Multimodal System Performance Measures Research and Application: Innovation and Research Plan

June 2019

FHWA-HOP-18-085

U.S. Department of Transportation
Federal Highway Administration

TECHNICAL REPORT DOCUMENTATION PAGE

<table>
<tr><td>1. Report No.
FHWA-HOP-18-085</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title
Multimodal System Performance Measures Research and Application: Innovation and Research Plan</td><td>5. Report Date
June 25, 2019</td></tr>
<tr><td>6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Authors
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<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address

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<tr><td>11. Contract or Grant No.
DTFH61-12-D-00050
Task 5023</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Highway Administration
1200 New Jersey Avenue, SE
Washington, DC 20590</td><td>13. Type of Report and Period Covered</td></tr>
<tr><td>14. Sponsoring Agency Code
HOTM</td></tr>
<tr><td colspan="3">15. Supplementary Notes
Rich Taylor was the Government Task Manager for this effort.</td></tr>
<tr><td colspan="3">16. Abstract
This is the final report for the Multimodal System Performance Measures Research and Application study. The purpose of this project was to identify multimodal system performance measures that measure the actual performance of all modes, including light and heavy vehicles, bus and light rail, and non-motorized (i.e., bicycle and pedestrian) travel from a user perspective. The research focused on identifying existing and potential multimodal data sources necessary to develop an "ideal" multimodal system performance measure (or suite of measures) and then pilot test the proposed measure(s). This Innovation and Research plan lays out potential next steps in acquiring the data necessary to calculate the proposed multimodal measures and identifies necessary additional research.</td></tr>
<tr><td colspan="2">17. Key Words
Multimodal System Performance Measures, Surrogate Measures, Multimodal Network, Multimodal measurement initiatives, Person Trips, Travel Modes, Multimodal System Productivity</td><td>18. Distribution Statement
No restrictions.</td></tr>
<tr><td>19. Security Classify. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
38
22. Price
n/a</td></tr>
</table>

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
APC	AVL particle counter
APTA	American Public Transit Association
AVL	automated vehicle locator
Caltrans	California Department of Transportation
DVRPC	Delaware Valley Regional Planning Commission
FHWA	Federal Highway Administration
GPS	Global Positioning System
GTFS	General Transit Feed Specification
ISTEA	Intermodal Surface Transportation Act
LBS	location-based services
LOS	level of service
MAP-21	Moving Ahead for Progress in the 21st Century
MSP	multimodal system productivity
NCTD	North County Transit District
OD	origin-destination
PHT	person hours traveled
PMT	person mile traveled
SANDAG	San Diego Association of Governments
TRB	Transportation Research Board
VMT	vehicle miles traveled
WMATA	Washington Metropolitan Area Transit Authority

EXECUTIVE SUMMARY

BACKGROUND AND PURPOSE

The Intermodal Surface Transportation Act (ISTEA) of 1991 shifted the focus of transportation policy from building the national highway network to integrating multimodal transportation systems. The Moving Ahead for Progress in the 21st Century (MAP-21) Act of 2012, continuing the policy goals of ISTEA, ushered in a performance-based approach to the Federal Aid Highway program. During the development of the MAP-21 system performance measures (the third performance management rule, sometimes referred to as PM3 or 23 CFR 490.500-490.800), the Federal Highway Administration (FHWA) received thousands of comments, including some asking for multimodal measures that quantify person movements across all modes rather than vehicle movements. Based on those comments, FHWA committed to conduct additional research on multimodal measures and the data needed/used to support them and to report those results. This report is considered the results of this additional research.

The goal of this inquiry, the **Multimodal System Performance Measures Research and Application** study, was to identify multimodal system performance measures that assess the actual performance of all modes, including light and heavy vehicles, bus and light rail, and non-motorized (i.e., bicycle and pedestrian) travel from a user perspective. The research focused on identifying existing and potential multimodal data sources necessary to develop a true multimodal system performance measure (or suite of measures) and then pilot test what was proposed. This Innovation and Research plan lays out potential next steps in acquiring the data necessary to calculate the proposed multimodal measures and identifies necessary additional research.

The work effort for the **Multimodal System Performance Research and Application** study was organized around the following work tasks:

1. Conducting a literature review.
2. Defining an "ideal" multimodal system performance measure. *Note: the term "ideal" is in quotation marks as a recognition that it would be difficult to identify a truly ideal measure, but that the goal of this task would be to get as close as possible to "ideal."*
3. Determining the gaps between data required by the identified "ideal" measure and data currently available.
4. Developing surrogate measures based on available data.
5. Identifying and testing the surrogate measures in three pilot locations.
6. Preparing an innovation and research plan based on the findings of the research.

This research effort relates to but differs from other multimodal measurement initiatives, such as multimodal accessibility and connectivity. This research focuses on the performance of the multimodal system in terms of the productivity of actual person trips made across the multimodal network. Accessibility focuses on the ability to reach destinations while connectivity quantifies the seamlessness of travel across modes.

COMPLETE TRIP PERSPECTIVE AND FRAMEWORK

Many currently used transportation performance measures are carryovers from the pre-ISTEA policy era that focused on individual modes rather than the coordination of modes. Roadway performance continues to rely on congestion-based measures. Some use the *Highway Capacity Manual*,[1] others use travel time data to determine delay and reliability. Facility based transit measures, such as passengers per route mile, focus on transit productivity and efficiency. Most bicycle and pedestrian measures focus on facility conditions, such as traffic volumes on adjacent streets. Commonly used system measures, such as vehicle miles traveled (VMT) and person hours traveled (PHT), provide feedback on the efficiency of travel across a modal network and, in some cases, across the multimodal system. Such measures reflect the systems perspective sought by this research, but do not provide a user perspective, i.e., the quality of travel for a user from an origin to a destination.

The "ideal" multimodal system performance measure sought by this research would provide feedback on how travel modes work in concert to serve travelers. It would measure performance from different perspectives, including system productivity, efficiency, and resiliency. It would apply across a variety of settings and locations in the country as well as differing time periods.

The research team quickly found that such a measure would require a new theoretical and analytical framework and new types of data. The new framework would need to orient around a multimodal, complete trip perspective rather than a single mode, facility-based perspective used by most current performance analysis.

Developing and applying complete, trip-based system measures presents several challenges. The first is obtaining complete trip information across all modes and at all times of the day. Some companies are collecting large amounts of complete trip information from cell phone and Global Positioning System (GPS) devices, but do not sell or share the data because of concerns about privacy and incompatibilities with business models. Other companies are expanding smaller samples of complete trip data to simulate travel throughout the day, but those data remain incomplete for a system measure. Despite the hurdles, it is possible to foresee a time in the not too distance future when such data will be readily available.

The second challenge is overcoming institutional and analytical inertia. The transportation profession has a long history and familiarity with single mode, facility-based measurements, due in large part to the availability of facility-based data and to the modal orientation of transportation agencies. Multimodal system performance measurement could fundamentally change both analytical methods and perspectives.

[1] Transportation Research Board (TRB) (2016-10-24). "Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis".

RESEARCH FINDINGS

The initial literature review found no "ideal" or universal multimodal transportation system performance measure or approach. It did uncover a high level of interest in pursuing, defining and testing such a method, however.

Multimodal system productivity (MSP) emerged as the "ideal" system measure. MSP is based on the classic definition of productivity: the ratio of inputs to outputs in the production process. For the multimodal transportation system, completed person trips are production outputs and network travel times, or network minutes, are production inputs. The MSP score is the number of completed person trips per network minute. The higher the score, the higher the productivity of the system.

The MSP measure requires completed person trip data, which were not available for the pilot tests. Two surrogate measures, person trips and time-weighted person trips, were used for the three pilot tests in downtown Philadelphia; the San Marco to Escondido corridor north of San Diego; and Crystal City in Arlington, Virginia. The following is a summary of the key findings from the pilot tests.

- The pilot sites were selected because of the availability of multimodal data, yet data gaps from all three would not allow for full measurements. The pilot study data issues reflect the disjointed nature of data collection across travel modes and the need for future initiatives and research on coordinating data collection.

- Feedback from the surrogate measures indicated how different modes performed and hinted at the interplay of travel demand across the modes, but the process confirmed the challenges of using facility-based data and measurements to report on multimodal system performance, primarily due to difficulties with defining the system and aggregating data.

- Without complete trip information and a complete trip perspective, the surrogates did not offer direct feedback from a traveler's perspective.

INNOVATION PLAN

The innovation plan, developed from the findings of this research, includes these proposed initiatives:

- Obtain and improve multimodal system performance measure data – the focus is on either obtaining complete person trip data from sources such as Google or Apple, which have large sample sizes, or improving the expansion techniques for sources with smaller sample sizes. Improvements in travel data, particularly coordinating collection across modes, are also recommended.

- Refine the MSP measure – the types of refinements include further developing the complete trip analytical framework, using complete trip data, once available, to develop and test the MSP, and testing the MSP in a variety of planning, programming, and management and operations applications.

RESEARCH PROGRAMS AND PROJECTS

Recommended research orients around support for innovation initiatives and other related research. For the innovation plan, research programs and projects focus on data development, measure development, and measure applications. Research on the opportunities for understanding relationships with multimodal system performance measures include the areas of policy development, transportation management and operations (focusing on system resiliency), transportation planning and programming, travel demand modeling and forecasting, and relationships with other transportation performance measures.

SUMMARY

The FHWA will consider these proposed innovation and research topics for future funding. As of Fall 2018, FHWA has identified a follow-on study for potential funding.

CHAPTER 1. INTRODUCTION

The FHWA recognized in the preamble of the final rule for the third performance management rulemaking (also known as PM3) that many commenters requested measures that were more multimodal in nature and focused on person movement. The preamble in the final rule noted these comments and provided a response from FHWA:

"The FHWA also recognizes that data collection and analytic capacity are not yet developed enough to respond effectively to many commenters' suggestions, particularly in measuring multimodal performance. Therefore, FHWA is working to develop more sophisticated performance metrics and may issue an updated rulemaking on performance measures related to person throughput and multi-modal performance in the future, following completion of ongoing research regarding multimodal system performance measures in Fall 2018."[2]).

This report constitutes the results of the above referenced research. FHWA initiated this **Multimodal System Performance Measures Research and Application** study with the goal of identifying and testing a multimodal system performance measure that quantifies the actual performance of all modes, including light and heavy vehicles, bus and light rail, and non-motorized (i.e., bicycle and pedestrian) travel (and potentially ferry travel as well) from the vantage point of the user. The research focuses on identifying existing and potential multimodal data sources necessary to develop a true multimodal system performance. This Innovation and Research plan lays out potential next steps in acquiring the data necessary to calculate the proposed multimodal measures and identifies necessary additional research.

The tasks for this research project began with defining an "ideal" multimodal system performance measure, then determining the gaps between data required by the "ideal" measure and currently available data, developing surrogates for the "ideal" measure based on data gaps, and testing those surrogate measures. *Note: the term "ideal" is in quotation marks as a recognition that it would be difficult to identify a truly ideal measure, but that the goal of this task would be to get as close as possible to "ideal."* Recognizing the scope and breadth of developing a truly multimodal system performance measure and the continuing data limitations, the end products of the research are an innovation and research plan that includes a proposed listing of innovation activities and related research projects.

This Innovation and Research Plan contains the following chapters:

- Chapter 2 – definitions and work scope.
- Chapter 3 – research findings.
- Chapter 4 – innovation plan.
- Chapter 5 – research programs and projects.

[2] National Performance Management Measures; Assessing Performance of the National Highway System, Freight Movement on the Interstate System, and Congestion Mitigation and Air Quality Improvement Program Final Rule, 82 Federal Register 5970, January 18, 2017, at p. 5973 (codified at 23 CFR Part 490).

CHAPTER 2. DEFINITIONS AND WORK SCOPE

Transportation performance measures continue to evolve as travel demands and transportation systems become more complex and the richness and affordability of data improves. Early measures, still in use today, focus on relationships between travel demand and network conditions on facility segments of a single mode. While transportation agencies are developing and applying multimodal measures, such as multimodal levels of service (mode-specific measures), many of those measures continue to focus on network segments rather than larger systems. The transportation industry has yet to define an integrated multimodal system performance measure, primarily due to a lack of data for such a measure. Developing such a measure will not only require new data, but a conceptual shift from a mode specific, network-based perspective to a multimodal complete trip-based perspective. This chapter details the reasons for and dynamics of the multimodal complete person trip perspective. It then describes the characteristics of an integrated multimodal system measure and the data required for such a measure. It concludes with the specific objectives and a description of the research plan.

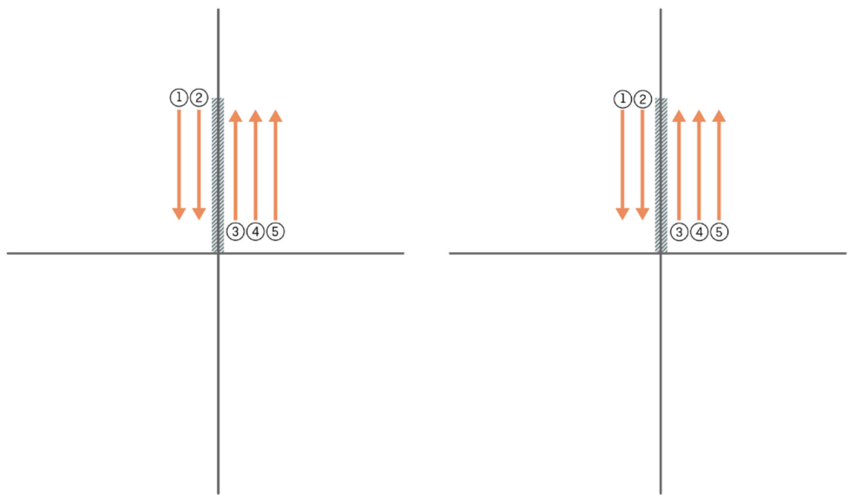
There are several related multimodal system performance research initiatives underway, including accessibility and connectivity. The former focuses on the number of destinations within a reasonable time frame of a given origin, while the latter focuses on how well differing modes connect with each other to provide seamless travel. This multimodal system performance research is intended to provide a different perspective by homing in on how well the multimodal system performs in concert to serve actual travel on the system. The "ideal" multimodal system performance measure would ultimately provide operators and planners to adjust and improve networks in ways that optimize overall system productivity.

COMPLETE TRIP PERSPECTIVE

The multimodal transportation system provides a web of travel mode and path options for travelers. The system has become increasingly complex, particularly in urban areas where travel across multiple modes is high. Technology is adding to the complexity by increasing both the number of travel options and the information travelers use to explore among options. Transportation agencies are tasked with continually modifying the system to improve how well it serves travelers based on performance feedback. Current transportation performance measures assess performance on mode specific facility segments, with adjustments and improvements on problematic segments assumed to benefit the larger system.

This single mode, facility-based perspective is due primarily to the type of data available: facility-oriented travel data. While system performance monitoring can be improved by increasing the number and duration of travel data recording locations, such data may provide an incomplete, and perhaps an inaccurate, picture of performance. This is because the characteristics of trips on any given network segment differ: some trips are short, others are long; some are bound for work, others bound for a store; some have many viable travel options, others have few; etc. Knowing such characteristics can provide additional context for defining performance problems and potential solutions.

Figure 1 illustrates facility-based performance measurements. It depicts two segments located in different areas (contexts). Roadway demand, shown by the orange lines on both figures is five trips per hour, which equals the simplifying fictitious capacity of five trips per hour. Given limited information, it is logical to conclude neither segment performs well and that adding capacity, either through operational or geometric improvements, is the best way to improve performance.



a) Segment 1. b) Segment 2.

Figure 1. Illustration. Compound graphic depicts two simplified facility-based perspectives.

Figure 2 enhances the perspective by adding the complete multimodal network to the picture. Segment 1 on the left has multiple alternative travel mode and path options, with both a transit route (shown by blue dots) and a walking / bike trail (shown by green dots) running parallel to the study segment, while segment 2 has limited options (a transit line, in blue dots, running perpendicular to the study segment. This enhanced perspective reflects the intent of recent context-sensitive, Complete Streets initiatives, and hints at the possibility for strategies other than adding capacity to segment 1 to improve performance. Unfortunately, because the problem continues to be defined by facility-based count data, it is difficult to draw definitive conclusions on how a richer system serves travel demand.

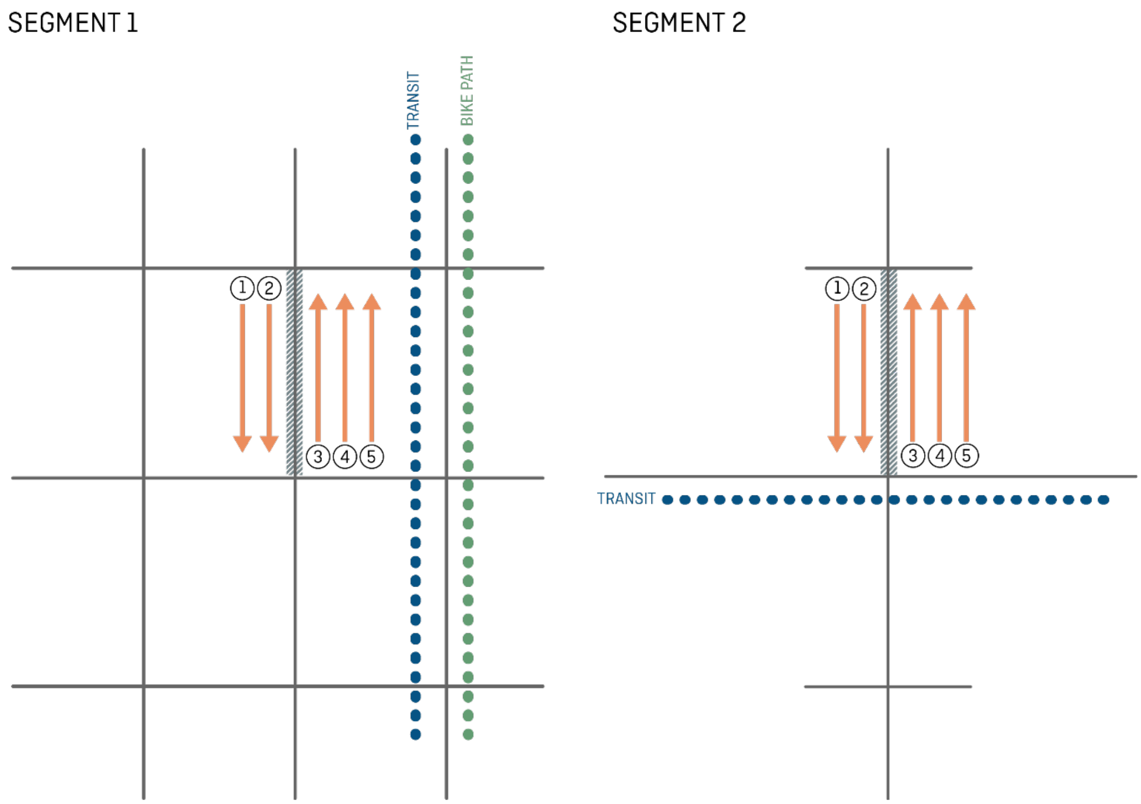


Figure 2. Illustration. Compound figure depicts contextualized facility-based perspectives

Figure 3 enhances the perspective even further by adding not only the system information shown in figure 2, but the origins and destinations of all trips on the two example segments. This new "complete trip" perspective more clearly illustrates the travel market for trips and how well the system serves those markets (vehicle trips are shown by orange lines, transit trips are shown by blue lines, bike trips shown by green lines). The origins and destinations of trips on segment 1 match the orientation of the travel modes and paths reasonably well, further supporting the possibility of improvements other than added roadway capacity to segment 1.

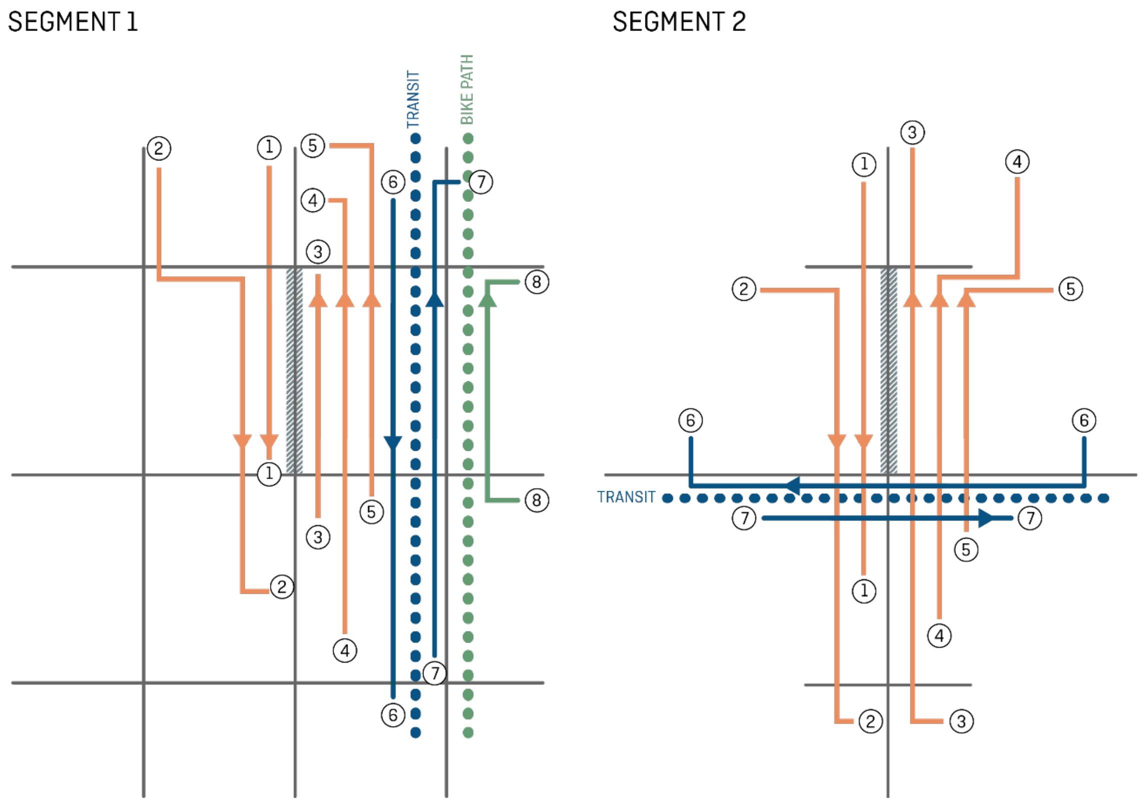


Figure 3. Illustration. Compound figure depicts the complete trip perspective.

PERFORMANCE FEEDBACK

The research focused on the ability of multimodal system performance measures to provide feedback on system performance from three perspectives:

- System productivity, which is defined as how well the multimodal system serves travelers. Productivity in a production process is the ratio of inputs to outputs. In the "transportation production process," completed trips are outputs and network travel times, or network minutes, are inputs. Multimodal system productivity is the sum of completed trips divided by the network minutes required to complete those trips. The greater the ratio of completed trips to network minutes, the higher the system productivity.

- Network efficiency, which is defined as how well the network supports system productivity. There are capital and operational costs associated with travel on the network and those costs are incurred primarily by distance. Efficiency is estimated by dividing system productivity by network distances, or complete trips per network minute per network mile. Higher ratios reflect greater efficiencies.

- System resiliency, which is defined as how well the system responds to disruptions. This third perspective measures the impact of both short- and long-term disruptions to the system and the time it takes for the system to recover.

MEASURE CHARACTERISTICS

Complete Person Trips

As described in the last section, complete person trip information provides an enhanced perspective on performance and it reflects and quantifies the primary goal of travelers, which is to reach desired destinations within a reasonable amount of time and cost. Complete trip data also simplifies how performance is measured by simplifying the definition of the system being measured and the aggregation of data across the multimodal system.

Regarding simplifying the definition of the system: because complete trips are indivisible, they provide a well-defined, travel market-based, rationale for selecting the system to measure. Mode-specific facility-based travel data currently in use record only portions of trips and offer no clear-cut rationale for selecting the system. As demonstrated in the figures on the previous pages, it is difficult to discern potential relationships between travel demand and multimodal networks using mode-specific facility-based data. As a result, analysts make educated guesses about such relationships.

Regarding the second point about simplifying data aggregation: complete trip data are readily totaled once the system is defined and records are selected. Because single mode facility-based data often count the same trip over multiple segments, data must be proportioned by length of the segments, which then become the basis of measurement. To illustrate this, assume the multimodal network, or system, is defined as four adjacent segments and each segment is a quarter mile long. Peak hour person trip counts over the four segments are 100, 200, 200, and 100 and travel times are 1, 2, 2, and 1 minutes. Adding the counts and dividing by the total travel time (600 trips / 6 minutes = 100 trips per minute) will over-estimate network productivity if some or all the trips are counted multiple times. To account for this, segment counts are multiplied by segment lengths and summed across the network (100*0.2 5 + 200*0.25 + 200*0.25 + 100*0.25 = 150). The total system Person Miles Traveled (PMT) is then divided by the overall travel time (150 PMT / 6 minutes = 25 trips per minute) to estimate performance. The resulting score appears to adjust for over counting, but it is possible that the summed PMT may go too far and under-estimate performance. An extreme example illustrates why this is so. If all trips on each network segment begin and end at the end points of that segment, thus no trips are double counted, network performance would indeed be 600 not 150. Consequently, PMT based performance results are likely to differ from complete trip-based results. They are also likely to vary by the somewhat arbitrary decisions about how segments are defined.

Finally, complete person trips, not vehicle trips, are needed for measurement because person trips account for the total number of trips made. In addition, they account for differences in the characteristics of person trips made on each vehicle. Person trips on nearly all transit vehicles and on many automobiles, have differing trip origins, destinations, and travel times.

Continuous Information

Travel demand on the transportation network changes constantly during the course of a day. Continuous data, or data summarized into short time slices, provides feedback on those differing conditions. Continuous data are necessary to measure system resiliency, or the ability of the transportation system to provide viable travel options and/or a quick return to typical travel conditions. Information should be summed at hourly intervals (time slices) or preferably less, given the short durations of most incidents.

Traceable Trips

As noted above, complete trip data that records the times and locations of trips as they move through the system can match trips with the network, thereby allowing analysts to select complete trip information for any given segment or collection of segments on the network. They also allow analysts to partition complete trip travel times across any of the segments used by the trip.

Scalability and Perspective

Multimodal system measures should have the ability to quantify performance at differing levels of geographic detail, i.e., sub-areas, corridors, and regions, to enable consistent and comparable results among and across regions. When scaling the measure, there is a need to consider that as the geographic focus for measurement zooms in the differences between the spatial extent and orientation of travel demand and networks increase. At a regional scale or greater, the multimodal network extends well beyond the spatial extent of most complete person trips, but as the focus zooms in to a corridor or sub-area, the geographic extent of complete person trips will reach beyond the selected study network. Such differences strain the integrity of the measurement and creates the dilemma of whether to maintain integrity from a network based perspective of shift to a place-based perspective.

A complete person trip's basis for measurement, by default, generates a place-based measurement, where the spatial pattern of selected complete trips dynamically defines the study network. This is a far different perspective than the traditional practice of drawing boundaries around a portion of a network, be it a corridor or a sub-area, and measuring performance within the bounds of that network. Because networks ultimately are designed to serve places, such as travel to and from an employment center, measuring performance from a place-based perspective has value and is worth exploring in future multimodal system performance measure research and applications.

SUPPORTING DATA

Currently available transportation network data is abundant, detailed, and accurate for roads and transit. Bicycle and pedestrian information are of reasonable quality and improving over time. Continuous, real-time roadway travel times from crowd-sourced mobile devices are equally abundant and have evolved to the point where it is increasingly possible to track all trips (or a large enough sample of trips) across all travel modes and travel paths. Unfortunately, those data sources are under the control of private vendors and not readily available to transportation agencies at this time. The richness of data, if made accessible by transportation agencies, will allow for a complete multimodal system performance measure in time.

RESEARCH FOCUS

This research is designed to identify a system performance measure and the data needed to support the measure. Given the lack of data and fundamental research into multimodal system performance measures, the research does not delve into potential applications of such a measure, although potential applications provided context for the research process.

The research focused on measuring existing and past conditions, not on multimodal modeling and forecasting. Nevertheless, it recognizes important connections between the measure and modeling including:

- Regional travel demand models estimate complete trip information for existing and future conditions, thereby providing opportunities to both test the measure until crowdsourced data become available to evaluate forecasts.
- Once multimodal system performance measure data become available, allowing for research of the measure, research results will likely improve those models.

The research focused on passenger travel and, as such, insights on freight and goods movement are limited to passenger trips made by this important travel market, not on the magnitude of freight and goods moving through the system.

RESEARCH WORK SCOPE

The research effort is divided into the following tasks:

- Literature review – conduct a scan of multimodal system measured developed and applied and the data used for those measures.

- Define an "ideal" measure – identify one or more "ideal" multimodal system performance measures based on the increasing potential of evolving data sources, particularly data from mobile devices. *Note: the term "ideal" is in quotation marks as a recognition that it would be difficult to identify a truly ideal measure, but that the goal of this task would be to get as close as possible to "ideal."*

- Determine gaps between an "ideal" measure and currently available data – identify gaps based on the literature review findings and the "ideal" measure data needs.

- Identify surrogate measures based on available data – develop measures resembling the "ideal" measure(s) that can be tested given available data.

- Pilot test measures – pilot test the surrogate measure at a minimum of three locations in the United States.

- Innovation and research plan – identify additional research needs based on results of the research.

CHAPTER 3. RESEARCH FINDINGS

LITERATURE REVIEW

The literature review found no "ideal" or universal multimodal transportation system performance measure or approach. There is clearly a strong focus on measuring performance through speed, delay, and reliability. The identified measurement processes focus most substantially on the performance of the highway system, for reasons of historical priority naturally buttressed by the most prolific data, now being enhanced through crowdsourced data from GPS devices. Transit performance measurement is making progress, aided by the increased use of automated vehicle locator (AVL) technology that provides continuous information on vehicle position that can be used to determine speed, delay, and on-time performance. The same types of technology innovations have not made their way to the non-motorized modes, although automatic counting devices are beginning to return data on usage for some bicycle facilities.

Discussions with a wide cross-section of experts and practitioners in the field supported the findings of the literature review: no method truly compares and accounts for all of our modal options in the planning and programming process, which sustains modal thinking and program silos. At the same time, discussions indicated a high level of interests in pursuing, defining and testing such a method.

AN "IDEAL" MEASURE

The literature review task confirmed the findings of the project work statement that transportation system performance measurement continues to be modally oriented. The orientation is primarily due to data limitations, resulting in a mode specific, facility-based analytical framework. This framework has become so ensconced in the profession that it is taken as a given. Thus, an "ideal" measure faces not only data challenges but conceptual and acceptance challenges as well.

Chapter 2 presents the reasons why a complete person trip perspective is best suited for an "ideal" multimodal measure. Complete person trips reflect a traveler's perspective, provide a rational basis for defining the system, and reduce aggregation challenges. The "ideal" measure should also be easily understood by professionals and travelers and provide feedback on system performance at any selected location, regardless of size, across the United States. Finally, because it provides a new perspective, the "ideal" measure can become a capstone for a new set of related, complete, trip-based measures.

The research team developed MSP as the "ideal" measure of multimodal transportation system performance. Productivity is the ratio of inputs to outputs in a production process and, for transportation systems, completed person trips are outputs, and network travel times are production inputs. The MSP is the number of completed person trips per minutes over a selected network/area and during a selected travel time. The higher the score, the higher the productivity.

Table 1 illustrates a calculation method for the MSP (others are certainly possible). Eight differing complete person trips are listed in table 1 along with travel times for each under three scenarios. Trips per minute for each trip is totaled across all trips to calculate the MSP. The first scenario presents a base condition. In scenario 2, the travel times for trips 4 and 5 increase, reducing the MSP to 0.26. In scenario 3, scenario 1 travel times stay the same, but a walk trip is added to raise the MSP to 0.32. It is worth noting that even though the added walk trip is slow, its overall travel time is consistent with the other trips, thereby raising the score.

Table 1. Multimodal system productivity calculation.

Person Trip	Travel Mode	Scenario 1		Scenario 2		Scenario 3	
		Minutes	Trips/Minute	Minutes	Trips/Minute	Minutes	Trips/Minute
1	Auto	40	0.03	40	0.03	40	0.03
2	Auto	20	0.05	20	0.05	20	0.05
3	Auto	35	0.03	35	0.03	35	0.03
4	Auto	30	0.03	40	0.03	30	0.03
5	Auto	25	0.04	40	0.03	25	0.04
6	Auto	20	0.05	20	0.05	20	0.05
7	Auto	45	0.02	45	0.02	45	0.02
8	Auto	30	0.03	30	0.03	30	0.03
0	Walk	NA	NA	NA	NA	30	0.03
MSP		245	0.28	300	0.26	275	0.32

The MSP measure is designed to provide feedback on the three performance perspectives listed in the last chapter:

- System productivity – the MSP is a direct measure of system productivity and table 1 illustrates how it quantifies productivity.

- Network efficiency – in concept, efficiency would be measured by dividing the MSP by network miles. To illustrate the concept, assume that over a year the 80th percentile MSP score for area A during the 8AM to 9AM hour is 10,000, and that the total number of network miles (roadway lanes, transit routes, bicycle and pedestrian paths) during that same time period is 100. The resulting efficiency ratio is 1,000 completed person trips per minute per mile. In area B, the 80th percentile MSP score for the same time period is 18,000 over a 200-mile multimodal network, resulting in an efficiency ratio of 900 completed person trips per minute per mile, slightly lower than area A.

- System resiliency – in concept, resiliency would be measured by comparing MSP variations over time. For example, in area A during the mid-week AM peak period over the course of a year the average MSP is 8,000 person trips per minute with a standard deviation of 800. In area B over the same time period, the MSP average is also 8,000, but the standard deviation is 1,600, reflecting a higher frequency of disruptions, or lower network resiliency, or both in area B than in area A.

DATA GAP ANALYSIS

As noted in chapter 2, the MSP requires continuous and traced complete trip data. It also requires detailed network information. Standardized and detailed network data are readily available from several propriety and non-proprietary sources. Non-proprietary sources include Open Street for roadways, bicycle, and pedestrian facilities and General Transit Feed Specification (GTFS) for transit.

Complete person trip information is more elusive. Private companies such as Google, Apple, and Cubq, are collecting the data from mobile phones and GPS devices. GPS data provides accurate information but with small sample sizes. Based on GPS data, location-based services (LBS) data from mobile phone apps provide the same accuracy for an increasing number of trips. Companies such as Streetlytics, StreetLight, and Mobility Labs, are expanding GPS and LBS data into complete trip information using algorithms that weight sampled trips using points of interest data from the U.S. Census Bureau and private sources and other data. At the time of the research, only hourly auto vehicle trips averaged over a month were available from those vendors. It was speculated and confirmed by conversations with data vendors that Google collects large samples of complete person trips not only across the United States but across the world. Sample sizes would likely provide the type of continuous, multimodal data needed by the MSP, but privacy and cost issues make obtaining such data challenging.

The recommended MSP measure requires continuous and traceable complete trip information. Given the current limitations of such data, the research shifted to assessing the extent and quality of more conventional travel data collected through electronic traffic counting technology, transit AVL and passenger counter (known as APC) systems and GTFS-fed traveler information systems, and bicycle-pedestrian counting programs. Those data require surrogate measures, ones that attempt to replicate the MSP with the limited data. The first surrogate measure is total person trips, which approximates the MSP by estimating total system demand for any given time period. Person trips is the summation of total trips across study area segments. The second is "weighted person trips," which approximates the productivity of travel across the network. Weighted person trips is estimated in three steps, the first calculating PMT by segment (segment person trips multiplied by segment length), the second summing PMT across facility segments within the pilot test study area, and the third dividing the summed PMT by the total travel time across those same facility segments.

PILOT TESTS

The three pilot tests conducted for this research determined the quality of data collected and the feedback from surrogate measures described in the last section. Specifically, the pilot tests determined how well the surrogate measures answered questions such as:

- How complete and accurate are collected data?
- How effective is the feedback from the measures in determining how well the system operates in concert to serve travelers, particularly during peak and disrupted periods?
- Can the measures provide insights on the source of problems and potential solutions?

Pilot Test Locations

A national scan of potential pilot test sites proved challenging because of the lack of multimodal data at any potential location. The lack of data was particularly true for bicycle and pedestrian data. The scan resulted in three pilot locations:

- The San Marcos to Escondido corridor north of San Diego (Figure 4) – This pilot study measured performance along a 5-mile multimodal corridor, which includes an expressway, arterials, light rail transit line, bus routes, and a dedicated bicycle and pedestrian trail.

- Crystal City in Arlington, VA (Figure 5) – This pilot measured the performance of travel into and out of a high-intensity, mixed-use center on the edge of downtown Washington, D.C. The area includes a robust multimodal network including a major arterial (US 1), local streets, Metro subway, Arlington bus routes, and bicycle and pedestrian connections.

- Downtown Philadelphia (Figure 6) – Like Crystal City, this pilot measured multimodal travel into and out of the Philadelphia Central Business District (CBD).

The pilot tests measured performance from differing perspectives. The San Diego pilot tested the surrogate measures across a multimodal corridor. In both the Crystal City and Philadelphia pilots, the perspective changed to measuring performance of trips beginning or ending in the study area.

The San Diego corridor was divided into three segments. The California Department of Transportation (Caltrans) provided the SR 78 count and travel time data, the North County Transit District (NCTD) provided count and travel-time data for its Sprinter rail and local bus transit systems. Bicycle and pedestrian counts, not travel times, were provided by the San Diego Association of Governments (SANDAG) for three locations along the corridor's bicycle and pedestrian trail.

In Philadelphia, the Delaware Valley Regional Planning Commission (DVRPC) collected highway, transit, bicycle, and pedestrian count data along a cordoned area surrounding downtown Philadelphia. The count locations have remained consistent during differing data collection periods so that DVRPC could track changes in travel among modes over time. Data collection periods extended over short periods (1 or 2 days at most). DVRPC did not collect travel times.

The study team developed roadway data in Crystal City from crowdsourced data provided by StreetLight, which were checked against a limited set of traffic count data provided by Arlington County. The StreetLight data was averaged by hour and month, and included segment vehicle counts, segment travel times, and origin-to-destination travel times and distances. The Washington Metropolitan Area Transit Authority (WMATA) provided tap-on and tap-off records for riders either entering or exiting the Metro transit system at the Pentagon City and Crystal City stations. Bus data from both WMATA and Arlington Transit provided daily on and off information for study area stops, but not information about travel times on the system. Arlington County provided bicycle and pedestrian count information from four locations in the study area. Bicycle and pedestrian travel time data were not available.

Figure 4. Map. Escondido to San Marcos (California) study corridor.[3]

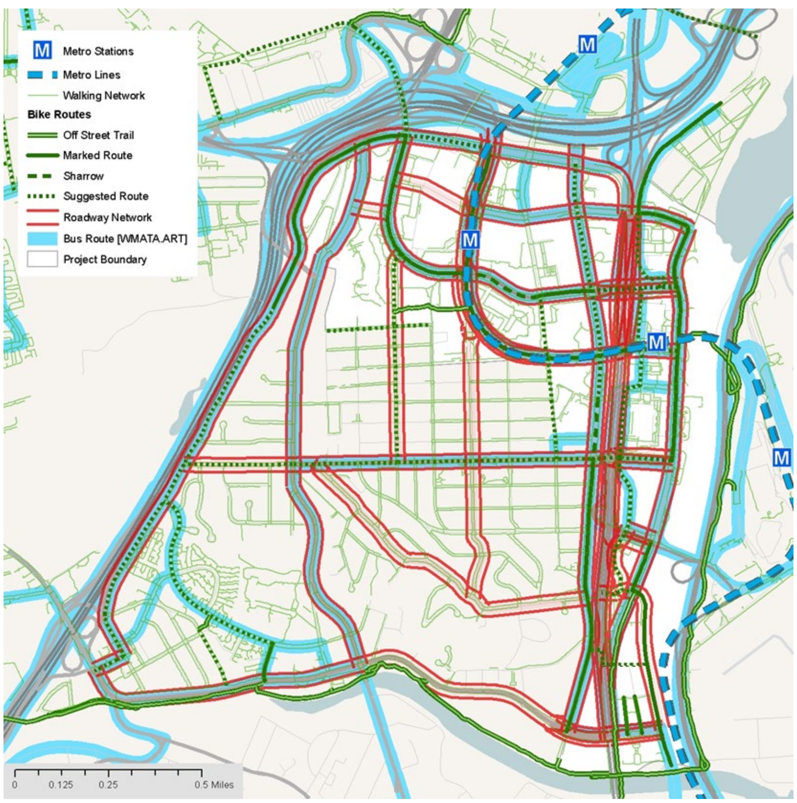


Figure 5. Map. Crystal City (Arlington, VA) study area.[4]

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[3] Baes map provided by Google, overlays by Renaissance Planning
[4] Map created by Renaissance Planning

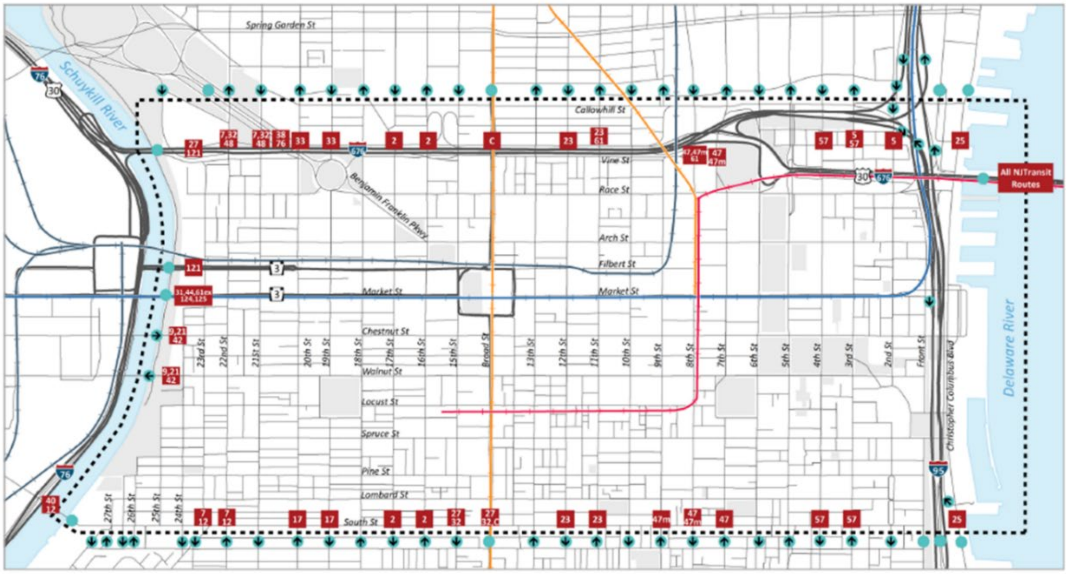

Figure 6. Map. Downtown Philadelphia study area (image provided by Delaware Valley Regional Planning Commission).[5]

Results

Data. To the extent they could be cross-checked, the facility-based, pilot-test data appeared accurate. The biggest data issues were inconsistencies in the timing, location, and types of travel data, making it difficult to paint a complete picture of multimodal performance for any of the pilots.

Measures. Despite inconsistent and incomplete data, the surrogate measures provided both expected and insightful feedback on multimodal performance. Insights of note include the following:

- Both surrogate measures accurately reflected roadway density and flow dynamics. Results during congested conditions on major roadways align with density and flow theories; vehicle densities reached a breaking point where both density (total trips) and flow (trips per minute) drop.

- Results from both surrogate measures suggested that vehicle trips divert from major roadways and use alternative travel paths during peak periods. Results indicated the larger roadway networks performed better than the major roadway in the network, suggesting that the typical practice of focusing on the performance of a major facility may overstate the loss of system productivity. Alternative routes appear to provide additional productivity that offsets, to differing degrees, the loss of productivity on the major road.

[5] Map provided by Delaware Regional Planning Commission

- Results from both surrogates indicate a performance boost from dedicated guideway transit during peak periods. Guideway transit accommodated a higher proportion of person trips during peak demand and did so with greater productivity.

- Bus transit and bicycle and pedestrian trips exhibit the same weekday peaking patterns as the other modes, but for the San Diego and Crystal City pilot sites tested, those modes did not add significantly to total person trips (less than 3 percent). Walking and bicycle trips (5 and 1 percent of total trips, respectively) provided a greater increase in person trips in Philadelphia, but were still comparatively low.

- Deviations in total person trips and weighted person trips were lower than anticipated. Major road deviations were highest during peak hours, likely due to saturation dynamics, while major transit deviations were lowest during peak hours, likely due to the consistency of commuting trips.

- While the measures did reflect extended disruptions, such as holidays and snow days, they did not demonstrate travel path and/or mode shifts during short-lived disruptions. This could be due to the coarseness of the data. It is also possible the measures accurately reflect the lack of travel path and modal shifts due to relatively short-lived disruptions. Travelers are committed to travel modes, and possibly paths, when incidents occur. It is possible that both are true.

Observations

Completeness and Quality of Data. The notable data problem uncovered by the pilot tests was the challenge of obtaining complete trip data. At the time of the tests, only complete auto vehicle trip data were available, and those data were provided as hourly averages by month, not continuous over small time slices. Because complete trip data were not available, pilot test results were unable to test the MSP measure (completed person trips per network minute).

The pilot tests uncovered other data problems, most notably the lack of coordination among agencies and modes when collecting travel data. An exhaustive national scan of potential pilot test sites identified only one location, downtown Philadelphia, with a coordinated multimodal data collection effort. The scan made it apparent that bicycle and pedestrian data are scarce, thus the availability of those data became the primary criterion when contacting agencies. Even with reasonable bicycle and pedestrian data, it was difficult to find locations where data from differing modes were collected during the same time periods, indicating that most data collection efforts support single mode performance measurement, not multimodal measurements.

System Definition

Confirming the system definition challenge highlighted in chapter 2, defining the pilot test networks was difficult because of the lack of information about travel demand and how it related to the selected networks. The study team defined the networks for two of the pilot studies (the Philadelphia pilot area was defined by the DVRPC). The San Marcos to Escondido study area was easier to define because it was larger than Crystal City (demand and network differences increase as the geographic focus increases) and because the network has a one-dimensional (east-west) orientation. Experience with travel demand in similar corridors, rather than a data based rationale, played a part in how to bound the study area. Crystal City presented a greater challenge because it was smaller and was designed to reflect how well the transportation system serves a place-based destination. Decisions about how to define the network were complicated. The most clear-cut decision was to include only ramps and not the mainlines of the expressways on the edge of Crystal City. This eliminated through trips from the analysis. Such decisions could not be made for arterials and transit.

When reporting on the relationships for major roads and premium transit in both the San Marcos to Escondido corridor and Crystal City, it had to be assumed that those networks served the same travel markets, a necessary and often taken-for-granted assumption in segment-oriented performance measures. It was possible in Escondido and Crystal City that the roadway and transit travel markets differ significantly, thereby leading to the erroneous conclusion that the major facilities in both areas worked together to serve demand. This potential travel market disparity was particularly true in Crystal City, where the network extended in several directions. To address this issue, the Crystal City pilot added an assessment of travel along the north-south US-1 and Metrorail corridor. Even then, the relationships between travel markets on both facilities likely differed because of differences in the areas served by the roadway and transit networks.

Aggregation Challenges. For reasons described in chapter 2, aggregating modal segment information into a single system measure was difficult. For the person trip surrogate measure, screenlines were used to account for over-counting person trips on segments. For the weighted person trip measure, segment person trips were multiplied by segment lengths and divided by travel times across aggregated segments.

In addition, it was difficult to create apples to apples aggregations across modes. This was particularly true for Crystal City where the network extends in different directions. Ultimately, the Crystal City segments were organized around the US-1 and Metrorail corridor.

What If?

Assuming complete person trip data were available for all three sites, it is likely the pilot test analysis could have been simpler and the feedback more straightforward and understandable. Areas, not networks, would have been selected and subdivided by parcels, geography based on U.S. Census Bureau data, or traffic analysis zones. Complete person trip data for a defined time period would have been collected for each subdivision with dynamic networks defined by the traced paths of those trips. An MSP score for each subdivision would have been determined by first calculating the number of person trips traveling between each subdivision (origin) and destination (origin-destination, or OD, pair), then dividing the total by the travel time between the OD pair, then summing the scores for all pairs (similar in concept to the example in table 1). The areawide MSP would be the summation of all OD pair scores. The overall MSP score could have been stratified in many ways, such as by mode, corridor, destination type, etc. The MSP scores could have provided insightful feedback on network efficiency and resiliency. While those place-based MSP scores could indicate poor performance to and from a given area, traced path information, in combination with facility-based performance analysis, would be needed to identify specific network problems causing the poor performance.

CHAPTER 4. INNOVATION PLAN

The study team understood at the outset of the research that measuring multimodal system performance required a fundamental change in perspective and a new set of data, and that developing such measures would occur in phases. This research represents the first phase of the overall effort, with the goal of gaining insights that could add specificity to needed research. The innovation plan presented in this chapter outlines three potential innovation initiatives, which in turn helped define potential topics for further research included in the next chapter.

DEVELOP AND OBTAIN MULTIMODAL SYSTEM PRODUCTIVITY DATA

As highlighted in earlier chapters, an integrated multimodal system performance measure requires complete person trip data. Conversations with data providers found evidence that this information is collected by companies such as Google and Apple but is not available for transportation planning because of privacy and business model issues. The first proposed initiative of the innovation plan is obtaining and/or developing accurate continuous and traced complete person trip data.

This initiative would explore options, such as:

- Reaching an agreement with Google, Apple, or other companies to provide the data. Such an agreement would address privacy issues, costs, access, etc.

- Working with vendors such as StreetLight, Streetlytics, and Mobility Labs to improve methods for expanding smaller sample sizes available from other companies. All three companies are using similar methods for expanding data and exploring new ways to improve these methods. For example, Google is comparing expanded data developed by Mobility Labs, an Alphabet company, to check the accuracy of these data.

- Working independently to identify methods for improving crowd source data. Such methods could include calibrating crowd-source data using travel data or developing apps which collect travel survey data.

- Work with other agencies and private companies to improve the information used to expand complete trip samples. For example, vendors use U.S. Census Bureau demographic data, and adjustments to the kinds of information that are collected could improve the expansion methods.

Differing mechanisms can be used to test the differing strategies, such as:

- Awarding demonstration grants (such as the Smart City or Advanced Transportation and Congestion Management Technology Deployment – ATCMTD - grants) to agencies and companies interested in testing strategies. Differing grants could explore each of the strategies listed above or others, allowing for comparisons that ultimately define the preferred strategy.

- Coordinate with stakeholder groups such as Transportation Research Board (TRB), the American Association of State Highway and Transportation Officials (AASHTO), and the American Public Transit Association (APTA) to develop and fund research on the strategies.

- Incorporating this initiative into existing performance management initiatives, such the Transportation Performance Management effort sponsored by the FHWA and the Transportation Performance hub and portals sponsored by AASHTO.

REFINE THE "IDEAL" MULTIMODAL SYSTEM PRODUCTIVITY MEASURE(S)

The second initiative of the innovation plan proposes to build on the concepts presented in this research and refine the MSP into a practical, implementable, and accepted measure. The types of refinements suggested include:

- *Further developing the complete trip perspective framework*. As noted in earlier chapters, a complete trip perspective and the concept of productivity underpin multimodal system performance measurement. This initial multimodal measure research effort may only touch on foundational concepts; more research may be needed to further define and understand the perspective, like the research undertaken over time to develop the *Highway Capacity Manual*.

- *Defining the MSP measure*. As noted earlier, the MSP can be estimated in differing ways. While estimation is not the ultimate objective (actual calculated performance is), it is a first step in better understanding the MSP measure. This step in the refinement process determines the optimal way(s) for calculating the MSP given the characteristics of available data.

- *Testing MSP applications*. This report identifies how the MSP can be used to provide feedback on productivity, efficiency, and resiliency. Detailed tests of the measure across those and other areas will refine and illustrate how the MSP can be used for planning, programming and management. and operations.

The mechanisms available to accomplish this effort are similar to those listed under the first initiative, including demonstration grants, funded research, and alignment with current performance management efforts.

CHAPTER 5. RESEARCH PROGRAM AND PROJECTS

The innovation plan presented in the last chapter lays out the proposed innovation initiatives for multimodal system performance measurement. This chapter suggests topics for future research needed to further develop and implement the MSP.

INNOVATION PLAN SUPPORT

The following sections list related research to support the innovation plan initiatives. Within each of the sections are recommendations for specific research projects.

Data Development Research

Research to Improve the Accuracy and Calibration of Data. Multimodal system measurement requires detailed network data and continuous, traceable, complete trip data. Detailed network data are readily available apart from bicycle and pedestrian facility data. Those data typically are updated continually by public agencies and private companies to account for errors and network changes. This research program focuses on methods for collecting and calibrating complete trip data developed from privately owned mobility devices and publicly owned detection devices.

- *Research to Further Develop and Apply Mobility Device Data.* Crowdsourced mobility data record time and location stamps for individual trips, resulting in traced complete person trip information needed by the MSP. Research will identify and develop methods for expanding and calibrating data, building on the work of companies such as StreetLight, Streetlytics, and Mobility Labs. It will also identify ways to download, manipulate, review, and store large datasets.

- *Research to Further Develop and Apply Travel Data.* Travel data record the number of trips counts and, in some cases, travel speeds, at recording locations to provide a means of enhancing and calibrating mobility data. Research will identify methods for calibrating mobility device data using travel information, including methods for optimally locating detection data collection devices for calibration. It will also identify ways to download, manipulate, review, and store data.

Research to Improve the Coordination of Multimodal Data Collection. Current travel data collection efforts reflect the modal orientation of planning and performance monitoring, resulting in a lack of complete, overlapping information across modes. The national scan for pilot sites conducted under this research confirmed this problem. This research also found that privately developed crowdsourced data samples are expanded with several data sources, including travel data, but those companies indicated calibration would improve with better data. A multimodal system performance measure will need a more coordinated, systematic data collection approach. The purpose of this research is to develop cost effective methods for coordinating the collection, sharing, and storage of network, crowd-source, and travel data.

Research into the Acquisition of Data. Crowdsourced data from private companies is not free. Increasingly, transportation agencies are purchasing those data for use across multiple agencies. For example, the Virginia Department of Transportation purchased StreetLight data for use by regional and local agencies across the Commonwealth. Research will identify innovative methods for acquiring data and negotiating cost effective data purchase agreements with vendors.

Measure Development Research

This Innovation and Research Plan focuses on the steps to implement multimodal system performance measures and acquire the data needed for such measures. It is but a first step in implementing an "ideal" measure. In the meantime, research in this area will focus on how to reframe traditional transportation performance measurement from a single mode, facility-based perspective to a multimodal complete trip-based perspective. The key areas of measure development research are:

Research into the Geography and Perspective of Multimodal System Performance Measurement. As noted in this report, multimodal system performance measurement introduces both scalability and perspective opportunities and challenges. Defining the system to measure, particularly at the corridor and sub-area levels, presents the primary challenge that could be simplified with complete trip data and a place-based perspective. Such changes will create a new analysis framework for most transportation agencies. Research will identify and develop methods for measuring multimodal system performance at differing geographic scales and from both perspectives.

Research into Measuring Multimodal System Performance Across Time. Changing travel demand puts different pressures on multimodal networks, particularly during periods of peak demand and system disruptions. This research will identify and develop methods that measure performance across time, with a focus on quantifying performance during peak periods and system disruptions.

Research into Reporting Multimodal System Performance. MSP scores will likely remain relative, requiring some sort of benchmarking to simplify reporting, similar to the highway level of service (LOS) grading system. The research will explore and develop reporting methods for the MSP and related measures, such as network efficiency and resiliency.

Measure Applications Research

The ultimate goal for the multimodal system measure is to provide meaningful feedback to planners, operators, decision makers, and the public. This proposed research would test and refine the measure for use in the following areas:

Research into Transportation System Management and Operations Applications. Operators could use MSP feedback to adjust operations across the system, with a focus on improving resiliency. The MSP is not likely to provide real time information in the near future because of the challenge of collecting count data, but it can pinpoint recent performance issues. For example, MSP scores could identify the advantage of implementing transit pre-emptive signal timing along a congested corridor. The research would focus on how system managers and operators could most effectively use the measures in their day-to-day operations.

Research into Transportation Planning Applications. Planners would use the MSP feedback to identify system problems and properly weigh multimodal improvement options, such as whether to take away a traffic lane for exclusive transit use. The research would identify how the measures could improve the coordination and cross evaluation of travel modes, from a system perspective, in the planning process.

Research into Project Programming Applications. The MSP can provide feedback to decision makers on the relative performance improvements of planned transportation projects. For example, the MSP could become another factor in the Virginia Department of Transportation's Smart Scale program. The research would identify methods to improve how projects are prioritized across modes and from a system perspective.

RELATED AREA RESEARCH

The following research topics focus on how multimodal system performance measurement can support or be supported by other programs, research areas and initiatives.

Research into Multimodal System Performance and System Resiliency. The science behind how management and operations can improve transportation system resiliency is under development and there is a clear relationship between that science and multimodal system measurement. This research would identify the synergies of data collection and analysis methods developed under both initiatives, such as the coordination of crowdsourced and travel data collection efforts.

Research into Multimodal System Performance and System Planning and Programming. The complexity of transportation planning and programming continues to increase yet performance metrics have not kept pace. As a result, many State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) are reluctantly planning and programming with outdated measures or developing new measures on an ad hoc basis. The research in this research project illuminated several important dynamics of multimodal system measurement, such as the need for and value of complete person trip data and a place-based perspective that could influence how transportation planning and programming are done. For example, place-based assessments could improve the integration of land use and transportation planning and with it, relationships between transportation agencies and local government. This area of research will explore the relationships between multimodal system measures and transportation planning, such as how such measures would influence the development of a MPO long-range transportation plan or possibly a local government comprehensive plan.

Research into the MSP and Travel Demand Modeling and Forecasting. A technical relationship already exists between the MSP and travel demand forecasting models used for transportation planning. Transportation models have long generated complete person trip information, yet despite this richness of data from models, it reflects the single-mode, facility-based orientation of the profession, that multimodal system measures have not been developed. Once multimodal system data and methods "catch-up" with travel demand models, it will be possible to evaluate performance seamlessly in the past and the future. This area of research will identify how to integrate the data and methods across both platforms, most notably, how multimodal system measurement data can improve the calibration of forecasting models.

Research into the MSP and Other Performance Measures. Although the MSP will add a new, more integrated perspective to performance measurement, it does not preclude the need for currently used mode specific, facility-based measures, such as highway level of service, and system measures, such as vehicle miles traveled. As noted earlier, facility-based measures can help diagnose the reasons for poor multimodal system performance. This research will identify how multimodal system performance and other measures can be used in concert to improve planning and operations.

SUMMARY

The innovation and research projects listed above are proposals developed from the insights gained from this research effort. The FHWA will follow its normal research development process and may undertake some of the proposed innovation and/or research topics identified in this report in the future. As of fall 2018, FHWA has identified a follow-on study for potential funding.

U.S. Department of Transportation
Federal Highway Administration

U.S. Department of Transportation
Federal Highway Administration
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https://ops.fhwa.dot.gov

June 2019

FHWA-HOP-18-085