facilities. Table 3 lists the recommended performance metrics according to the modes they measure and the Boston Region MPO goals to which the metrics relate.

Table 3
Selected Performance Metrics

Performance Metric	Mode Measured	Boston Region MPO Goal
Bicycle crashes*	Bicycle	Safety
Bicycle facility continuity (bicycle facility presence)*	Bicycle	Capacity Management and Mobility
Level of traffic stress	Bicycle	Safety
Bicycle rack presence	Bicycle	Capacity Management and Mobility
Proximity to bike network*	Bicycle	Capacity Management and Mobility
Safe crossing opportunities/safe crosswalks per mile*	Pedestrian †	Safety
Sidewalk presence and condition*	Pedestrian	System Preservation/Capacity Management and Mobility
Pedestrian crashes*	Pedestrian	Safety
Vehicle-pedestrian buffer*	Pedestrian	Safety
Transit time index*	Transit	Capacity Management and Mobility
Level of transit time reliability	Transit	Capacity Management and Mobility
Person hours of delay per bus trip*	Transit	Capacity Management and Mobility
Vehicle delay per bus run	Transit	Capacity Management and Mobility
Load factor/passenger crowding*	Transit	Capacity Management and Mobility
Safe crossings opportunities at transit stops	Transit	Safety
Truck travel time reliability index	Trucks	Capacity Management and Mobility
Percentage of truck traffic	Trucks	Safety
Buffer time per trip/ total hours of daily truck buffer time	Trucks	Capacity Management and Mobility
Duration of congestion/congested time*‡	Vehicles	Capacity Management and Mobility
Travel time index*	Vehicles	Capacity Management and Mobility
Vehicle-miles traveled*	Vehicles	Capacity Management and Mobility
Average vehicle delay	Vehicles	Capacity Management and Mobility
Roadway lane density	Multimodal	Capacity Management and Mobility
Person throughput	Multimodal	Capacity Management and Mobility

* This metric was previously used by Boston Region MPO.
† Sidewalk capacity for pedestrians was not directly measured in this study.
‡ For the *duration of congestion/congested time* metric, the definition of congestion on arterials is the total time when travel speeds are below 19 miles per hour.
Source: Central Transportation Planning Staff.

6 PERFORMANCE METRIC DEFINITIONS

This section provides a brief overview of the performance metrics that were selected for the multimodal performance monitoring criteria. For a detailed description of each performance metric and the data required for monitoring, please refer to Table A.1 in Appendix A.

6.1 Bicycle Metrics[10]

Bicycle Crashes

The *bicycle crashes* performance metric analyzes the safety of a corridor, based on the number and severity of bicycle crashes. The crashes will be assessed based on the bicycle EDPO score at the intersections in the corridor.[11] This metric is different from the *absence of bicycle crash* metric that was presented in the Boston Region MPO's bicycle level of service metric study,[12] which rates bicycle safety by the presence of HSIP clusters.

Bicycle Facility Continuity (Bicycle Facility Presence)

The *bicycle facility continuity* metric examines the length of a bicycle facility (such as a bicycle lane) compared to the roadway segment where the bicycle facility is located.

Level of Traffic Stress

The metric for *level of traffic stress* experienced by bicyclists is based on vehicular travel speeds, vehicular volumes, and the presence of buffers between vehicles and bicyclists. There are various degrees of stress that bicyclists can experience on a roadway segment or corridor, which would determine the recommended experience needed for a bicyclist to traverse through a roadway segment or corridor. Detailed tables that demonstrate the process for calculating level of stress are located in Appendix B.[13]

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[10] Please refer to Appendix A for information about data sources for bicycle performance metrics.

[11] Equivalent Property Damage Only (EDPO) is an index used by MassDOT to rate the safeness of an intersection or corridor. In the EDPO index, crashes resulting in property damage only are given one point, crashes that result in an injury are awarded five points, and crashes that involve a fatality are given ten points each. The EDPO index can monitor vehicles, bicyclists, and pedestrians separately or together.

[12] Casey-Marie Claude, "Development of a Scoring System for Bicycle Travel in the Boston Region," Boston Region MPO, accessed February 15, 2019, https://www.ctps.org/data/pdf/studies/bikeped/bicycle-level-of-service.pdf.

[13] Maaza C. Mekuria Ph.D., P.E., PTOE, Peter G. Furth, Ph.D. and Hilary Nixon, Ph.D., "Low-Stress Bicycling and Network Connectivity," Mineta Transportation Institute, accessed February 15, 2019, https://transweb.sjsu.edu/sites/default/files/1005-low-stress-bicycling-network-connectivity.pdf.

Bicycle Rack Presence

The *bicycle rack presence* metric indicates if a corridor has bicycle parking available nearby. This may include bicycle racks along a street, bicycle racks located near a transit station or bus stop, or bicycle racks that are located on nearby private property where any bicyclist is permitted to park a bike. Racks located at a transit or bus stops give the additional benefit of providing a connection to other modes for travelers.

Proximity to Bike Network

The *proximity to bike network* performance metric evaluates ways that a roadway segment serves as a connection to a bicycle route. Roadway segments within one-quarter mile of a bicycle facility that provide bicycle accommodations that separate bicyclists from mixed traffic are ideal.

6.2 Pedestrian Metrics[14]

Safe Crossing Opportunities/Safe Crosswalks per Mile[15]

The *safe crossing opportunities* performance metric reflects the number of crosswalks that are present along roadway segments. This metric is reported as the number of crosswalks per linear mile.

Safe crossing opportunities per mile = number of safe crosswalks along a roadway segment/length of roadway segment in miles

Sidewalk Presence and Condition

The *sidewalk presence* performance metric indicates whether sidewalks are present along a roadway segment or at an intersection and are in good condition.[16] Sidewalks that are valid for evaluation are those that meet American with Disabilities Act (ADA) standards. This metric is measured by each direction of travel.
Sidewalk presence and condition (calculated for each individual direction of travel) = total length of sidewalks in good condition/total length of roadway

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[14] Please refer to Appendix A for information about data sources for pedestrian performance metrics.

[15] The safe crosswalks metric can also be measured by block as a substitute for miles if desired by evaluators.

[16] Missouri Department of Transportation, "642.1 Sidewalk Design Criteria," Engineering Policy Guide, accessed February 15, 2019, http://epg.modot.org/index.php/642.1_Sidewalk_Design_Criteria.

Pedestrian Crashes

The *pedestrian crashes* performance metric documents areas where pedestrian crashes are common. This performance metric will be assessed based on the EDPO in the corridor. The EDPO score is presented in a per mile basis for the entire corridor.

Vehicle-Pedestrian Buffer

The *vehicle-pedestrian buffer* measures the total distance between vehicular traffic and pedestrian traffic. The vehicle-pedestrian buffer includes any infrastructure that is present between a vehicle travel lane and an adjacent sidewalk or walkway. A buffer helps reduce vehicle-pedestrian traffic incidents, which often result in bodily injuries or fatalities.

6.3 Transit Metrics[17]

Transit Time Index

The *transit time index* compares the average travel time of a transit vehicle to the tenth percentile daily travel time of the daily bus run. This measure can be used to calculate delay along a transit route.

Transit time index = average travel time/tenth percentile daily travel time

Level of Transit Time Reliability

The *level of transit time reliability* metric measures the variation of the travel time for a transit route during a typical weekday. This metric indicates if there is variability or consistency in travel times on a route from day to day. MBTA timepoint crossing summary data will be used to measure this metric.

Level of transit time reliability = 80th percentile travel time for transit vehicle/50th percentile travel time

Person Hours of Delay per Bus Trip

The *person hours of delay per bus trip* metric combines ridership numbers with the travel time delay of transit vehicles. The delay for each run can be multiplied by the average ridership. The hours of delay can be calculated for the peak period, entire day, or entire year.

Person hours of delay = transit vehicle delay * average number of people on transit

[17] Please refer to Appendix A for information about data sources for transit performance metrics.

Vehicle Delay per Bus Run

The *vehicle delay per bus run* metric shows the average vehicle delay per trip for a bus route regardless of service frequency.

Bus run delay = (average travel time for bus run + departure delay time) – free-flow or baseline travel time

Load Factor/Passenger Crowding

Passenger crowding is measured as the ratio of the number of passengers on a vehicle at the maximum load point to the number of seats on the vehicle.

Passenger crowding = number of passengers on the vehicle/number of seats on the vehicle

Safe Crossing Opportunities at Transit Stops

The *safe crossing opportunities at transit stops* metric analyzes the percentage of transit or bus stops in a corridor that have safe crossings nearby.

6.4 Truck Metrics[18]

Truck Travel Time Reliability Index

The *truck travel time reliability index* was introduced by the Federal Highway Administration and is calculated using the National Performance Management Research Dataset. This metric can be used to identify predictable bottlenecks on individual roadway segments. Values on this index are calculated by dividing the 95th percentile travel time by the 50th percentile travel time.

Truck travel time reliability index = 95th percentile travel time/50th percentile travel time

Percentage of Truck Traffic

The *percentage of truck traffic* metric shows the percentage of vehicles on a roadway that are trucks. This performance metric is a useful tool for prioritizing transportation projects. Corridors with a high percentage of truck traffic have different needs from corridors that have little truck traffic. Therefore, if two projects have equal evaluation scores, the project that is located on the corridor that has a higher percentage of trucks may be prioritized higher with respect to freight needs. This metric is not rated as good, average, or poor. Instead, this metric is rated as *low truck traffic, medium truck traffic,* and *high truck traffic*.

[18] Please refer to Appendix A for information about data sources for truck performance metrics.

Buffer Time per Trip/Total Hours of Daily Truck Buffer Time

The *buffer time per trip* and *total hours of daily truck buffer time* metrics indicate the amount of contingency time that freight providers would need to consider to ensure that a truck trip is completed on time 95 percent of the time. These metrics can either be calculated by analyzing an individual truck trip (buffer time per trip) or the total truck trips (total hours of daily truck buffer time) that are made daily. Finding the total daily truck buffer time would require data on daily truck volumes.

Buffer time per trip (minutes) = 95th percentile travel time – average travel time

Total hours of daily truck buffer time (hours) = (95th percentile travel time – average travel time) * truck volumes

6.5 Vehicle Metrics[19]

Duration of Congestion/Congested Time

Congested time is the average number of minutes that drivers experience congested conditions (speeds below 19 miles per hour [mph] on arterials), during a peak period. Congested time is measured in minutes per peak period hour.

Congested time (minutes) = (number of minutes with speeds below 19 mph/total number of minutes in sample) * number of minutes in peak period

Travel Time Index

The *travel time index* compares travel conditions during the peak period to travel conditions during free-flow periods. The *travel time index* is the ratio of peak period time to free-flow time.

Travel time index = average travel time/free-flow travel time

Vehicle-Miles Traveled

Vehicle-miles traveled (VMT) are the total number of miles that every vehicle travels through a roadway segment, corridor, or region within a specified period of time. This metric is becoming a basis for measuring transportation patterns, as evidenced by California Senate Bill 743. Additionally, many transportation departments across the United States are switching from LOS-based metrics to VMT-based metrics. The reason for this change is that it is desirable to determine if a proposed project will result in an increase in VMT in the surrounding area.

[19] Please refer to Appendix A for information about data sources for vehicle performance metrics.

Vehicle-miles traveled = segment length X vehicle volumes

Average Vehicle Delay per Mile

The *average vehicle delay per mile* metric shows the amount of delay that a vehicle would experience when traveling through a corridor at a designated time.

Average vehicle delay per mile (seconds) = (average travel time for monitoring period – free-flow or baseline travel time)/length of corridor

6.6 Multimodal Metrics[20]

Roadway Lane Density

Roadway lanes are most effective when the throughput of people is maximized. Data for the *roadway lane density* metric will be based on observations of travelers passing through a corridor during a specified period of time. The type of vehicles, vehicle volumes, and vehicle occupancies will be recorded. Reducing the percentage of single-occupancy vehicles and increasing the percentage of vehicles that have high occupancies, such as buses, would help increase roadway lane density. Bicyclists and pedestrians are not included in this metric.

Roadway lane density = (vehicle volumes for one hour period * occupancy counts for one hour period)/number of lanes

Person Throughput

Person throughput is a time-based metric that indicates the number of people attempting to enter a segment or corridor during a specified monitoring period. All parallel transportation facilities, including sidewalks and bicycle lanes, are included in this metric. This metric reflects the number of people who travel in a corridor by walking, biking, taking the bus, and driving in an automobile. A higher person throughput indicates that a transportation facility is moving more people during a specified time. The thresholds for this metric can vary depending on the evaluator’s choice (rural versus urban standards, for example).

Peak hour person throughput = vehicle, bicycle, and pedestrian volumes for one-hour period * occupancy counts for one-hour period

[20] Please refer to Appendix A for information about data sources for multimodal performance metrics.

7 CORRIDOR SELECTION FOR METRICS TESTING

Only arterial corridors monitored on the CMP network and identified as an LRTP priority corridor or a subregional priority roadway were considered for evaluating the potential metrics for calibration. The two corridors selected for the testing were as follows:

- Route 16 in Medford between the Mystic River and the Everett city line
- Route 9 in Brookline between the Newton city line and Washington Street

These corridors are between one and five miles long, which is a corridor length that can accommodate travelers of all modes. The selection process ruled out corridors where projects funded through the MPO's Transportation Improvement Program (TIP) have recently occurred and corridors where construction is currently underway. Oftentimes, construction activities distort performance monitoring for all modes.

8 PERFORMANCE METRICS TEST AND CALIBRATION

8.1 Procedure

The actual conditions on the two corridors were analyzed for the AM peak period (6:30 AM to 9:30 AM) to determine the thresholds that should be applied to the performance metrics. Additionally, MPO staff surveyed AM peak hour (8:00 AM to 9:00 AM) conditions on-site. Performance metrics were rated based on the data collected at the corridor and from various sources. The performance metrics for each corridor ranked as excellent, average, or poor, based on the actual values of the performance metrics versus the thresholds.

The thresholds for most metrics were set based on how they were used in previous programs, such as the CMP, bicycle and pedestrian activities, and studies done by other organizations. The thresholds for new metrics were determined by staff judgements that were based on evaluations from the test runs compared to the observation of real-time conditions. These thresholds are deemed tentative and are subject to change based on further input. Additionally, evaluators can change the thresholds to cater to their study, if desired. Table 4 presents the thresholds for each individual performance metric and the source of the thresholds. Please see Table A.1 in Appendix A for the threshold sources for each individual metric.

Table 4
Thresholds for Performance Metrics

Mode	Performance Metric	Good	Average	Poor
Bicycle	Bicycle EDPO per mile	Less than 4	4 to 6	6 or higher
Bicycle	Bicycle facility continuity (bicycle facility presence)	Facility matches corridor length	Facility is shorter than corridor	No facility
Bicycle	Level of traffic stress (LTS)	LTS 1	LTS 2 or 3	LTS 4
Bicycle	Bicycle rack presence and utilization	Utilization is less than 50 percent	Utilization is 50 to 70 percent	No bicycle spaces or utilization is more than 70 percent
Bicycle	Proximity to bike network	Yes	Partially	No
Pedestrians	Safe crossing opportunities/Safe crosswalks per mile	More than 7 per mile	5 to 7 per mile	Fewer than 5 per mile
Pedestrians	Sidewalk presence and condition	Sidewalks are present on both sides of the street and in good condition	Sidewalks are present on one side of the street	No sidewalk facilities
Pedestrians	Pedestrian EDPO per mile	Less than 5	5 to 10	10 or higher
Pedestrians	Vehicle-pedestrian buffer	More than 10 feet	5 to 10 feet	Less than 5 feet
Transit	Transit time index	Less than 1.30	1.30 to 2.00	More than 2.00
Transit	Level of transit time reliability	Less than 1.30	1.30 to 1.50	More than 1.50
Transit	Person hours of delay per bus trip	Less than 1 hour	1 to 2 hours	More than 2 hours
Transit	Vehicle delay per mile per bus run	Less than 30 seconds	30 to 60 seconds	More than 60 seconds
Transit	Load factor/passenger crowding	Less than 0.90	0.90 to 1.40	More than 1.40

Mode	**Performance Metric**	**Good**	**Average**	**Poor**
Transit	Safe crossings at transit stops	More than 75 percent of transit stops	50 to 75 percent	Less than 50 percent
Trucks	Truck travel time reliability index	Less than 1.30	1.30 to 1.50	More than 1.50
Trucks	Percentage of truck traffic	N/A	N/A	N/A
Trucks	Buffer time per trip per mile	Less than 2 minutes per mile	2 to 5 minutes per mile	More than 5 minutes per mile
Trucks	AM total hours of daily truck buffer time	Less than 25 hours	25 to 60 hours	More than 60 hours
Vehicles	Duration of congestion/congested time	Less than 15 minutes	15 to 30 minutes	More than 30 minutes
Vehicles	Travel time index	Less than 1.30	1.30 to 2.00	More than 2.00
Vehicles	Vehicle-miles traveled	Less than 20,000 miles	20,000 to 30,000 miles	More than 30,000 miles
Vehicles	Average vehicle delay per mile	Less than 60 seconds	60 to 90 seconds	More than 90 seconds
Multimodal	Peak hour roadway lane density	More than 800 people	600 to 800 people	Fewer than 600 people
Multimodal	Peak hour person throughput	More than 2,200 people	1400 to 2,200 people	Fewer than 1,400 people

Note: The *percentage of truck traffic* performance metric is not rated on this scale. This metric is rated as *low truck traffic* for corridors with less than four percent truck traffic, *medium truck traffic* for corridors with four percent to six percent truck traffic, and *high truck traffic* for corridors with more than six percent truck traffic.

EPDO=Equivalent Property Damage Only Index. N/A= not applicable.

Source: Central Transportation Planning Staff.

8.2 Evaluation Results

Travel lanes for both directions on Route 9 (in Brookline between the Newton city line and Washington Street) and Route 16 (in Medford between the Mystic River and the Everett city line) were evaluated during the AM period of 6:30 AM to 9:30 AM and during the peak hour of 8:00 AM to 9:00 AM on-site to determine how efficiently travelers moved through the corridor using various modes of transportation. Table 5 shows the performance metric values for these sections of Route 9 and Route 16. Table 5 also shows the performance metric ratings, which indicate mobility on the corridors.

Route 9

Travel on both directions of Route 9 is not very suitable for bicyclists or pedestrians. On Route 9 eastbound, however, the bike path surrounding the Brookline Reservoir provides a partial bicycle and pedestrian connection. Transit on Route 9 rates well on comfort-based performance metrics but poorly on mobility-based measures, indicating that transit riders may experience delays in this corridor. There is a moderate percentage of truck traffic, but truckers require a significant buffer time to travel this corridor. Travelers in personal vehicles experience significant delays in both directions, as evidenced by congested time, travel time index and vehicle delay. Person throughput is typical for a multimodal corridor.

Route 16

There are facilities and connections to trails for bicyclists on Route 16, but bicyclists experience a high level of stress because they must share the roadway with vehicular traffic. This corridor is also not pedestrian friendly, as there are safety and comfort concerns. Buses on Route 16 eastbound experience significant delays during the peak periods. There is significant truck traffic on Route 16, and truckers need to budget significant amounts of buffer time when traveling this route. There is a moderate amount of vehicular delay on Route 16 during the AM peak period. Person throughput is high on Route 16 as there are several buses that travel through this corridor, which leads to Wellington Station.

Table 5
Performance Metrics Data
Route 9 in Brookline between Newton City Line and Washington Street and Route 16 in Medford between the Mystic River and Everett City Line

Performance Metric	Route 9 Eastbound	Route 9 Westbound	Route 16 Eastbound	Route 16 Westbound
Bicycle EDPO per mile	7.85 (poor)	7.85 (poor)	4.61 (average)	4.61 (average)
Bicycle facility continuity	40% (average)	0% (poor)	31% (average)	31% (average)
Level of traffic stress (LTS)	LTS 4 (poor)	LTS 4 (poor)	LTS 4 (poor)	LTS 4 (poor)
Bicycle rack presence and utilization	15% (good)	15% (good)	20.50% (good)	20.50% (good)
Proximity to bike network	partial connection (average)	no connection (poor)	full connection (good)	full connection (good)
Safe crosswalks per mile	5 (average)	5 (average)	2.3 (poor)	2.3 (poor)
Sidewalk presence and condition	100% coverage, fair condition (average)	90% coverage, fair condition (average)	95% coverage, good condition (average)	95% coverage, good condition (average)
Pedestrian EDPO per mile	8.21 (poor)	8.21 (poor)	39.23 (poor)	39.23 (poor)
Vehicle-pedestrian buffer	1 feet (poor)	6 feet (average)	0.5 feet (poor)	0.5 feet (poor)
Transit time index	1.27 (good)	1.35 (average)	1.66 (average)	1.45 (average)
Level of transit time reliability	1.17 (good)	1.18 (good)	1.17 (good)	1.12 (good)
Person hours of delay per bus trip	4.03 (poor)	0.49 (good)	1.88 (average)	0.61 (good)
Vehicle delay per mile per bus run	99.64 (poor)	42.86 (average)	39.35 (average)	28.55 (average)
Load factor	0.33 (good)	0.21 (good)	0.31 (good)	0.15 (good)
Safe crossings at transit stops	55% (average)	55% (average)	100% (good)	100% (good)
Truck travel time reliability index	2.45 (poor)	2.38 (poor)	3.34 (poor)	2.73 (poor)
Percentage of truck traffic	4.90% (medium truck traffic)	3.95% (low truck traffic)	6.60% (high truck traffic)	6.60% (high truck traffic)

Performance Metric	Route 9 Eastbound	Route 9 Westbound	Route 16 Eastbound	Route 16 Westbound
Buffer time per trip per mile (minutes)	8.21 (poor)	4.75 (poor)	7.60 (poor)	8.15 (poor)
AM total hours of daily truck buffer time	63.25 (poor)	34.55 (average)	60.76 (poor)	69.36 (poor)
Duration of congestion (minutes per hour)	35.04 (poor)	23.15 (average)	21.00 (average)	12.60 (good)
Travel time index	2.59 (poor)	2.01 (poor)	1.59 (average)	1.61 (average)
Vehicle-miles traveled (daily)	39,200 (poor)	45,885 (poor)	29,998 (average)	32,045 (poor)
Average vehicle delay per mile (minutes)	2.46 (poor)	1.33 (average)	1.02 (average)	0.82 (good)
Peak hour roadway lane density	716 (average)	826 (good)	778 (average)	790 (average)
Peak hour person throughput	1,431(poor)	1,651 (poor)	2,332 (average)	2,368 (average)

Blue = Good
Black = Average (and *low, medium,* or *high truck traffic*)
Red = Poor

EPDO=Equivalent Property Damage Only.
Source=Central Transportation Planning Staff.

9 STUDY FINDINGS

9.1 Findings

A good multimodal monitoring program should include multiple performance metrics. It is best to use four to six performance metrics to measure each mode. This allows for an evaluation of both comfort and mobility factors for each mode operating in a corridor. Each individual metric should be scored separately to identify specific deficiencies within a corridor and to determine strategies to better accommodate multimodal travel. Additionally, even though metrics such as *intermodal connectivity* and *viability of weather* were recommended from survey respondents, certain metrics were not used for this study while elements of those metrics were incorporated into other selected metrics.

Lane density and *person throughput* are very important metrics for factoring vehicle occupancies for different modes. These measures penalize corridors that have a high number of single-occupancy vehicles. It is very important to increase the number of people traveling through a corridor without increasing the number of vehicles. In addition to mobility, traveler comfort is very important to monitor, especially with regard to pedestrians, bicyclists, and transit riders. If traveler comfort is poor for pedestrians and bicyclists, new travelers many not be attracted to these modes and there could be an increase in single-occupant vehicle travel.

Obtaining real-time data on-site is more useful for multimodal performance monitoring than modeling data. Modeled data is problematic because it focuses on volume versus capacity rather than on the movement of people. Also, traveler comfort is often not monitored with modeled data.

9.2 Recommendations

Though not required, MPO staff recommend that the Boston Region MPO use the multimodal performance monitoring criteria presented in this memorandum for assisting with various studies. These criteria can be used in corridor studies and CMP activities, and some criteria can also be considered for use in the LRTP and the TIP. The use of the selected performance metrics would help fulfill the MPO’s goals of improving safety, capacity management and mobility, and preservation of the transportation network in the Boston region. They would also be excellent tools for communities to use to rate their transportation facilities and would help public officials prioritize and secure funding for transportation projects that facilitate the movement of people rather than the movement of vehicles.

9.3 Next Steps

The next step is to refine the performance measures based on feedback from stakeholders. In addition, the evaluation criteria will need to be promoted through outreach to regional planners, engineers, and the public, so that these stakeholders can consider incorporating this tool into their planning processes, if desired. The criteria that are derived from this study will be used in some upcoming Boston MPO corridor studies. Also, the MPO should analyze this process to determine if the evaluation process is suitable for other MPO practices and planning efforts, such as the CMP, LRTP, and the TIP.

RH/rh

APPENDICES

APPENDIX A

DETAILED INFORMATION FOR MULTIMODAL METRICS

Table A.1
Detailed Information for Multimodal Metrics

Mode	Performance Measure	Definition/Description	Required Data	Data Sources/Dataset Provider	Thresholds	Threshold Source	Type of Multimodal Transportation Goal Performance Measure Assesses
Bicycle	Bicycle Equivalent Property Damage Only (EDPO) per Mile	This performance metric analyzes the safeness of a corridor, based on the presence of crashes near a corridor. The Massachusetts state crash database is used to determine the locations and prevalence of bicycle crashes. Bicycle crashes will be assessed based on the bicycle EDPO score in the corridor. The EDPO score is presented on a per-mile basis for the entire corridor. This metric is different from the Absence of Bicycle Crash metric that was presented in the bicycle level of service study, which rates bicycle safety by the presence of Highway Safety Improvement Program (HSIP) clusters.	Number of bicycle crashes Severity of bicycle crashes Corridor Length	MassDOT crash database	*Good* - Less than four per mile *Average* - Four to six per mile *Poor* - Six or higher per mile	Development of a Scoring System for Bicycle Travel in the Boston Region[1] (modified to use EDPO)–Boston Region MPO	Safety
Bicycle	Bicycle Facility Continuity (Bicycle Facility Presence)	The Bicycle Facility Continuity metric examines the length of a bicycle facility (such as a bicycle lane) compared to the roadway segment where the bicycle facility is located.	Corridor length Length of bicycle facility	Aerial imagery	*Good* - Bicycle facility matches corridor length *Average* - Facility is shorter than corridor *Poor* - No facility is present in the corridor	Development of a Scoring System for Bicycle Travel in the Boston Region –Boston Region MPO	Capacity Management and Mobility
Bicycle	Level of Traffic Stress	The Level of Traffic Stress (LTS) experienced by bicyclists is based on vehicular travel speeds, vehicular volumes, and the presence of buffers between vehicles and bicyclists. Distinct levels of stress that are present on a roadway segment or corridor, which would determine the recommended experience needed for a bicyclist to traverse through a roadway segment or corridor. A modified version of the LTS from the Mineta Low-Stress Bicycling and Network Connectivity Study will represent the LTS for this study. Bicycle lane blockage will not be included due to data availability. The factors that will be used for LTS are: • Type of bicycle facility/mixed traffic • Number of vehicle travel lanes • Presence of street parking • Bike lane width or sum of bike lane width and parking lane width • Speed limit or vehicle speeds LTS evaluation tables are present in Appendix B: If there is a bike lane present alongside a parking lane, refer to table B.1. If there is a bike lane but no parking lane present, refer to table B.2. If there is a pocket bike lane present, refer to table B.3. If there is no bike lane and no right turn lane, refer to table B.4. If there is no bike lane and but there is a right turn lane, refer to table B.5.	Number of travel lanes (for mixed traffic or regular bike lane) Roadway speed limit (for mixed traffic or regular bike lane) Bike lane width (not alongside parking lane) Sum of bike width and parking lane width (alongside parking lane)	MassDOT roadway inventory Aerial imagery Field collection	*Good* - LTS 1 *Average* - LTS 2 or 3 *Poor* - LTS 4	Low-Stress Bicycling and Network Connectivity - Mineta Transportation Institute[2]	Safety
Bicycle	Bicycle Rack Presence and Utilization	This metric indicates if a corridor has bicycle parking nearby. This may include bicycle racks along a street, bicycle racks located near a transit station or bus stop, or bicycle racks located on nearby private property in which any bicyclist is permitted to park their bike. Bicycle racks should be available every quarter-mile of a corridor. For a bicycle rack to count towards this metric, it should be safe, visible, and have spaces available during the time of observation. Racks located at a transit or bus stop have the additional benefit of providing a connection of multiple modes for travelers. This metric shows the ratio of bicycles parked per mile to bicycle spaces per mile.	Number of bicycle spaces along corridor Number of bicycles parked along corridor Corridor length	Boston MPO Bicycle Rack Survey Field collection	*Good* - Utilization is less than 50 percent *Average* - Utilization is 50 to 70 percent *Poor* - No bicycle spaces or utilization is more than 70 percent	CMP Monitoring – Boston Region MPO/Evaluation Results	Capacity Management and Mobility

[1] Casey-Marie Claude, “Development of a Scoring System for Bicycle Travel in the Boston Region,” Boston Region Metropolitan Planning Organization, accessed February 15, 2019, https://www.ctps.org/data/pdf/studies/bikeped/bicycle-level-of-service.pdf.

[2] Maaza C. Mekuria Ph.D.,P.E, PTOE, Peter G. Furth, Ph.D., and Hilary Nixon, Ph.D., “Low-Stress Bicycling and Network Connectivity,” Mineta Transportation Institute, accessed February 15, 2019, https://transweb.sjsu.edu/sites/default/files/1005-low-stress-bicycling-network-connectivity.pdf.

Table A.1 (Cont.)
Detailed Information for Multimodal Metrics

Mode	Performance Measure	Definition/Description	Required Data	Data Sources/Dataset Provider	Thresholds	Threshold Source	Type of Multimodal Transportation Goal Performance Measure Assesses
Bicycle	Proximity to Bike Network	The Proximity to Bike Network performance metric considers how a roadway segment serves as a connection along a bicycle route. This addresses one Capacity Management and Mobility objective, which calls for creating a connected network of bicycle facilities by expanding existing facilities and closing gaps. Roadway segments within one-quarter mile of a bicycle facility, defined as bicycle accommodations that separate bicyclists from mixed traffic, that have a robust connection to the corridor will be rated as "good."	Presence of any nearby trails Connection to any nearby trails	Aerial imagery	*Good* - Corridor fully connects to a nearby bike trail *Average* - Corridor partially connects to a nearby bike trail *Poor* - Corridor does not connect to a nearby bike trail	Development of a Scoring System for Bicycle Travel in the Boston Region – Boston Region MPO	Capacity Management and Mobility
Pedestrians	Safe crossing opportunities/Safe Crossing Opportunities per Mile	The Safe Crossing Opportunities performance metric reflects the number of crosswalks that are present alongside roadway segments. A corridor is deemed to have safe crossing opportunities if there are at least seven crosswalks per mile. This metric states the number of safe crossing opportunities per linear mile. For a crossing opportunity to be safe, the following criteria must be met: • There should be a crosswalk or bridge crossing the street. • The crosswalk should not cross any more than two lanes at a time unless there is a pedestrian indication present. • If the roadway speeds are more than 30 miles per hour (mph), then the crossing should be protected for pedestrians, either with an exclusive phase or an extended phase, to allow sufficient time to cross the roadway. *Safe Crossing Opportunities per Mile = number of safe crosswalks along a roadway segment/length of roadway segment in miles*	Number of safe crossing opportunities Corridor length Pedestrian phase for locations with roadway speeds higher than 30 mph	Aerial imagery Field collection Functional design reports	*Good* - More than 7 safe crossings per mile *Average* - between 5 to 7 safe crossings per mile *Poor* - Less than 5 safe crossings per mile	Pedestrian Level-of-Service Memorandum - Boston Region MPO[3]	Safety
Pedestrians	Sidewalk Presence and Condition	The Sidewalk Presence and Condition performance metric indicates whether sidewalks are present along a roadway segment and are in good condition. For the sidewalk coverage to be valid, the sidewalk must meet the American with Disabilities Act (ADA) standards, as stated below: • Sidewalk width must be at least 5 feet wide. • Sidewalks must have a slope of less than 1:20. • Curb cuts are required on sidewalks that cross a curb. • The sidewalk must remain at least three feet wide when passing an obstruction, such as light poles, trees, or other infrastructure. • A cross slope must be between 1.0 percent to 2.0 percent. • A clear space of 80 inches must be maintained above the sidewalk. • Additionally, the sidewalks must be in generally good condition, as determined by the surveyor's discretion. *Sidewalk Presence and Condition (calculate for each individual direction of travel) = total length of sidewalks in good condition/total length of roadway*	Length of sidewalk facilities that meet minimum ADA standards Corridor length	MassDOT roadway inventory Field collection	*Good* - Sidewalks are present on both sides of the street and in good condition *Average* - Sidewalks are present on one side of the street *Poor* – No sidewalk facilities	Pedestrian Level-of-Service Memorandum - Boston Region MPO	System Preservation/ Capacity Management and Mobility
Pedestrians	Pedestrian Equivalent Property Damage Only (EDPO) per Mile	The Pedestrian EPDO performance metric documents areas where pedestrian crashes are common. This performance metric is presented based on the EDPO in the corridor. The EDPO score is presented on a per-mile basis for the entire corridor.	Number of pedestrian crashes Severity of pedestrian crashes Corridor length	MassDOT crash database	*Good* - Less than five per mile *Average* - Five to ten per mile *Poor* - Ten or more per mile	Pedestrian Level-of-Service Memorandum - (modified to use EDPO)–Boston Region MPO	Safety

[3] Ryan Hicks and Casey Marie- Claude, "Pedestrian Level of Service Memorandum," Boston Region Metropolitan Organization, accessed February 15, 2019, https://www.ctps.org/data/pdf/studies/bikeped/pedestrian_level_of_service.pdf.

Table A.1 (Cont.)
Detailed Information for Multimodal Metrics

Mode	Performance Measure	Definition/Description	Required Data	Data Sources/Dataset Provider	Thresholds	Threshold Source	Type of Multimodal Transportation Goal Performance Measure Assesses
Pedestrians	Vehicle-Pedestrian Buffer	The Vehicle-Pedestrian Buffer measures the total distance between vehicular traffic and pedestrian traffic. The vehicle-pedestrian buffer includes any infrastructure that is present between a vehicle travel lane and an adjacent sidewalk or walkway. This includes, but is not limited to, marked roadway shoulders, bicycle lanes, pedestrian furniture, vehicle parking, grass strips, and vegetation. A buffer is good for reducing vehicle-pedestrian traffic incidents, which often result in injuries or fatalities.	Distance between vehicle travel lanes and sidewalks or pedestrian walkways	Aerial imagery	*Good* - More than ten feet of buffer *Average* - Five feet to ten feet of buffer *Poor* - Less than five feet of buffer	Pedestrian Level-of-Service Memorandum - Boston Region MPO	Safety
Transit	Transit Time Index	The Transit Time Index compares the average travel time of a transit vehicle to the tenth percentile daily travel time of the daily bus run. This measure is used to calculate delay along a transit route. Routes that have a Transit Time Index value greater than 1.3 shows congestion. *Transit Time Index = average travel time/tenth percentile daily travel time*	Travel times from MBTA Timepoint dataset	MBTA Timepoint dataset	*Good* - Less than 1.30 Transit Time Index *Average* - 1.30 to 2.00 Transit Time Index *Poor* - More than 2.00 Transit Time Index	CMP Monitoring – Boston Region MPO	Capacity Management and Mobility
Transit	Level of Transit Time Reliability	Level of Transit Time Reliability measures the variation of the travel time for a transit route during a typical weekday. This metric indicates if there is variability or consistency in travel times on a route from day to day. A transit route that has a Level of Transit Time Reliability of more than 1.5 is unreliable. MBTA crossing summary data will be used to measure this metric. *Level of Transit Time Reliability= 80th percentile travel time for transit vehicle/50th percentile travel time*	Travel times from MBTA Timepoint dataset	MBTA Timepoint dataset	*Good* - Less than 1.30 Level of Transit Time Reliability *Average* - 1.30 to 1.50 Level of Transit Time Reliability *Poor* - More than 1.50 Level of Transit Time Reliability	Evaluation results	Capacity Management and Mobility
Transit	Person Hours of Delay per Bus Trip	This metric combines ridership numbers with the travel time delay of transit vehicles. The delay for each run is multiplied by the average ridership. The results represent the peak period, the entire day, or the entire year. *Person Hours of Delay = transit vehicle delay * average number of people on transit*	Travel times from MBTA Timepoint dataset Automatic Passenger Count (APC) data	MBTA Timepoint dataset MBTA APC data	*Good* - Less than one hour *Average* - One to two hours *Poor* - More than two hours	CMP Monitoring – Boston Region MPO	Capacity Management and Mobility
Transit	Vehicle Delay per Mile per Bus Run	This performance metric shows the average vehicle delay per trip for a bus route regardless of service frequency. *Bus Run Delay = (average travel time for bus run + departure delay time) – free-flow or baseline travel time*	Travel times from MBTA Timepoint dataset Departure time delay from MBTA Timepoint dataset	MBTA Timepoint dataset	*Good* - Less than 30 seconds per mile *Average* - 30 to 60 seconds per mile *Poor* - More than 60 seconds per mile	CMP Monitoring – Boston Region MPO	Capacity Management and Mobility
Transit	Load Factor/Passenger Crowding	Passenger Crowding is measured as the ratio of the number of passengers on a vehicle to the number of seats on a bus. The comfort load point is 0.90, which indicates that all riders can easily find a seat. The maximum load point is 1.40, which indicates that all riders are experiencing an uncomfortable ride. *Passenger Crowding = number of passengers on a bus/number of seats on a bus*	Automatic Passenger Count (APC) data Number of seats on a bus	MBTA APC data	*Good* - Less than 0.90 *Average* - 0.90 to 1.40 *Poor* - More than 1.40	MBTA/CMP Monitoring – Boston Region MPO	Capacity Management and Mobility

Table A.1 (Cont.)
Detailed Information for Multimodal Metrics

Mode	Performance Measure	Definition/Description	Required Data	Data Sources/Dataset Provider	Thresholds	Threshold Source	Type of Multimodal Transportation Goal Performance Measure Assesses
Transit	Safe Crossings at Opportunities Transit Stops	This performance metric analyzes the percentage of transit or bus stops in a corridor that have safe crossings nearby. Ideally, 75 percent of transit or bus stops should have safe crossings leading to the boarding location. This metric may only include transit or bus stops that have a certain amount of boardings and alightings. The definition of a safe crossing at a transit stop is as follows: • There should be a crosswalk or bridge that crosses the roadway leading to the station or stop. • The crosswalk should not cross any more than two lanes at a time unless there is a pedestrian signal present. • If the roadway speeds are more than 30 mph, the crossing should be protected for pedestrians, either with an exclusive phase or an extended phase, to allow sufficient time to cross the roadway.	Number of transit stops Number of transit stops that have safe crossings Pedestrian phase for locations with roadway speeds higher than 30 mph	Aerial imagery Field Collection	*Good* - More than 75 percent of transit stops have safe crossings *Average* - 50 percent to 75 percent of transit stops have safe crossings *Poor* - Less than 50 percent of transit stops have safe crossings	Evaluation results	Safety
Trucks	Truck Travel Time Reliability Index	This performance metric is from the Federal Highway Administration and is calculated using the National Performance Management Research Dataset (NPMRDS). This metric identifies predictable bottlenecks on individual roadway segments. Values on this index are calculated by dividing the 95th percentile travel time by the 50th percentile travel time. Any roadway segment that has a Truck Travel Time Reliability Index value of more than 1.50 is unreliable for truck traffic. *Truck Travel Time Reliability Index = 95th percentile travel time/50th percentile travel time*	Truck Travel Times from NPMRDS	NPMRDS	*Good* - Less than 1.30 Truck Travel Time Reliability Index *Average* - 1.30 to 1.50 Truck Travel Time Reliability Index *Poor* - More than 1.50 Truck Travel Time Reliability Index	Federal Highway Administration[4]	Capacity Management and Mobility
Trucks	Percentage of Truck Traffic	This metric shows the percentage of vehicles on a roadway that are trucks. This performance metric is a useful tool for prioritizing transportation projects. Corridors with a high percentage of truck traffic have different needs from corridors that have little truck traffic. Therefore, if two projects have equal evaluation scores, the project that is located in the corridor that has a higher percentage of trucks will be prioritized higher concerning freight. This metric is not rated as good, average, or poor. Instead, this metric is rated as *low truck traffic*, *medium truck traffic*, and *high truck traffic*.	Total number of vehicles traveling through a corridor Number of trucks traveling through a corridor	Functional design reports Field collection	*Low truck traffic* - Less than four percent truck traffic *Medium truck traffic* - Four percent to six percent truck traffic *High truck traffic*- More than six percent truck traffic	Evaluation results	Safety
Trucks	Buffer Time per Trip per Mile	The Buffer Time per Trip per Mile metric indicates the amount of contingency time that freight providers considered to ensure that a truck trip is completed on-time 95 percent of the time. *Buffer Time per Trip (minutes) = 95th percentile travel time - average travel time*	Travel times from NPMRDS Corridor length	NPMRDS Functional design reports Field collection	*Good* - Less than two minutes per mile *Average* - Two to five minutes per mile *Poor* - More than five minutes per mile	Federal Highway Administration (Modified)[5]	Capacity Management and Mobility
Trucks	AM Total Hours of Daily Truck Buffer Time	The Total Hours of Daily Truck Buffer Time metric indicate the total hours of contingency time needed for all daily AM truck traffic. Finding the total daily truck buffer time requires daily truck volumes. *Total Hours of Daily Truck Buffer Time (hours) = (95th percentile travel time – average travel time) * truck volumes*	Travel times from NPMRDS Truck volumes	NPMRDS Functional design reports Field collection	*Good* - Less than 25 hours *Average* - 25 to 60 hours *Poor* - More than 60 total hours	Federal Highway Administration (Modified)	Capacity Management and Mobility

[4] Federal Highway Administration, "Transportation Performance Management," accessed February 15, 2019, https://www.fhwa.dot.gov/tpm/rule/pm3/freight.pdf.

[5] Federal Highway Administration, "Travel Time Reliability: Making it There on Time, All the Time," accessed February 15, 2019, https://ops.fhwa.dot.gov/publications/tt_reliability/TTR_Report.htm.

Table A.1 (Cont.)
Detailed Information for Multimodal Metrics

Mode	Performance Measure	Definition/Description	Required Data	Data Sources/Dataset Provider	Thresholds	Threshold Source	Type of Multimodal Transportation Goal Performance Measure Assesses
Vehicles	Duration of Congestion/ Congested Time	Congested Time is the average number of minutes that drivers experience congested conditions (speeds below 19 mph on arterials), during a peak period. Congested Time is measured in minutes per peak period hour. *Congested Time (in minutes) = (number of minutes with speeds below 19 mph/total number of minutes in sample) * number of minutes in peak period*	Number of total data samples used Number of data samples that are indicated to be congested	INRIX	*Good* - Less than 15 minutes *Average* - 15 to 30 minutes *Poor* - More than 30 minutes	CMP Monitoring – Boston Region MPO	Capacity Management and Mobility
Vehicles	Travel Time Index	Travel Time Index compares travel conditions during the peak period to travel conditions during free-flow periods. Travel Time Index is the ratio of peak period time to free-flow time. For example, a Travel Time Index of 1.20 indicates a trip that takes 20 minutes in the off-peak period will take 24 minutes in the peak period, 20 percent longer. *Travel Time Index = average travel time/free-flow travel time*	Travel times from INRIX dataset	INRIX	*Good* - Less than 1.30 *Average* - 1.30 to 2.00 *Poor* - More than 2.00	CMP Monitoring – Boston Region MPO	Capacity Management and Mobility
Vehicles	Vehicle-Miles Traveled	Vehicle-Miles Traveled (VMT) is the total number of miles that every vehicle travels through a roadway segment, corridor, or region within a specified period. This metric is becoming a basis for measuring transportation patterns, as evidenced by California Senate Bill 743. Additionally, many transportation departments across the United States are switching from level-of-service-based metrics to VMT-based metrics. The reason for this change is that it is desirable to determine if a proposed project will result in an increase in VMT in the surrounding area. *Vehicle-Miles Traveled = segment length * vehicle volumes*	Corridor length Vehicle volumes	Travel demand model Functional design reports Field collection	*Good* - Less than 20,000 miles *Average* - 20,000 miles to 30,000 miles *Poor* - More than 30,000 miles	Evaluation results	Capacity Management and Mobility
Vehicles	Average Vehicle Delay Per Mile	This performance metric shows the amount of delay that a vehicle would experience by traveling during a specific monitoring time. This indicates the expected delay from traveling through a corridor at a designated time. This metric is stated in delay per mile of travel, to eliminate any bias against longer corridors. *Average Vehicle Delay Per Mile(seconds) = (average travel time for monitoring period – free-flow or baseline travel time)/length of corridor*	Corridor length Travel times from INRIX dataset	INRIX	*Good* - Less than 60 seconds *Average* - 60 seconds to 90 seconds *Poor* - More than 90 seconds	CMP Monitoring – Boston Region MPO	Capacity Management and Mobility
Multimodal	Peak Hour Roadway Lane Density	Roadway lanes are most effective when the throughput of people is maximized. This metric will observe travelers that pass through a corridor for a certain period by observing the type of vehicles, vehicle volumes, and vehicle occupancies. Reducing the percentage of single-occupancy vehicles and increasing the percentage of vehicles that have high occupancies, such as buses, would help increase roadway lane density. Bicyclists and pedestrians are not included in this metric. Required data includes the following: • Vehicle volumes • Occupancy counts • Vehicle classification (automobiles, trucks, buses, etc.) *Roadway Lane Density = (vehicle volumes for one hour period * occupancy counts for one hour period)/number of lanes*	Vehicle volumes Occupancy counts	Functional design reports Field collection	*Good* - More than 800 people *Average* - 600 to 800 people *Poor* - Less than 600 people	Evaluation results	Capacity Management and Mobility

Table A.1 (Cont.)
Detailed Information for Multimodal Metrics

Mode	Performance Measure	Definition/Description	Required Data	Data Sources/Dataset Provider	Thresholds	Threshold Source	Type of Multimodal Transportation Goal Performance Measure Assesses
Multimodal	Peak Hour Person Throughput	This time-based metric indicates the number of people attempting to enter a segment or corridor during a specified monitoring period. All parallel transportation facilities, including sidewalks and bicycle lanes, are included in this metric. This metric includes people who travel in a corridor by walking, biking, bus, and automobile. A higher person throughput indicates that a transportation facility is moving more people during a specified time. The following data is required to measure person throughput: • Automobile volumes • Automobile occupancy • Bus volumes • Number of people on buses • Pedestrian counts • Bicycle counts • Truck volumes Peak Hour Person Throughput = vehicle, bicycle and pedestrian volumes for one hour period * occupancy counts for one hour period	Automobile volumes and occupancies Bus volumes and occupancies Pedestrian volumes Bicycle volumes Truck volumes and occupancies	Functional design reports Field collection	*Good* - More than 2,200 people *Average* – 1,400 to 2,200 people *Poor* - Less than 1,400 people	Evaluation results	Capacity Management and Mobility

APPENDIX B

LEVEL OF TRAFFIC STRESS

Table B.1
Criteria for Bike Lanes Alongside a Parking Lane

Criteria	LTS ≥ 1	LTS ≥ 2	LTS ≥ 3	LTS ≥ 4
Street width (through lanes per direction)	1	(no effect)	2 or more	(no effect)
Sum of bike lane and parking lane width (includes marked buffer and paved gutter)	15 feet or more	14 or 14.5 feet[a]	13.5 feet or less	(no effect)
Speed limit or prevailing speed	25 mph or less	30 mph	35 mph	40 mph or more

[a] If the speed limit is less than 25 mph or the roadway is classified as residential, then any width is acceptable for LTS 2.
LTS = level of traffic stress. mph = miles per hour. (no effect) = factor does not trigger an increase to this level of traffic stress.

Table B.2
Criteria for Bike Lanes Not Alongside a Parking Lane

Criteria	LTS ≥ 1	LTS ≥ 2	LTS ≥ 3	LTS ≥ 4
Street width (through lanes per direction)	1	2, if directions are separated by a raised median	more than 2, or 2 without a separating median	(no effect)
Bike lane width (includes marked buffer and paved gutter)	6 feet or more	5.5 feet or less	(no effect)	(no effect)
Speed limit or prevailing speed	30 mph or less	(no effect)	35 mph	40 mph or more

LTS = level of traffic stress. mph = miles per hour. (no effect) = factor does not trigger an increase to this level of traffic stress.

Table B.3
Level of Traffic Stress Criteria for Pocket Bike Lanes

Configuration	Level of Traffic Stress
Single right-turn lane as long as 150 feet starting abruptly while the bike lane continues straight, and having an intersection angle and curb radius such that turning speed is less than 15 mph	LTS ≥ 2
Single right-turn lane longer than 150 feet starting abruptly while the bike lane continues straight, and having an intersection angle and curb radius such that turning speed is less than 20 mph.	LTS ≥ 3
Single right-turn lane in which the bike lane shifts to the left but the intersection angle and curb radius are such that turning speed is less than 15 mph.	LTS ≥ 3
Single right-turn lane with any other configuration: dual right-turn lanes or right-turn lane along with an option (through-right) lane.	LTS = 4

LTS = level of traffic stress. mph = miles per hour.

Table B.4
Criteria for Level of Traffic Stress in Mixed Traffic

Speed Limit	2-3 lanes	4-5 lanes	6+ lanes
25 mph or less	LTS 1[a] or 2[a]	LTS 3	LTS 4
30 mph	LTS 2[a] or 3[a]	LTS 4	LTS 4
35+ mph	LTS 4	LTS 4	LTS 4

[a] Use lower value for streets without marked centerlines or classified as residential and with fewer than three lanes; use higher value otherwise.

LTS = level of traffic stress. mph = miles per hour.

Table B.5
Level of Traffic Stress Criteria for Mixed Traffic in the Presence of a Right-turn Lane

Configuration	Level of Traffic Stress
Single right-turn lane less than 75 feet long and intersection angle and curb radius limit turning speed to 15 mph	(no effect on LTS)
Single right-turn lane between 75 and 150 feet long and intersection angle and curb radius limit turning speed to 15 mph	LTS ≥ 3
Other configurations	LTS = 4

LTS = level of traffic stress. mph = miles per hour.

APPENDIX C

SAMPLE SURVEY

New and Emerging Metrics for Roadway Usage—Survey

New and Emerging Metrics for Roadway Usage

This survey is being conducted by the Boston Region Metropolitan Planning Organization (MPO) to better evaluate the multimodal transportation network in the Boston region. Your role is valuable in providing input about performance metrics that could be used to determine the mobility of the transportation network at specific locations.

1. **What type of organization do you represent?**

- Municipal Government
- MPO or other regional government organization
- Regional Transit Agency
- Other
- Private transportation provider or Transportation Management Association
- State Department of Transportation

2. **Please rank each mode of transit by importance to multimodal transportation planning? (1= highest rank; 5=lowest rank)**

- Automobiles
- Transit
- Bicycle
- Pedestrian
- Freight

3. **What are the most important attributes for measuring multimodal mobility?**

- Measuring vehicle speeds
- Measuring person throughput
- Ensuring that corridors are suitable for multiple modes
- Measuring modal split

New and Emerging Metrics for Roadway Usage—Survey

Please look over the performance metric definitions provided below. The performance metrics are separated by travel mode. What is your opinion of the definitions provided for each performance metric listed below?

Bicycle Metrics

Pavement Condition:

Pavement condition for roadways are collected through the Highway Performance Monitoring System (HPMS). The HPMS supplies an International Roughness Index (IRI) for most of the National Highway System and arterial roadways. Generally, it is preferred that a roadway segment have an IRI of 95 inches per mile or less to ensure a comfortable ride. (Please note that IRI data coverage may be limited for off road trails).

Bicycle Crashes:

This performance metric analyzes the safeness of a bicycle network, based on the presence of crashes near a segment or corridor. The Massachusetts state crash database is used to determine the locations and prevalence of bicycle crashes.

Bicycle Facility Continuity:

The Bicycle Facility Continuity metric examines the length of a bicycle facility (such as a bicycle lane) compared to the roadway segment where the bicycle facility is located.

Bicycle-Miles Traveled:

Bicycle-Miles Traveled is a travel demand model-based performance metric that observes the number of miles traveled by bicycle on a designated roadway network. This metric is calculated by multiplying the volume of bicycles by the length of a roadway segment.

Bicycle-Miles Traveled = segment length * bicycle volumes

Level of Traffic Stress:

The level of traffic stress experienced by bicyclists is based on vehicular travel speeds, vehicular volumes, and the presence of buffers between vehicles and bicyclists. There are various levels of stress that can be present on a roadway segment or corridor, which would determine the recommended experience needed for a bicyclist to traverse through a roadway segment or corridor.

4. *Bicycle Definitions*

	Understandable and Accurate	Understandable but Inaccurate	Unclear but Accurate	Unclear and Inaccurate
Pavement Condition	○	○	○	○
Bicycle Crashes	○	○	○	○
Bicycle Facility Continuity	○	○	○	○
Bicycle-Miles Traveled	○	○	○	○
Level of Traffic Stress	○	○	○	○

Pedestrian Metrics

Crossing Opportunities/Crosswalks per Mile

The Crossing Opportunities performance metric reflects the number of crosswalks that are present along roadway segments. This metric is reported as the number of crosswalks per linear mile. Crossing opportunities are also measured at intersections by analyzing the presence of crosswalks at each approach.

Crossing Opportunities per Mile = number of crosswalks along a roadway segment/length of roadway segment in miles

Pedestrian Signal Presence:

The Pedestrian Signal Presence performance metric quantifies the characteristics of pedestrian signals. This metric documents whether the pedestrian signals are exclusive or concurrent, if there are *no turn on red* signs, or if there is a Leading Pedestrian Interval at an intersection.

Percent Sufficient Walkway Width:

This metric indicates whether a sidewalk that is located parallel to a roadway is at least five-feet wide.

Percent Sufficient Walkway Width = length of sidewalks (5’+)/total sidewalk length

Sidewalk Presence:

The Sidewalk Presence performance metric indicates whether sidewalks are present along a roadway segment or at an intersection.

Sidewalk Presence = total length of sidewalks/total length of roadway (If measuring sidewalk length on both sides of the roadway, double the roadway length.)

Pedestrian Volumes:

The Pedestrian Volumes performance metric represents the number of pedestrians traveling through a location during a period of time.

5. *Pedestrian Definitions*

	Understandable and Accurate	Understandable but Inaccurate	Unclear but Accurate	Unclear and Inaccurate
Crossing Opportunities	○	○	○	○
Pedestrian Signal Presence	○	○	○	○
Walkway Width	○	○	○	○
Sidewalk Presence	○	○	○	○
Pedestrian Volumes	○	○	○	○

Transit Metrics

On Time Performance:

On Time Performance of transit service is measured at both terminuses of the route and at midpoints. These locations are called time points. If a transit vehicle arrives late to a time point, then the time point is flagged. A transit route is determined not to be on time if less than 60 percent of its time points are reached by the designated time.

Transit Time Index:

The Transit Time Index compares the average travel time of a transit vehicle to the scheduled travel time. This measure can be used to calculate delay along a transit route. Routes that have a Transit Time Index value greater than 1.3 are considered to be congested.

Transit Time Index = average travel time/scheduled travel time

Person Hours of Delay:

This metric combines ridership numbers with the travel time delay of transit vehicles. The delay for each run can be multiplied by the average ridership. The hours of delay can be calculated for the peak period, entire day, or entire year.

Person Hours of Delay = transit vehicle delay * average number of people on transit

Load Factor/Passenger Crowding:

Passenger Crowding is measured as the ratio of the number of passengers on a vehicle at the maximum load point (1.40) to the number of seats on the vehicle.

Passenger Crowding Threshold = maximum load of more than 1.40 passengers per seat

Transit Passenger-Miles Traveled:

Transit-Miles Traveled is a performance metric that observes the number of miles that are traveled by transit on a designated roadway network. This metric is calculated by multiplying the volume of passengers on transit by the length of a roadway segment.

Transit Passenger-Miles Traveled= segment length * transit ridership

6. *Transit Definitions*

	Understandable and Accurate	Understandable but Inaccurate	Unclear but Accurate	Unclear and Inaccurate
On Time Performance	○	○	○	○
Transit Time Index	○	○	○	○
Person hours of delay	○	○	○	○
Load Factor/Passenger Crowding	○	○	○	○
Transit Passenger-Miles Traveled	○	○	○	○

Truck Metrics

Truck Vehicle-Miles of Travel:

This metric can be calculated by using truck volumes. To calculate this metric, the number of trucks are multiplied by the length of a roadway segment.

Truck Vehicle-Miles of Travel = segment length * truck volumes

Curb Radius:

This metric measures the curb radius of each curb at an intersection. A small curb radius ensures that trucks have enough space to execute a right turn without endangering pedestrians.

Truck Travel Time Reliability Index (TTTRI):

This is a performance metric that was introduced by the Federal Highway Administration and is calculated using the National Performance Monitoring Research Dataset. Values on this index are calculated by dividing the 95^{th} percentile travel time by the 50^{th} percentile travel time. Any roadway segment that has a TTTRI value of more than 1.50 is considered to be unreliable.

Truck Travel Time Reliability Index = 95^{th} percentile travel time/50^{th} percentile travel time

Truck Volumes:

This metric indicates the truck annual average daily traffic for a specific roadway segment. Truck volumes can be obtained from various data sources such as the Highway Performance Monitoring System or manual counts.

Buffer Time Index:

The Buffer Time Index measures trip reliability in terms of the amount of extra buffer time needed to arrive on time for 95 percent of the trips taken. Values on this index are calculated by the 95^{th} percentile travel time subtracted by the average travel time, and then divided by the average travel time.

Buffer Time Index = (95^{th} percentile travel time - average travel time)/average travel time

7. *Truck Definitions*

	Understandable and Accurate	Understandable but Inaccurate	Unclear but Accurate	Unclear and Inaccurate
Truck Vehicle-Miles Traveled	○	○	○	○
Curb Radius	○	○	○	○
Truck Travel Time Reliability Index	○	○	○	○
Truck Volumes	○	○	○	○
Buffer Time Index	○	○	○	○

Vehicle Metrics

Average Travel Speed:

Average Travel Speed for vehicles is associated with specific roadway segments and is calculated using travel times and segment lengths. The average travel speed can be measured for various times of the day.

Average Travel Speed (in miles per hour) [mph]) = (segment length/travel time) * 60

Duration of Congestion/Congested Time:

Congested Time is the average number of minutes that drivers experience congested conditions (speeds below 35 mph on expressways, or 19 mph on arterials), during a peak period. Congested Time is measured in minutes per peak period hour.

Congested Time (in minutes) = (number of minutes with speeds below 35 mph/total number of minutes in sample) * number of minutes in peak period

Travel Time Index:

Travel Time Index compares travel conditions during the peak period to travel conditions during free-flow periods. Travel Time Index is the ratio of peak period time to free-flow time. For example, a Travel Time Index of 1.20 indicates a trip that takes 20 minutes in the off-peak period, will take 24 minutes in the peak period, which is 20 percent longer.

Travel Time Index = average travel time/free-flow travel time

Vehicle-Miles of Travel:

Vehicle-Miles of Travel are the total number of miles that every vehicle travels through a roadway segment, corridor, or region within a specified period of time.

Vehicle-Miles of Travel = segment length * vehicle volumes

Volume-to-Capacity Ratio:

This metric indicates the ratio of traffic volume compared to the perceived capacity of a roadway segment. Roadway capacity is determined by the travel demand model.

Volume-to-Capacity Ratio =traffic volume of roadway/capacity of roadway

8. *Vehicle Definitions*

	Understandable and Accurate	Understandable but Inaccurate	Unclear but Accurate	Unclear and Inaccurate
Average Travel Speed	○	○	○	○
Duration of Congestion/Congested time	○	○	○	○
Travel time Index	○	○	○	○
Vehicle-Miles of Travel	○	○	○	○
Volume-to-Capacity Ratio	○	○	○	○

Multimodal Metrics

Travel time per Person:

This metric indicates the average travel time that a person would experience by traveling through a roadway segment or corridor at a specific time, regardless of the mode traveled.

Peak Period Length:

This metric indicates the peak times of the day that people travel through a roadway corridor. This performance metric factors in all people who travel on all modes. The peak period lengths can cover the AM peak, PM peak, off peak, or a combination of these time periods.

Person Throughput:

This metric indicates the number of people present on a segment or corridor at the beginning of the monitoring period, plus the number of people attempting to enter or who successfully entered a segment or corridor during a specified monitoring period. This metric includes people who travel using any mode of transportation.

Funds allocated by Mode:

This metric analyzes the amount of public funds spent on a transportation network, separated out by transportation mode. This metric can be shown numerically or as a percentage of the total amount spent.

9. *Multimodal Definitions*

	Understandable and Accurate	Understandable but Inaccurate	Unclear but Accurate	Unclear and Inaccurate
Travel Time per Person	○	○	○	○
Peak Period Length	○	○	○	○
Person Throughput	○	○	○	○
Funds allocated by Mode	○	○	○	○

New and Emerging Metrics for Roadway Usage—Survey

10. **Please rank each bicycle performance metric based on their significance of being incorporated into multimodal performance monitoring ? (1= highest rank, 5=lowest rank)**

- Pavement Condition
- Bicycle Crashes
- Bicycle Facility Continuity
- Bicycle-Miles Traveled
- Level of Traffic Stress

11. **Please rank each pedestrian performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 5=lowest rank)**

- Crossing Opportunities
- Pedestrian Signal Presence
- Walkway Width
- Sidewalk Presence
- Pedestrian Volumes

12. **Please rank each transit performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 5=lowest rank)**

- On Time Performance
- Transit Time Index
- Person Hours of Delay
- Load Factor/Passenger Crowding
- Transit Passenger-Miles Traveled

13. **Please rank each truck performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 5=lowest rank)**

- Truck Vehicle-Miles Traveled
- Curb Radius
- Truck Travel Time Reliability Index
- Truck Volumes
- Buffer Time Index

14. **Please rank each vehicle performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 5=lowest rank)**

- Average Travel Speed
- Duration of Congestion/Congested Time
- Travel time Index
- Vehicles-Miles Traveled
- Volume-to-Capacity Ratio

15. **Please rank each multimodal performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 3=lowest rank)**

- Travel Time per Person
- Peak Period Length (AM, PM or both)
- Person Throughput
- Funds allocated by Mode

16. **How important do you think it is to ensure good multimodal transportation in areas with the demographic characteristics listed below? Please assign a weight between one and five (1= lowest importance, 5=greatest importance)**

	1	2	3	4	5
Disabled population	○	○	○	○	○
Population over 75 years of age	○	○	○	○	○
Population under 18 years of age	○	○	○	○	○
Commuters who exclusively walk, bike, or take public transit	○	○	○	○	○
Population without access to vehicles	○	○	○	○	○
Residents in environmental justice areas (Low income or minority)	○	○	○	○	○
Residents within a quarter mile of a school or college	○	○	○	○	○

17. **Are there any performance metrics not on this list that should be added? Please elaborate.**

18. **Are there any performance metrics definitions that you would change? Please elaborate.**

19. **Please provide any feedback you would like to share regarding the multimodal performance metrics. Feel free to elaborate on any of the survey questions above.**

APPENDIX D

SURVEY RESULTS

New and Emerging Metrics for Roadway Usage—Survey

Thursday, May 09, 2019

Powered by SurveyMonkey

17

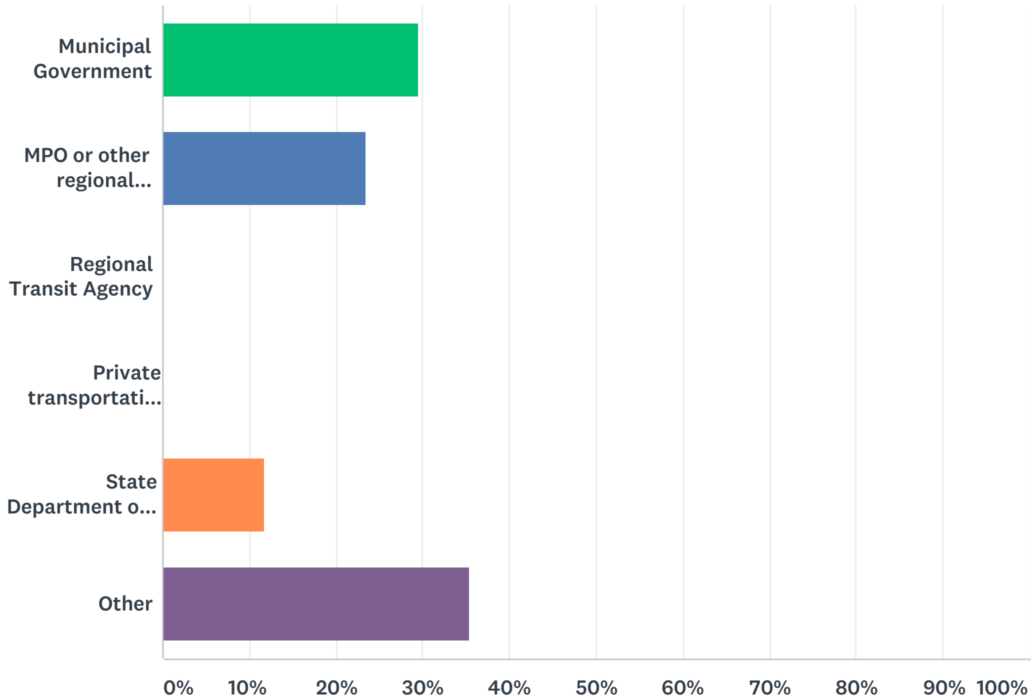
Total Responses

Date Created: Thursday, March 28, 2019

Complete Responses: 10

Q1 What type of organization do you represent?

Answered: 17   Skipped: 0

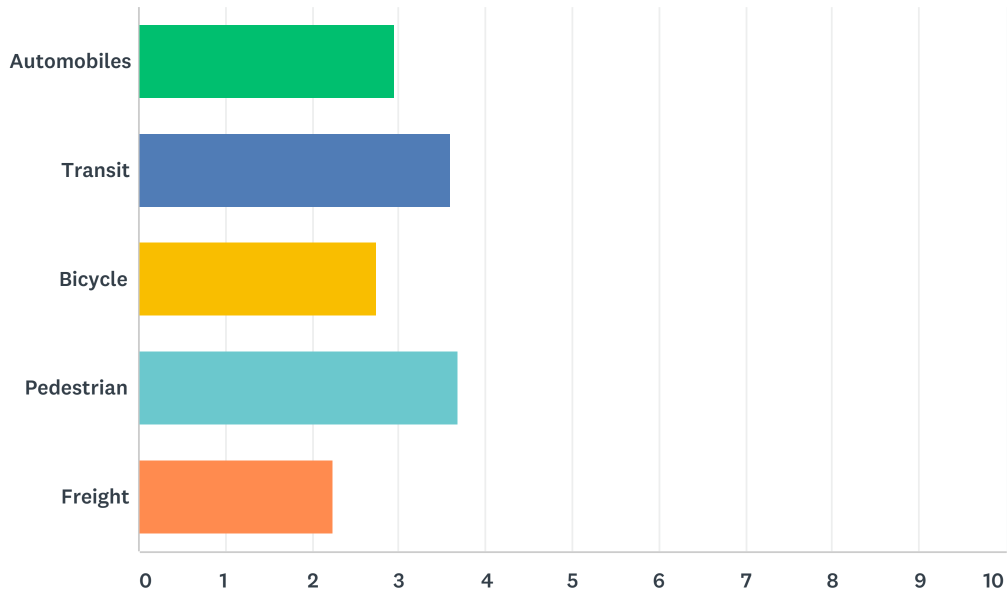


ANSWER CHOICES	RESPONSES	
Municipal Government	29.41%	5
MPO or other regional government organization	23.53%	4
Regional Transit Agency	0.00%	0
Private transportation provider or Transportation Management Association	0.00%	0
State Department of Transportation	11.76%	2
Other	35.29%	6
TOTAL		17

#	OTHER	DATE
1	Non-profit advocact	5/7/2019 1:23 PM
2	Non-profit	4/30/2019 12:24 PM
3	Consultant serving transportation agencies	4/27/2019 8:37 AM
4	State Port Authority	4/26/2019 10:56 AM
5	Transportation Advocacy	4/24/2019 9:08 AM
6	non-profit	4/23/2019 4:42 PM

Q2 Please rank each mode of transportation by importance to multimodal transportation planning? (1= highest rank; 5=lowest rank)

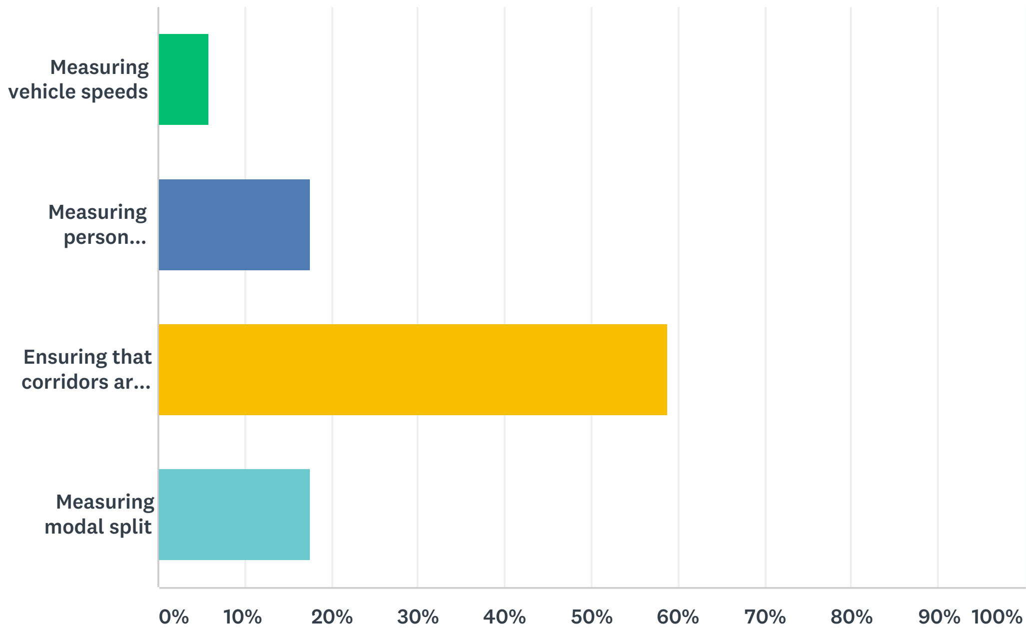
Answered: 17 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Automobiles	37.50% 6	0.00% 0	18.75% 3	6.25% 1	37.50% 6	16	2.94
Transit	29.41% 5	17.65% 3	41.18% 7	5.88% 1	5.88% 1	17	3.59
Bicycle	0.00% 0	37.50% 6	18.75% 3	25.00% 4	18.75% 3	16	2.75
Pedestrian	31.25% 5	31.25% 5	18.75% 3	12.50% 2	6.25% 1	16	3.69
Freight	5.88% 1	17.65% 3	0.00% 0	47.06% 8	29.41% 5	17	2.24

Q3 What are the most important attributes for measuring multimodal mobility?

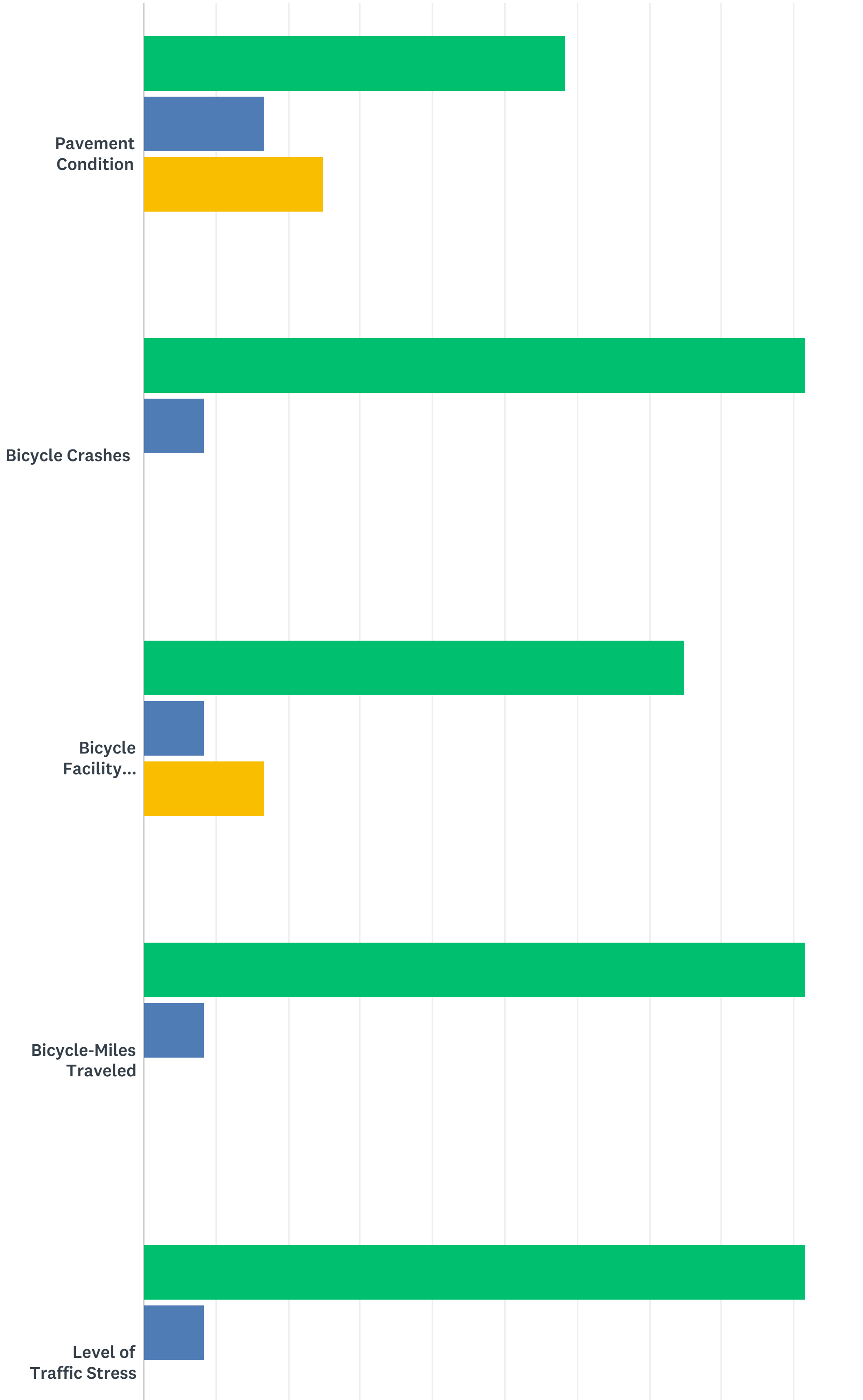
Answered: 17 Skipped: 0

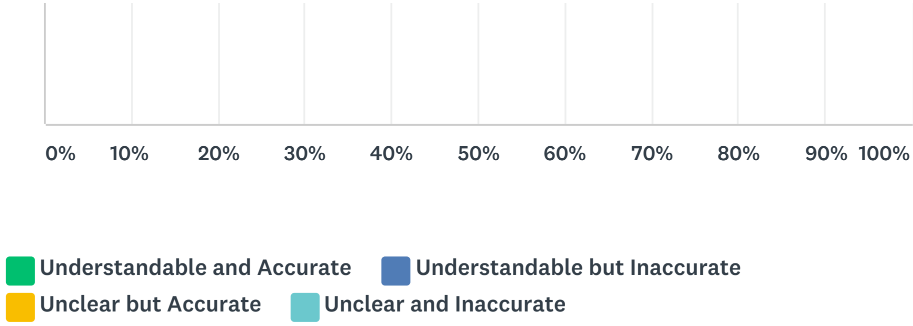


ANSWER CHOICES	RESPONSES	
Measuring vehicle speeds	5.88%	1
Measuring person throughput	17.65%	3
Ensuring that corridors are suitable for multiple modes	58.82%	10
Measuring modal split	17.65%	3
TOTAL		17

Q4 Bicycle Definitions

Answered: 12 Skipped: 5

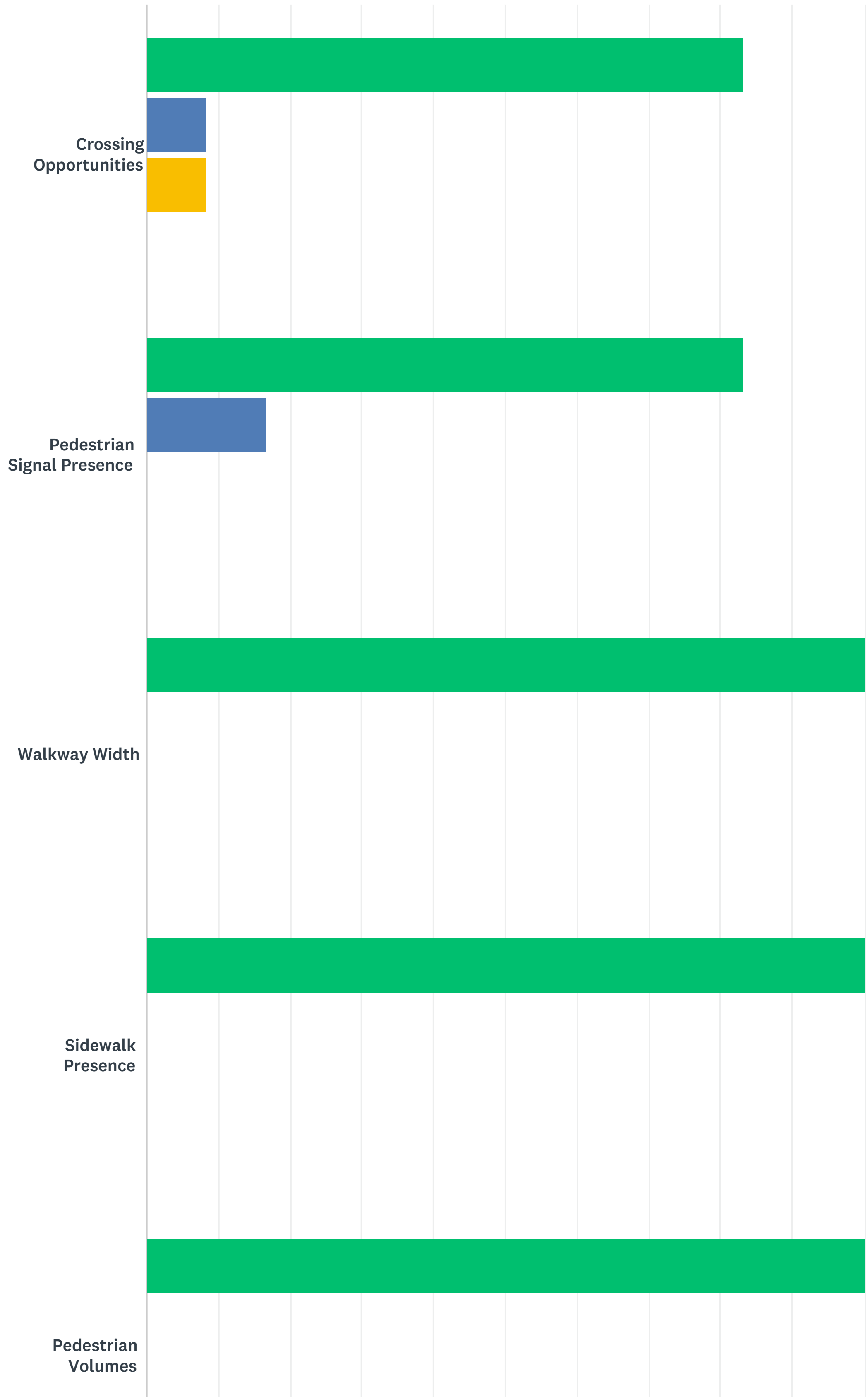


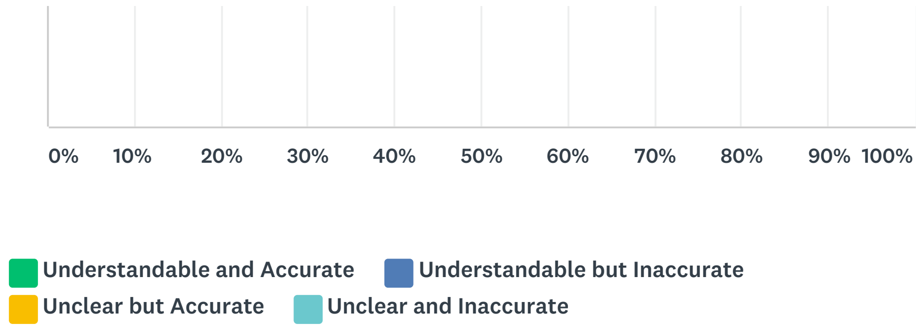


	UNDERSTANDABLE AND ACCURATE	UNDERSTANDABLE BUT INACCURATE	UNCLEAR BUT ACCURATE	UNCLEAR AND INACCURATE	TOTAL
Pavement Condition	58.33% 7	16.67% 2	25.00% 3	0.00% 0	12
Bicycle Crashes	91.67% 11	8.33% 1	0.00% 0	0.00% 0	12
Bicycle Facility Continuity	75.00% 9	8.33% 1	16.67% 2	0.00% 0	12
Bicycle-Miles Traveled	91.67% 11	8.33% 1	0.00% 0	0.00% 0	12
Level of Traffic Stress	91.67% 11	8.33% 1	0.00% 0	0.00% 0	12

Q5 Pedestrian Definitions

Answered: 12 Skipped: 5

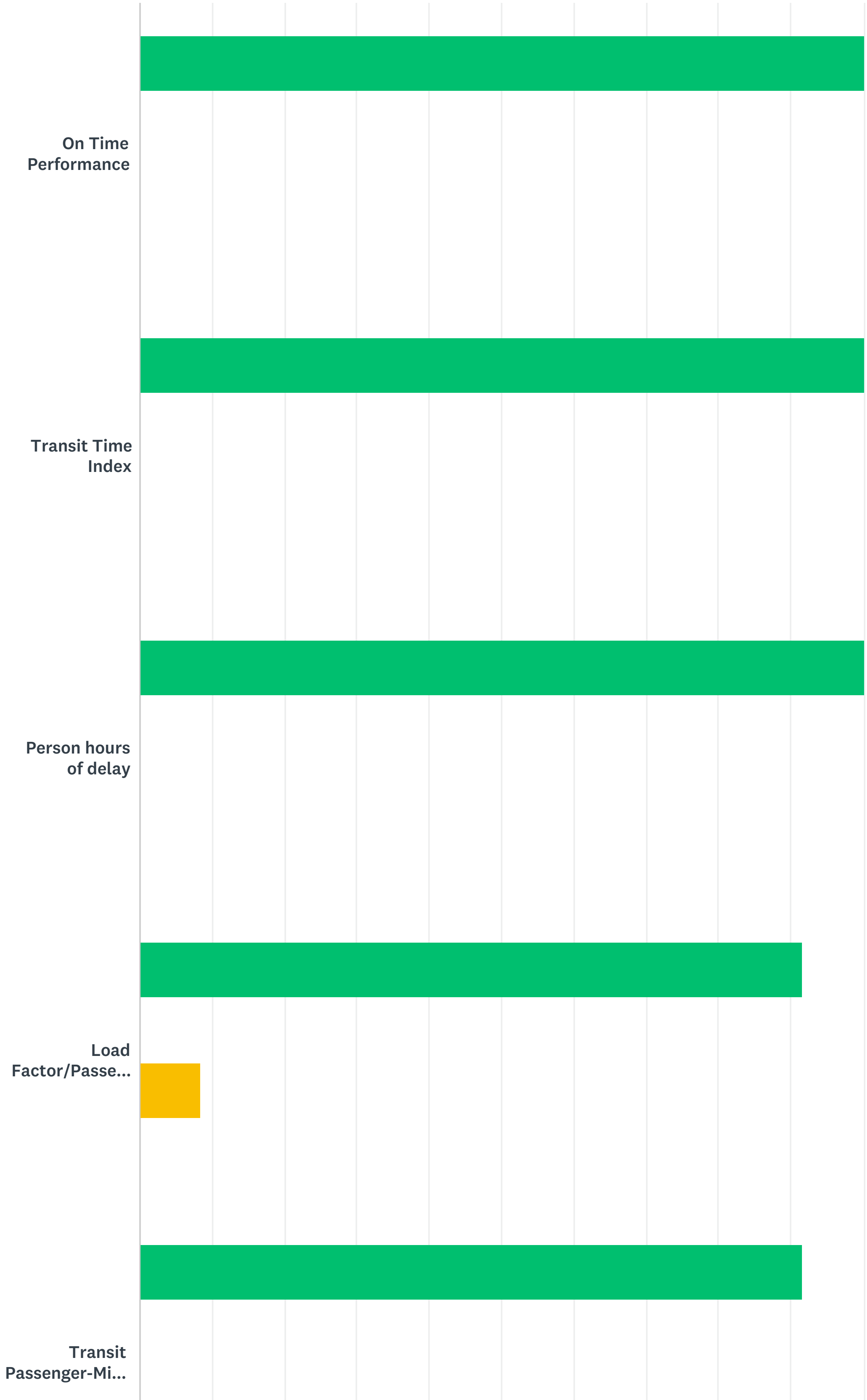


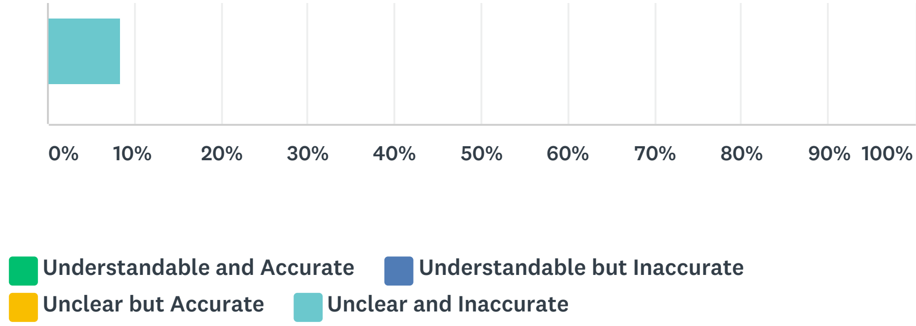


	UNDERSTANDABLE AND ACCURATE	UNDERSTANDABLE BUT INACCURATE	UNCLEAR BUT ACCURATE	UNCLEAR AND INACCURATE	TOTAL
Crossing Opportunities	83.33% 10	8.33% 1	8.33% 1	0.00% 0	12
Pedestrian Signal Presence	83.33% 10	16.67% 2	0.00% 0	0.00% 0	12
Walkway Width	100.00% 12	0.00% 0	0.00% 0	0.00% 0	12
Sidewalk Presence	100.00% 12	0.00% 0	0.00% 0	0.00% 0	12
Pedestrian Volumes	100.00% 12	0.00% 0	0.00% 0	0.00% 0	12

Q6 Transit Definitions

Answered: 12 Skipped: 5

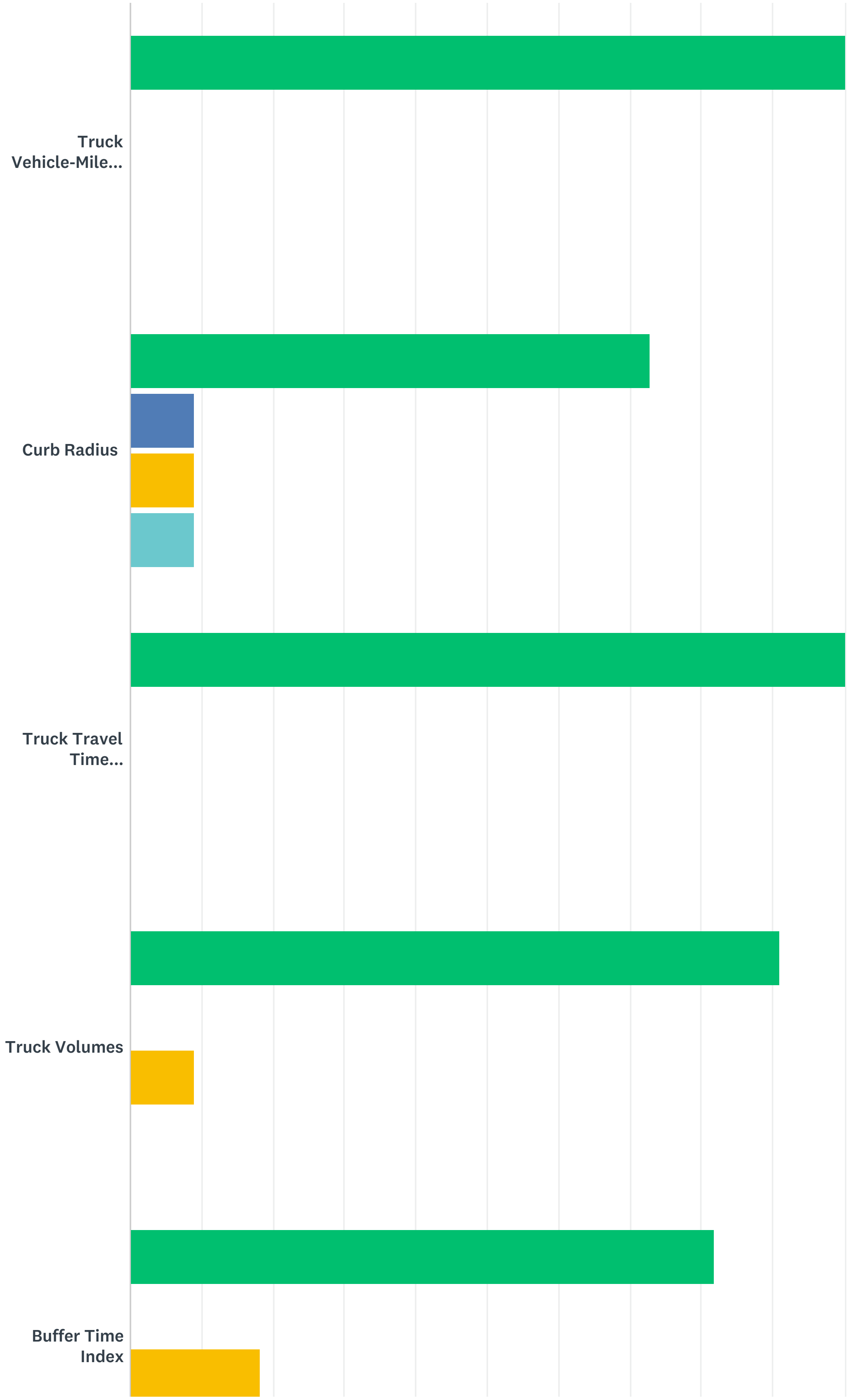


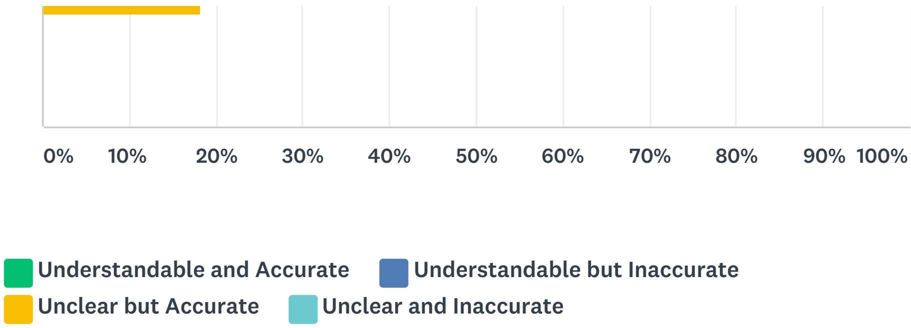


	UNDERSTANDABLE AND ACCURATE	UNDERSTANDABLE BUT INACCURATE	UNCLEAR BUT ACCURATE	UNCLEAR AND INACCURATE	TOTAL
On Time Performance	100.00% 12	0.00% 0	0.00% 0	0.00% 0	12
Transit Time Index	100.00% 12	0.00% 0	0.00% 0	0.00% 0	12
Person hours of delay	100.00% 12	0.00% 0	0.00% 0	0.00% 0	12
Load Factor/Passenger Crowding	91.67% 11	0.00% 0	8.33% 1	0.00% 0	12
Transit Passenger-Miles Traveled	91.67% 11	0.00% 0	0.00% 0	8.33% 1	12

Q7 Truck Definitions

Answered: 11 Skipped: 6

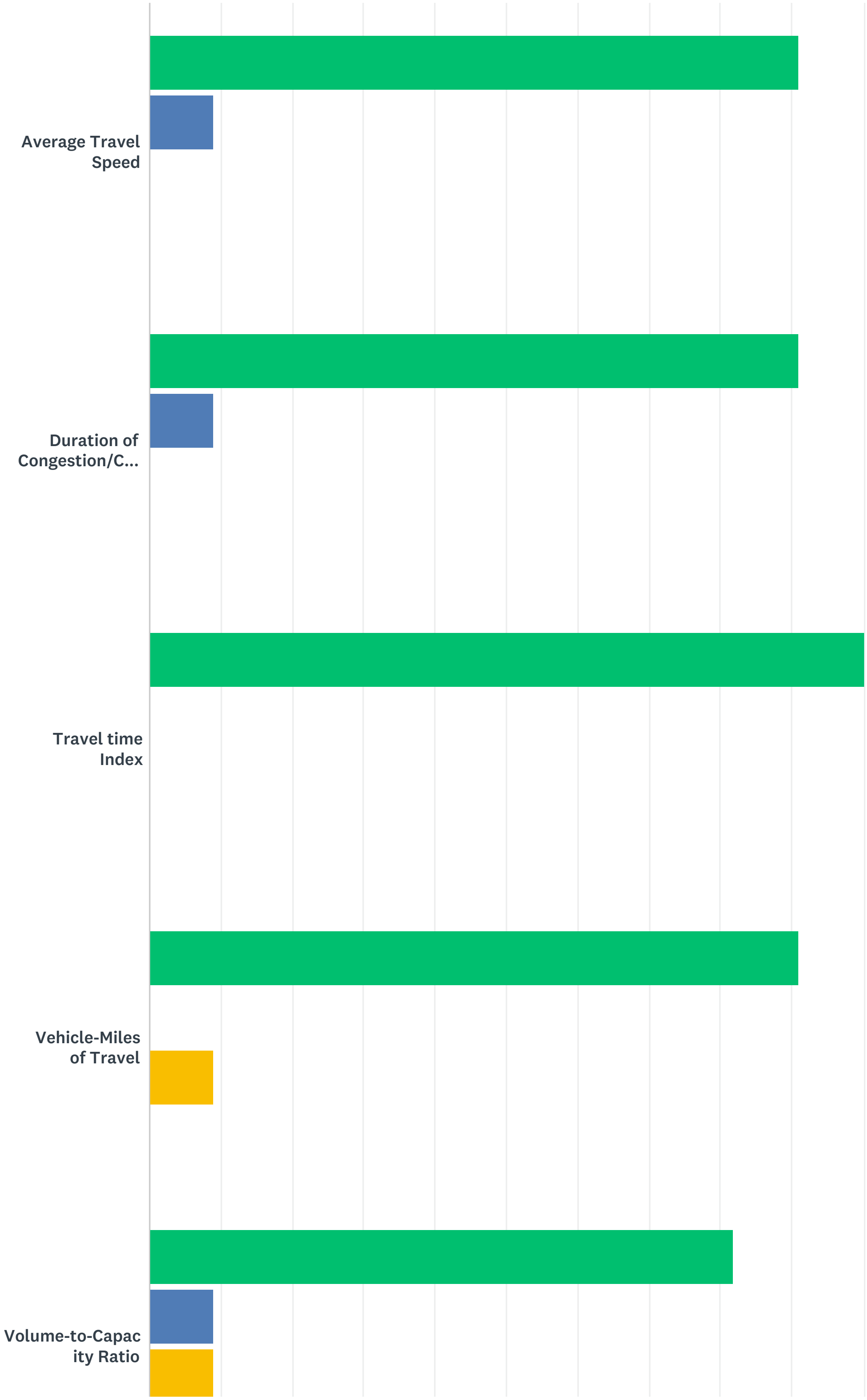


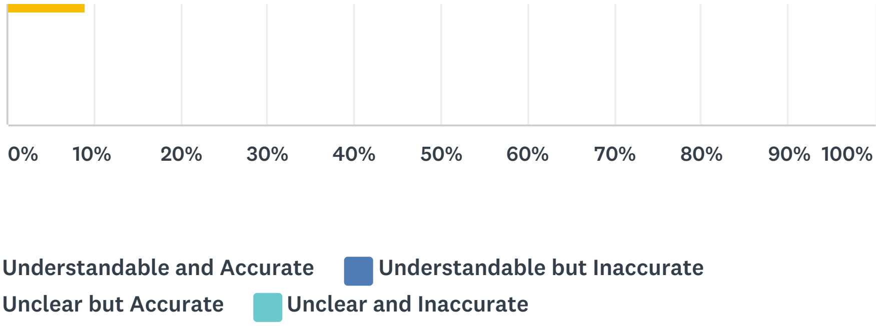


	UNDERSTANDABLE AND ACCURATE	UNDERSTANDABLE BUT INACCURATE	UNCLEAR BUT ACCURATE	UNCLEAR AND INACCURATE	TOTAL
Truck Vehicle-Miles Traveled	100.00% 11	0.00% 0	0.00% 0	0.00% 0	11
Curb Radius	72.73% 8	9.09% 1	9.09% 1	9.09% 1	11
Truck Travel Time Reliability Index	100.00% 11	0.00% 0	0.00% 0	0.00% 0	11
Truck Volumes	90.91% 10	0.00% 0	9.09% 1	0.00% 0	11
Buffer Time Index	81.82% 9	0.00% 0	18.18% 2	0.00% 0	11

Q8 Vehicle Definitions

Answered: 11 Skipped: 6

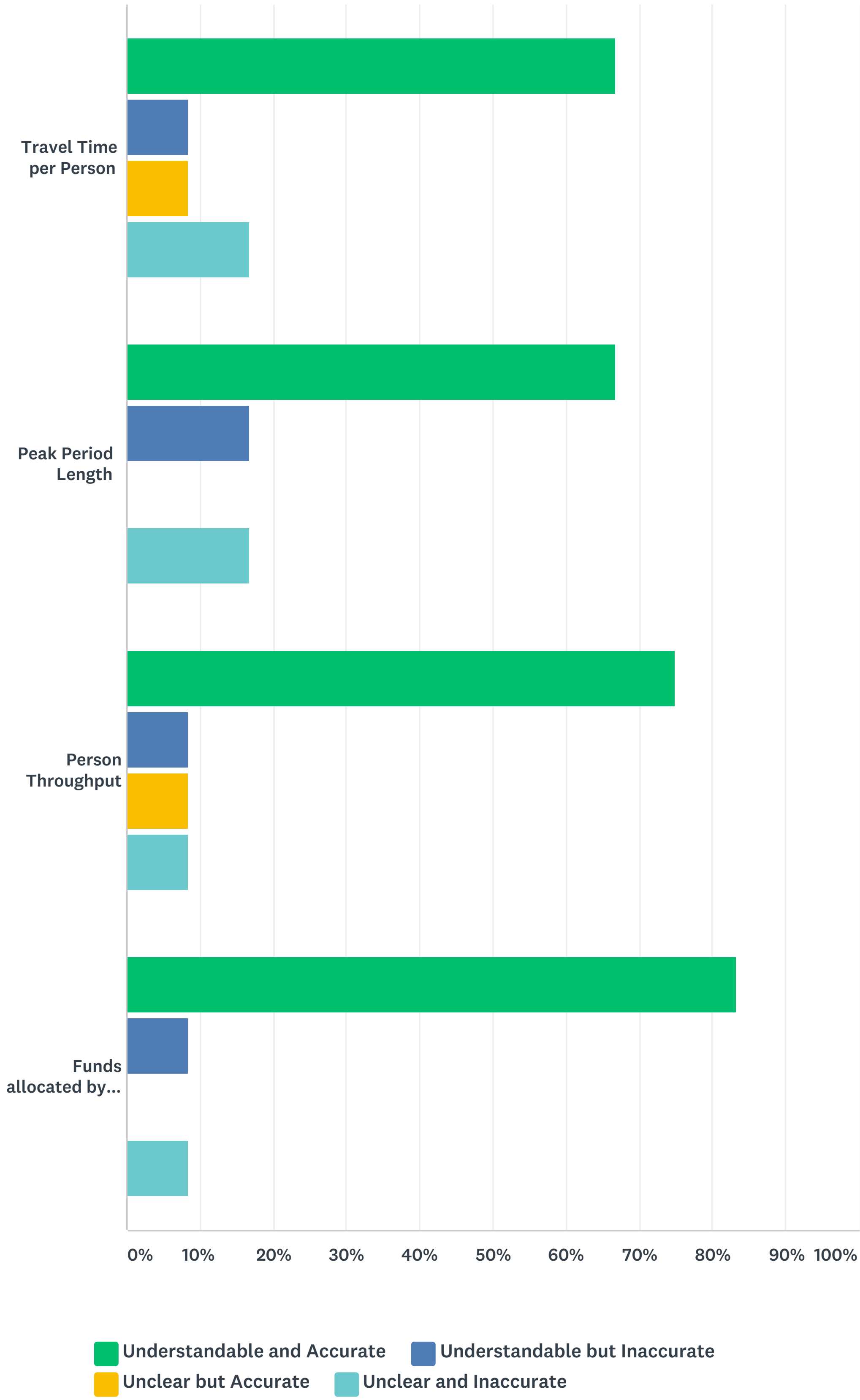




	UNDERSTANDABLE AND ACCURATE	UNDERSTANDABLE BUT INACCURATE	UNCLEAR BUT ACCURATE	UNCLEAR AND INACCURATE	TOTAL
Average Travel Speed	90.91% 10	9.09% 1	0.00% 0	0.00% 0	11
Duration of Congestion/Congested time	90.91% 10	9.09% 1	0.00% 0	0.00% 0	11
Travel time Index	100.00% 11	0.00% 0	0.00% 0	0.00% 0	11
Vehicle-Miles of Travel	90.91% 10	0.00% 0	9.09% 1	0.00% 0	11
Volume-to-Capacity Ratio	81.82% 9	9.09% 1	9.09% 1	0.00% 0	11

Q9 Multimodal Definitions

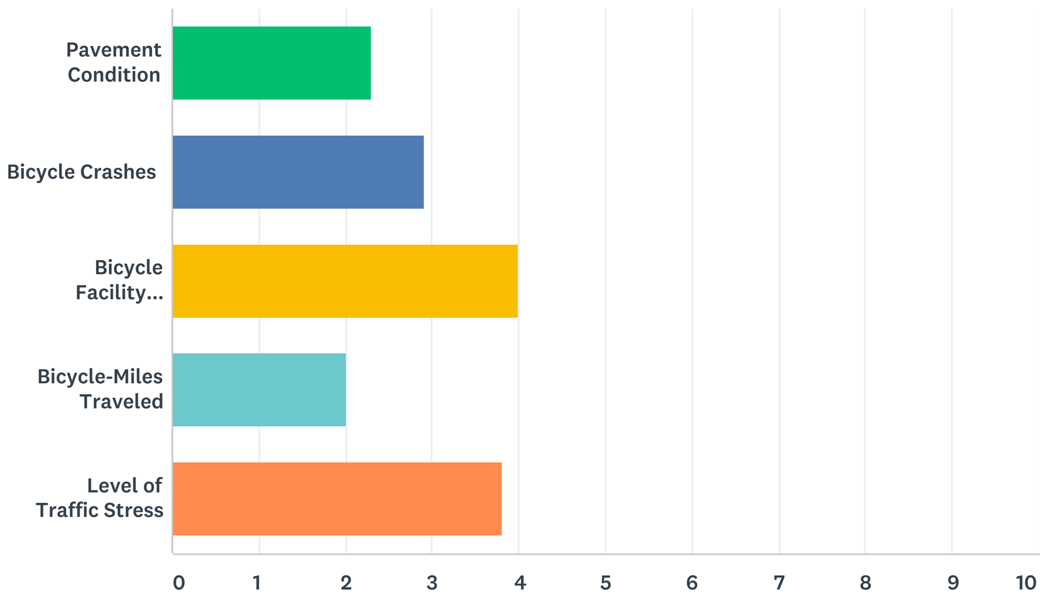
Answered: 12 Skipped: 5



	UNDERSTANDABLE AND ACCURATE	UNDERSTANDABLE BUT INACCURATE	UNCLEAR BUT ACCURATE	UNCLEAR AND INACCURATE	TOTAL
Travel Time per Person	66.67% 8	8.33% 1	8.33% 1	16.67% 2	12
Peak Period Length	66.67% 8	16.67% 2	0.00% 0	16.67% 2	12
Person Throughput	75.00% 9	8.33% 1	8.33% 1	8.33% 1	12
Funds allocated by Mode	83.33% 10	8.33% 1	0.00% 0	8.33% 1	12

Q10 Please rank each bicycle performance metric based on their significance of being incorporated into multimodal performance monitoring ? (1= highest rank, 5=lowest rank)

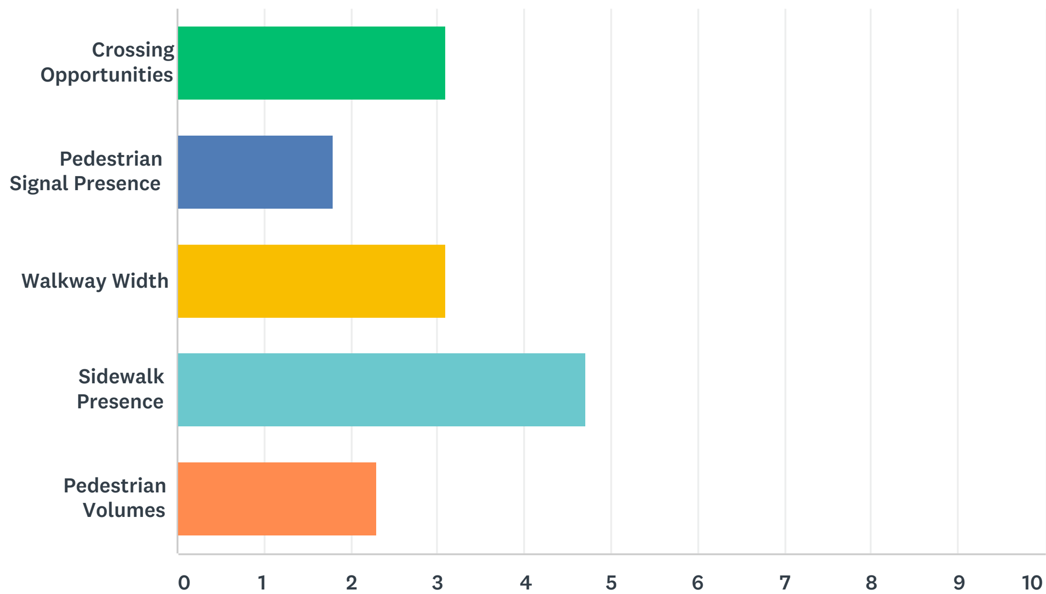
Answered: 10 Skipped: 7



	1	2	3	4	5	TOTAL	SCORE
Pavement Condition	10.00% 1	10.00% 1	10.00% 1	40.00% 4	30.00% 3	10	2.30
Bicycle Crashes	10.00% 1	20.00% 2	40.00% 4	10.00% 1	20.00% 2	10	2.90
Bicycle Facility Continuity	30.00% 3	50.00% 5	10.00% 1	10.00% 1	0.00% 0	10	4.00
Bicycle-Miles Traveled	10.00% 1	0.00% 0	10.00% 1	40.00% 4	40.00% 4	10	2.00
Level of Traffic Stress	40.00% 4	20.00% 2	30.00% 3	0.00% 0	10.00% 1	10	3.80

Q11 Please rank each pedestrian performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 5=lowest rank)

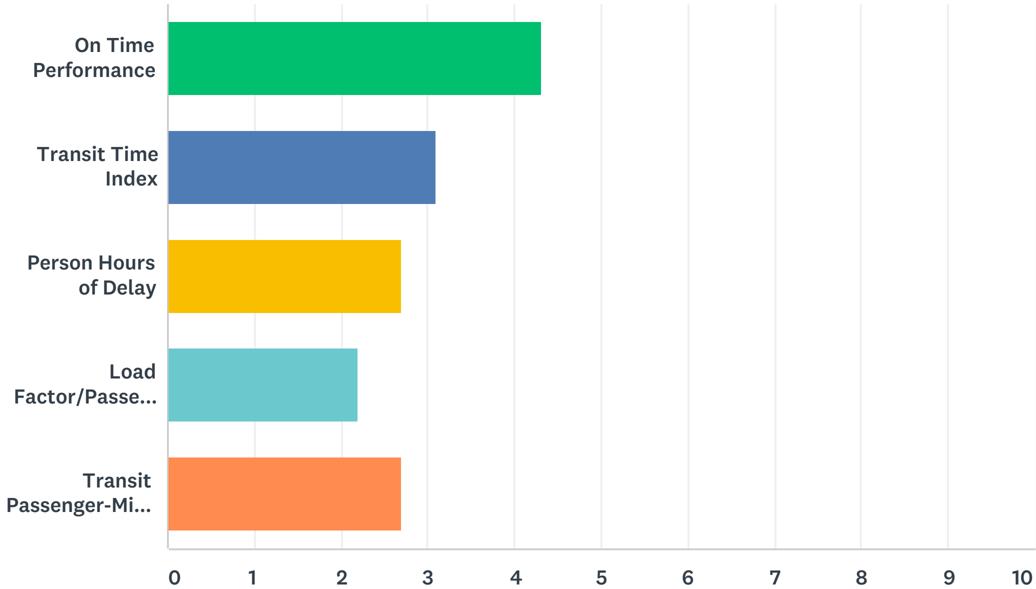
Answered: 10 Skipped: 7



	1	2	3	4	5	TOTAL	SCORE
Crossing Opportunities	10.00% 1	20.00% 2	40.00% 4	30.00% 3	0.00% 0	10	3.10
Pedestrian Signal Presence	0.00% 0	10.00% 1	10.00% 1	30.00% 3	50.00% 5	10	1.80
Walkway Width	0.00% 0	50.00% 5	20.00% 2	20.00% 2	10.00% 1	10	3.10
Sidewalk Presence	80.00% 8	10.00% 1	10.00% 1	0.00% 0	0.00% 0	10	4.70
Pedestrian Volumes	10.00% 1	10.00% 1	20.00% 2	20.00% 2	40.00% 4	10	2.30

Q12 Please rank each transit performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 5=lowest rank)

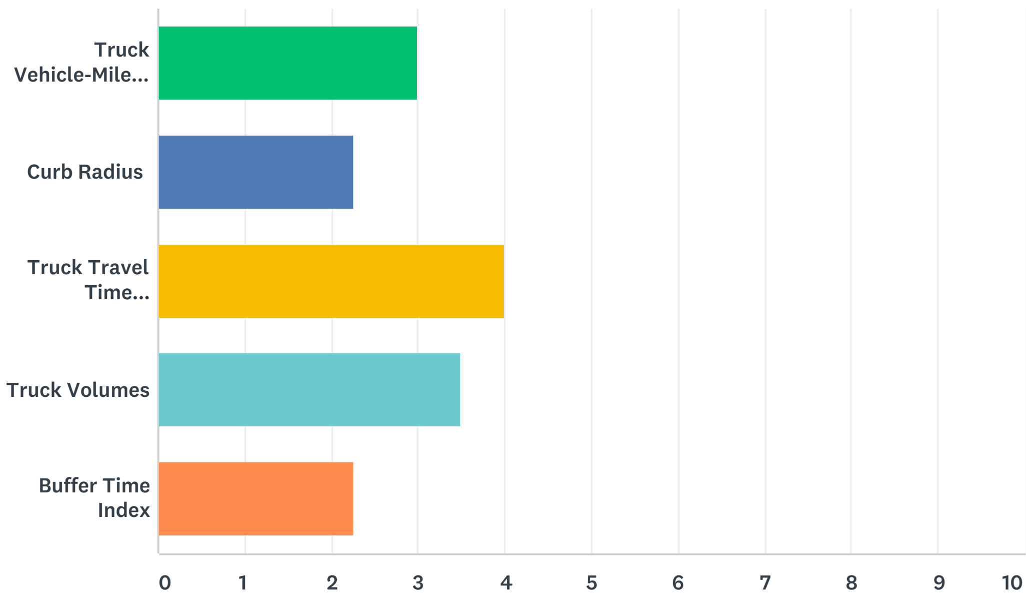
Answered: 10 Skipped: 7



	1	2	3	4	5	TOTAL	SCORE
On Time Performance	60.00% 6	20.00% 2	10.00% 1	10.00% 1	0.00% 0	10	4.30
Transit Time Index	10.00% 1	30.00% 3	40.00% 4	0.00% 0	20.00% 2	10	3.10
Person Hours of Delay	10.00% 1	20.00% 2	10.00% 1	50.00% 5	10.00% 1	10	2.70
Load Factor/Passenger Crowding	0.00% 0	10.00% 1	30.00% 3	30.00% 3	30.00% 3	10	2.20
Transit Passenger-Miles Traveled	20.00% 2	20.00% 2	10.00% 1	10.00% 1	40.00% 4	10	2.70

Q13 Please rank each truck performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 5=lowest rank)

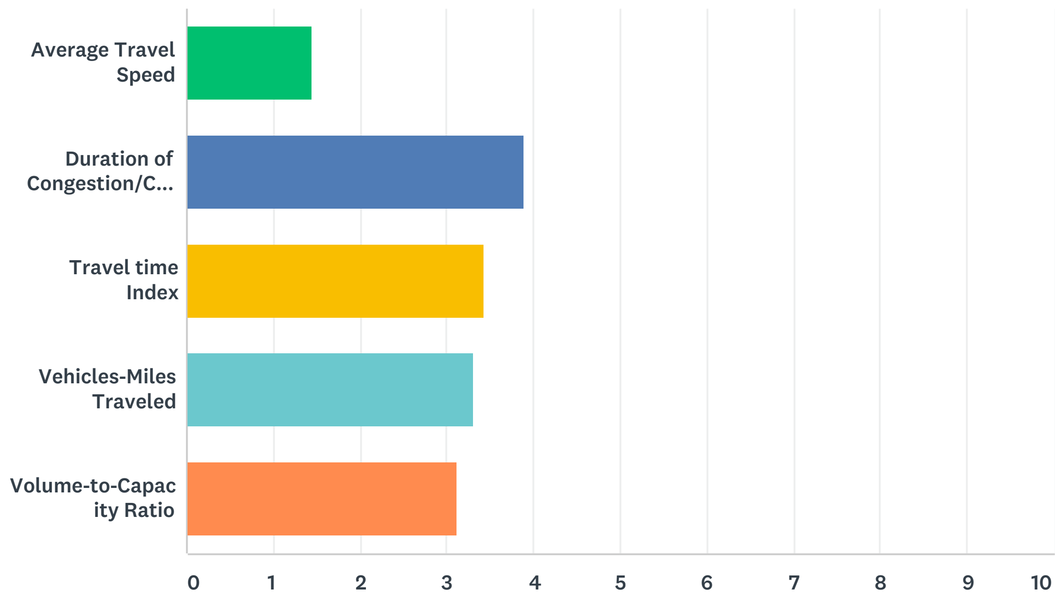
Answered: 8 Skipped: 9



	1	2	3	4	5	TOTAL	SCORE
Truck Vehicle-Miles Traveled	25.00% 2	0.00% 0	50.00% 4	0.00% 0	25.00% 2	8	3.00
Curb Radius	12.50% 1	12.50% 1	0.00% 0	37.50% 3	37.50% 3	8	2.25
Truck Travel Time Reliability Index	37.50% 3	37.50% 3	12.50% 1	12.50% 1	0.00% 0	8	4.00
Truck Volumes	25.00% 2	37.50% 3	0.00% 0	37.50% 3	0.00% 0	8	3.50
Buffer Time Index	0.00% 0	12.50% 1	37.50% 3	12.50% 1	37.50% 3	8	2.25

Q14 Please rank each vehicle performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 5=lowest rank)

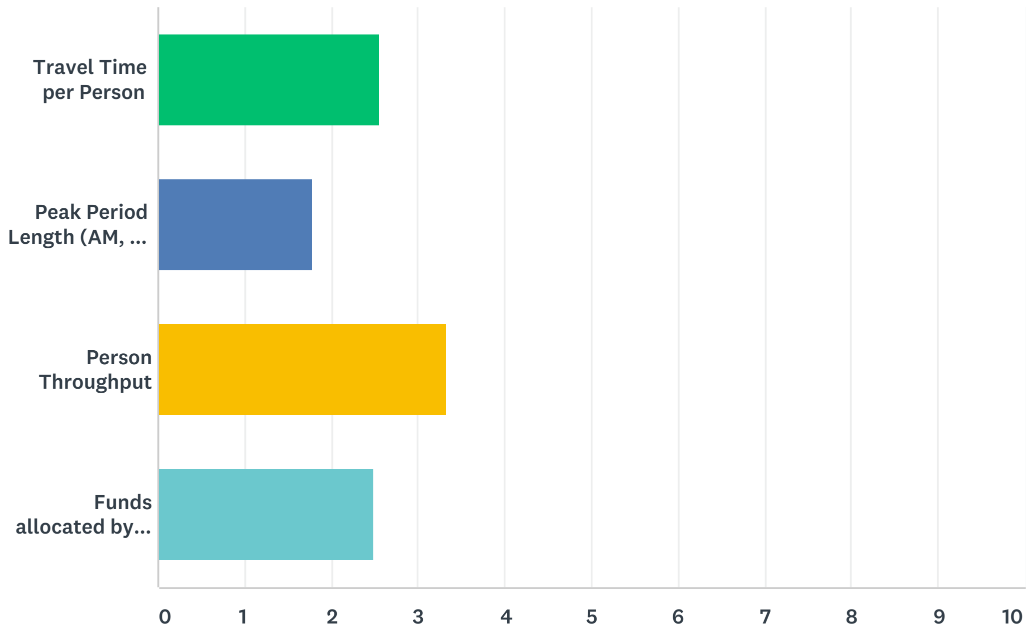
Answered: 10 Skipped: 7



	1	2	3	4	5	TOTAL	SCORE
Average Travel Speed	0.00% 0	0.00% 0	22.22% 2	0.00% 0	77.78% 7	9	1.44
Duration of Congestion/Congested Time	44.44% 4	22.22% 2	11.11% 1	22.22% 2	0.00% 0	9	3.89
Travel time Index	11.11% 1	44.44% 4	33.33% 3	0.00% 0	11.11% 1	9	3.44
Vehicles-Miles Traveled	30.00% 3	20.00% 2	10.00% 1	30.00% 3	10.00% 1	10	3.30
Volume-to-Capacity Ratio	22.22% 2	11.11% 1	22.22% 2	44.44% 4	0.00% 0	9	3.11

Q15 Please rank each multimodal performance metric based on their significance of being incorporated into multimodal performance monitoring? (1= highest rank, 3=lowest rank)

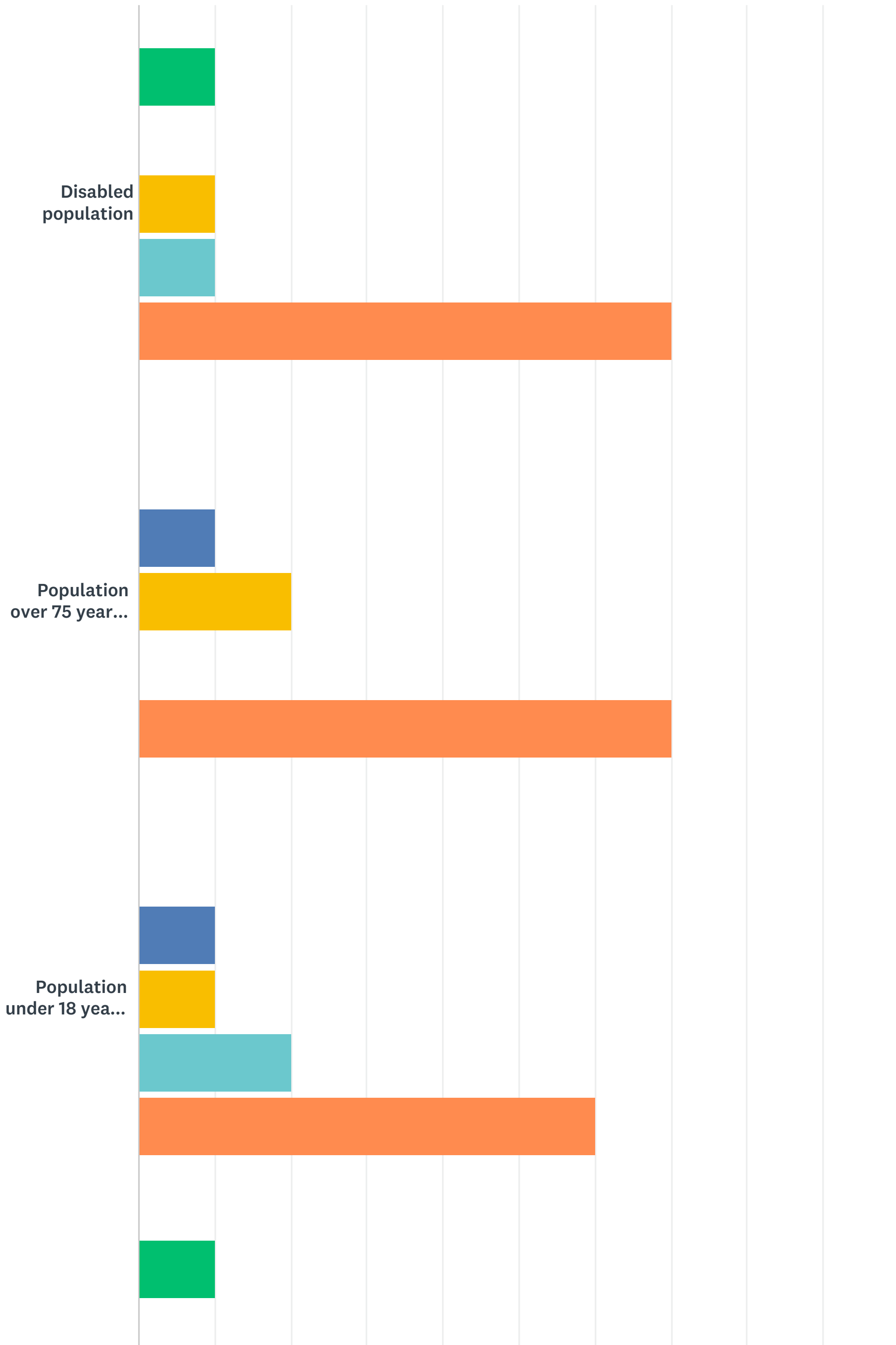
Answered: 10 Skipped: 7



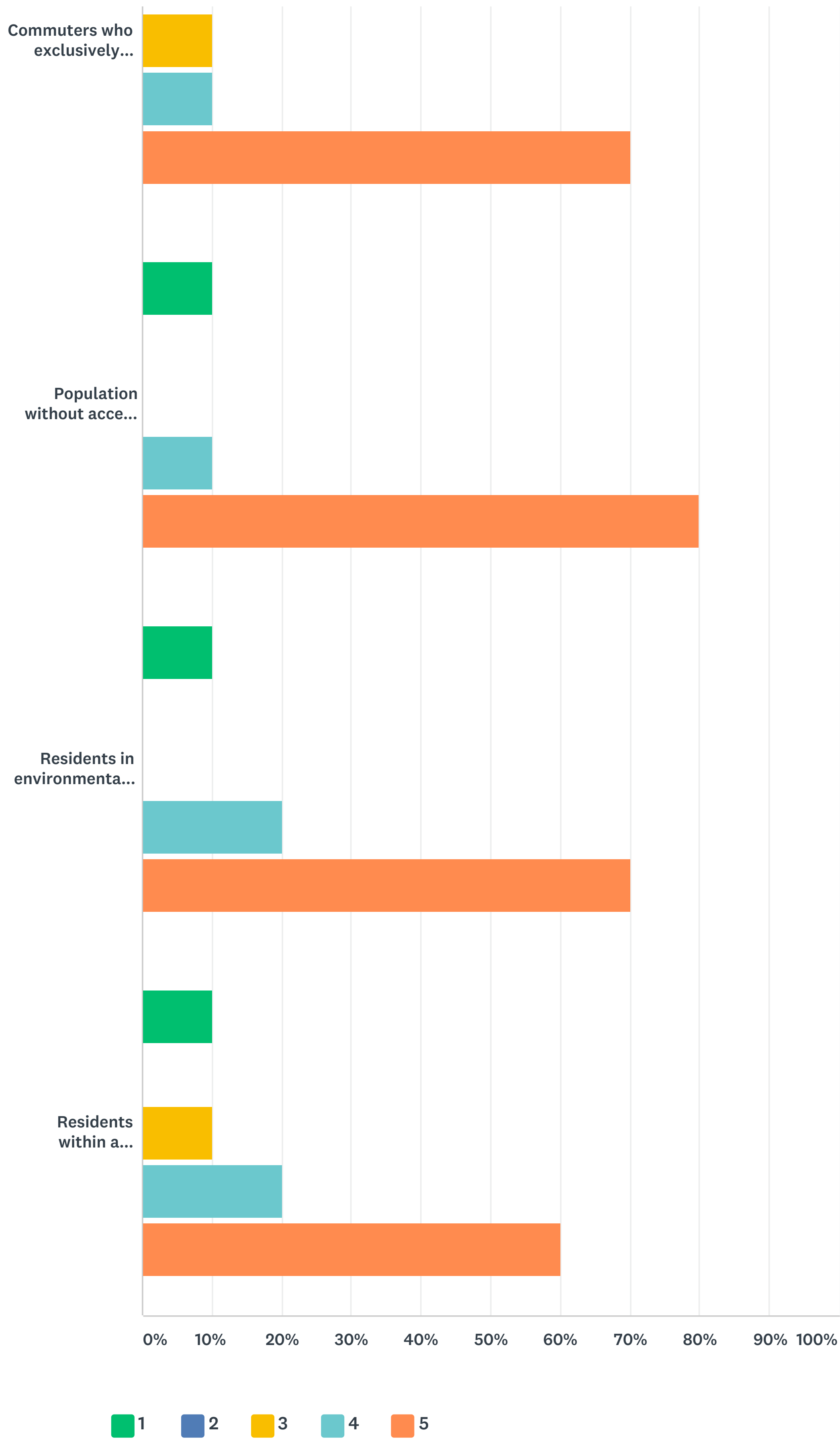
	1	2	3	4	TOTAL	SCORE
Travel Time per Person	11.11% 1	44.44% 4	33.33% 3	11.11% 1	9	2.56
Peak Period Length (AM, PM or both)	11.11% 1	11.11% 1	22.22% 2	55.56% 5	9	1.78
Person Throughput	55.56% 5	22.22% 2	22.22% 2	0.00% 0	9	3.33
Funds allocated by Mode	30.00% 3	20.00% 2	20.00% 2	30.00% 3	10	2.50

Q16 How important do you think it is to ensure good multimodal transportation in areas with the demographic characteristics listed below? Please assign a weight between one and five (1= lowest importance, 5=greatest importance)

Answered: 10 Skipped: 7



New and Emerging Metrics for Roadway Usage—Survey



	1	2	3	4	5	TOTAL	WEIGHTED AVERAGE

Disabled population	10.00% 1	0.00% 0	10.00% 1	10.00% 1	70.00% 7	10	4.30
Population over 75 years of age	0.00% 0	10.00% 1	20.00% 2	0.00% 0	70.00% 7	10	4.30
Population under 18 years of age	0.00% 0	10.00% 1	10.00% 1	20.00% 2	60.00% 6	10	4.30
Commuters who exclusively walk, bike, or take public transit	10.00% 1	0.00% 0	10.00% 1	10.00% 1	70.00% 7	10	4.30
Population without access to vehicles	10.00% 1	0.00% 0	0.00% 0	10.00% 1	80.00% 8	10	4.50
Residents in environmental justice areas (Low income or minority)	10.00% 1	0.00% 0	0.00% 0	20.00% 2	70.00% 7	10	4.40
Residents within a quarter mile of a school or college	10.00% 1	0.00% 0	10.00% 1	20.00% 2	60.00% 6	10	4.20

Q17 Are there any performance metrics not on this list that should be added? Please elaborate.

Answered: 8 Skipped: 9

#	RESPONSES	DATE
1	maybe cost per mile for different modes.	5/7/2019 2:55 PM
2	Unclear as to why crashes are included in bicycle metrics but not in the other metrics; also, why is bicycle volume not included for bicycle metrics but it is included for pedestrians, vehicles, and freight? There does not seem to be a clear consistency between the different metrics -- comparing similar types of data. Maybe I am confused about this project -- are bicycle volumes not a "new and emerging" data set on roadway usage, but pedestrian volumes are?	5/7/2019 2:00 PM
3	I didn't see any way to measure mult-modality - or how various modes interact.	5/7/2019 1:42 PM
4	Please see soon-to-be-released MassDOT Bike and Pedestrian Final Plans - final to be released in May with updated performance measures. For details, contact colleagues: Jackie DeWolfe and Pete Sutton	5/7/2019 12:51 PM
5	N/A	5/1/2019 4:06 PM
6	I think there need to be some performance metrics about the feeling of safety provided by walking infrastructure. In certain areas, even a 5-foot sidewalk does not feel safe if it immediately abuts a high-speed roadway. The presence of trees, parking, or other barriers can help with this. This kind of "level of walking stress" should somehow be captured. It should also include a factor as to whether the sidewalk is even and/or passable for individuals with limited mobility.	4/30/2019 1:14 PM
7	Intermodal connectivity - Bike and pedestrian facilities connecting to transit stations and corridors are especially important. Even park and ride facilities could be tracked in a connectivity metric. Multimodal journeys should be explicitly tracked.	4/27/2019 9:27 AM
8	shouldn't viability of the mode during weather / seasonal variations be a consideration? If some modes are temporarily unavailable it will impact other modes. The need for storage of transportation modes (parking, bike racks) within the available space should be a factor.	4/23/2019 4:31 PM

Q18 Are there any performance metrics definitions that you would change? Please elaborate.

Answered: 7 Skipped: 10

#	RESPONSES	DATE
1	no - this looks very well thought out	5/7/2019 2:55 PM
2	The first bicycle metric about pavement condition was too technical. Couldn't understand what was meant by "at least 95 inches per mile" on the IRI. Needs more clarification. For the multimodal metrics, the first one about travel time per person doesn't make sense to take the travel time regardless of mode. Pedestrians travel much slower than other modes -- that would skew the data. Even bicycles may be slower than other modes in most conditions, except where vehicle travel is already substantially congested. Finally, the funds spent per mode needs to be pegged to the percent of travel by mode. Often we overspend on infrastructure for private automobiles and underspend for other modes, especially biking and walking. Having percentage of spending next to modal splits would give a better idea of how to allocate resources.	5/7/2019 2:00 PM
3	Crossing opportunities per miles should measure skew - 5 crossings within a quarter mile with 3/4 of a mile without should not equal a full mile with 5 crossings equally spaced.	5/7/2019 1:42 PM
4	N/A	5/1/2019 4:06 PM
5	Cars operating at a high speed is almost always in direct conflict with the safety of other modes. Including this as a positive metric is disadvantageous to other modes.	4/30/2019 1:14 PM
6	Duration of Congested Time – its not clear how peak period will be defined. It seems like this will have a huge impact on this metric. Even within peak periods, congestion levels vary. I wonder if this measure could instead be something like Percent of 2-hour Peak Congested. Ped Signal Presence – Not only should there be LPIs but for concurrent signals it is important that vehicle and pedestrian signals have the same duration – many ped signals are shorter than vehicle signals. Additionally, the metric should consider whether ped signal cycles are on automatic recall or require button activation.	4/27/2019 9:27 AM
7	I'm not sure how you'd be able to separate funding by mode. When you rehab a street it would normally benefit buses, trucks, passenger vehicles, bicyclists and pedestrians. How much of those costs would be allocated to each mode?	4/23/2019 4:31 PM

Q19 Please provide any feedback you would like to share regarding the multimodal performance metrics. Feel free to elaborate on any of the survey questions above.

Answered: 3 Skipped: 14

#	RESPONSES	DATE
1	N/A	5/1/2019 4:06 PM
2	Funding is incredibly important. I was happy to see this.	4/30/2019 1:14 PM
3	Bike-miles Traveled – do you have a TDM that assigns bike trips? Is it even remotely accurate? Crossing Opps / Mi – Its quite unclear how intersections and non-intersection crosswalks will be considered? If this is a segment level metric will intersection crosswalks be assigned to the leg they are associated with? Bike - Pavement Condition – why use HPMS? Many NHS facilities prohibit bike travel? How will mixed-use paths, etc., be captured? Bike Facility Continuity – how will adjacent on-road and mixed-use paths be considered? It is reasonable to measure this at a segment level, or is this only appropriate at corridor and network levels? A bike lane that continues for 3 miles but then dumps the rider into a deadly roundabout is not continuous… Curb Radius – is should be clear what the standard is for this measure at different locations. Presumably not the entire network requires super wide turns. Travel time per Person – it should be made clear how modes will we weighted together to produce an aggregate travel time. Will only the fastest TT be used in which case this will just be an auto measure usually? Will modes be given equal weight? Will mode shares be used? How useful is this measure at a segment level? It seems its most useful at an O-D pair level since the best transit route might be on a parallel facility. Peak Period Length – How is peak defined? Why do we care? Is the goal to narrow peaks or spread peaks? Narrow peaks cause need for more service/infrastructure to serve peaks which is underutilized the rest of the day.	4/27/2019 9:27 AM