Identification and Assessment of Transportation Performance Measures for Growth Management and Transportation Impact Assessment Applications

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1. Background and Motivations

In the last two decades, the U.S. Department of Transportation (USDOT) has increasingly stressed the importance of planning for all modes of transportation and not just for the automobile. This change in emphasis began with the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, which began to fund bicycle and pedestrian projects through the Transportation Enhancements (TE) program. This change in emphasis has been reinforced through a number of policy initiatives and official statements by USDOT. For example, in 2010, US DOT Secretary Ray LaHood issued a Policy Statement on Bicycle and Pedestrian Accommodation Regulations and Recommendations (USDOT, 2010) and the Livable Communities Initiative, which is an initiative between the Federal Highway Administration (FHWA), the Department of Housing and Urban Development (HUD), and the US Environmental Protection Agency (EPA) to coordinate and leverage federal housing, transportation, water, and other infrastructure policies in the Interagency Partnership for Sustainable Communities (PSC). The PSC uses the following principles to guide efforts: (1) provide more transportation choices; (2) promote equitable, affordable housing; (3) enhance economic competitiveness; (4) support existing communities; (5) coordinate policies and leverage investment; and (6) value communities and neighborhoods. Despite the federal policy statements supporting for all modes of transportation, much of transportation planning practice continues to use measures that do not provide adequate information to decision makers to understand the transportation impacts of various forms of urban development. The majority of the statutory rules, measurements, management strategies and accountability have been framed in terms of passenger vehicle trips. Furthermore, the primary evaluation tool for impact assessment of land development has been the Level of Service (LOS) concept, which has traditionally assessed the quality of service for passenger vehicles. A handful of communities have attempted to rigorously integrate and support all modes of travel and the movement of people, not just vehicles, within the project review processes. However, the topic is often approached as an afterthought to a vehicular analysis rather than an integrated and coordinated evaluation of viable mobility options.

With the increasing shift in focus of transportation planning from purely congestion-mitigation towards safety, livability, and economic development a clear and corresponding need for a set of performance measures that assess whether specific projects can help communities achieve the multi-dimensional goals. In this context, the objectives of this research are to expand the local transportation practitioner’s toolbox beyond vehicular-based LOS measures and recommend appropriate measures that could be used to support multimodal growth management, site design and site impact studies. This wider range of performance measures should address the needs of all travelers and support the development of multimodal mobility systems.

The rest of this paper is organized as follows. The following section presents an overview of a variety of performance measures based on an extensive review of the literature. Section 3 quantitatively evaluates two different types of development patterns using some of the identified performance measures and state-of-practice travel demand models. The paper concludes with a summary and conclusion of major findings.

2. Performance Measures and their Classification

A review of the literature resulted in the identification of over two hundred performance measures (documented in detail in Elefteriadou et al 2012). The extensiveness of this list makes it difficult for effective and practical application of these in planning applications. Therefore, we present a systematic classification of these measures. First, the measures are classified in terms of the specific planning objectives they address. Second, they are classified in terms of the application context. Finally, they are classified in terms of practical applicability.

2.1 Classification by Planning Objective

The planning objectives themselves might be different from agency to agency, as such, we present a classification across seven mobility-related planning objectives identified in study from Texas (Ramani et al., 2009). Given space constraints, we present only a sample of performance measures for each objective. An extensive set of measures by objective is documented in Elefteriadou et al (2012).

Minimize ecological impact:

Increasing land use intensity and density can reduce ecological impacts in three ways. High intensity land uses clustered in close proximity support travel modes like walking, biking and transit trips that have lower environmental impacts per trip. Reducing parking and building footprints or increasing shade through tree cover also reduces heat island effects and run-off. Clustering and intensification of land uses in appropriate locations can allow for the preservation of environmentally sensitive systems in other areas. However, the mere intensification of land uses without attention to the mix of uses that can be served within the scale of the pedestrian, bicyclist or transit user will not produce the mode shift desired and therefore will not produce the environmental benefits that accompany this mode shift. To understand the importance of these components, it is useful to consider each of them separately.

Density without a mix of land uses means that residents have few destinations within a typical walk or bicycle distance; they may need to drive or use transit in order to go about the activities of daily living available to them. A mix of land uses without density or connectivity means that people cannot easily walk from their residence to other non-residential land uses, though their vehicular trips may be shorter, thus reducing fuel consumption to some degree. Good street connectivity with a single land use or with low density residential affords few opportunities for interaction between people. Increasing internal capture can provide secondary support for environmental goals as well by reducing VMT, VHT, and vehicular trips. Increasing the cost of vehicular trips through increased fuel taxes or consumption taxes also supports an environmentally beneficial mode shift.

Increase accessibility:

The lack of coordination of land use and transportation can create neighborhoods that are inaccessible. For non-vehicular modes, the primary barriers are often in the realm of accessibility. The measures that assess the physical, safety and financial limitations associated with these modes provide insights into removing these barriers and increasing mode shift. From a land use perspective, the scale and quality of the land use mix can also support non-vehicular accessibility. Increasing vehicular accessibility can reduce trip lengths, provides route redundancy and promotes significant community benefit through congestion reduction, lower resource consumption and potential reduction in the need for future roadway facilities.

School accessibility is valuable to communities in both the short and long-term. Congestion due to school trips can account for a large percentage of the AM peak hour volume on some roadways, thus mode shift within the school population can reap immediate congestion related benefits to drivers as well as benefits to the student population in the form of improved health (lower rates of obesity and related health problems) and greater attention (the connection between physical activity and concentration is found in studies). In the long-term, students that become comfortable biking or walking to school may be more likely to continue that pattern throughout their lives.

Increase non-SOV travel:

To achieve mode shift away from the single occupancy vehicle (SOV), mere accessibility for alternate modes is insufficient. Transportation and vehicle design engineers have spent nearly a century making automobile travel convenient, safe, comfortable and efficient. Many of the measures included in this category address the same issues for users of alternate modes. Most of them reflect pedestrian, bicycle or transit environment variables. However, parking supply and land use mix at a pedestrian scale are also crucial considerations in unfacilitating non-SOV travel.

One major issue for mode shift is the way that costs for travel and parking are bundled together. For instance, in most high-density neighborhoods, the parking for a condominium is bundled as a part of the cost for the unit. Selling the parking separately in areas where transit is readily available and goods and services are within walking or biking distance provides a choice to the traveler that can encourage transit usage. Most drivers fail to recognize that the most significant capital cost for passenger vehicle travel--roadway construction--has been bundled into federal, state and local taxes. Major universities and theme parks have high non-motorized mode splits for many reasons including the fact that cost bundling within the typical financial structure is common. At a university, on-campus housing usually provides limited, expensive parking that is usually located at quite a distance from the living space. Parking costs on campus are controlled by a single entity that has little ability to buy additional land and high motivation to use their existing land resources for buildings rather than parking. Many universities bundle transit costs into either employee costs or student fees. Similarly, theme parks charge a premium price for parking adjacent to the major attractions, but provide extensive, free transit service throughout their properties for both their customers and their employees. Performance measures that account for these costs and bundling effects can be used to significantly impact mode shift away from SOV travel both within the development review process and within long-range financing and funding implementation.

Reduce congestion:

Many tools are available for reducing congestion. Most jurisdictions consider the addition of roadway capacity or system optimization to reduce vehicle delays before they consider other options. Parking pricing supply and demand management strategies, in conjunction with the provision of high quality alternate modes, can reduce congestion through mode shift. Increasing connectivity can expand the extent that the network that can be used for through travel, reduce the distance that drivers have to travel around unconnected areas and increase the opportunity for travel on foot or by bicycle. Improved land use mix can reduce trip lengths by increasing accessibility to goods and services or even shift travel to non-vehicular modes which also reduces congestion. Fuel taxes or transportation fees can also reduce vehicle miles traveled through reduction in the number of trips, trip chaining or other strategies to minimize overall travel costs. Incident reduction and management can reduce incident-related congestion.

Optimize freight movement:

Freight management is a significant component of the transportation system and is crucial for both economic vitality and congestion management. As commerce shifts to electronic forms and land uses intensify, the opportunity to purchase goods and services online can substitute multiple comparison shopping trips with single chained trips via freight delivery. The successful provisioning of a community can significantly decrease vehicle trips and reduce congestion. The high quality measures that directly impact freight movement include the ability to connect to intermodal freight systems (air, rail and fleet), the distances that must be traveled between distribution centers and locations within urban areas, and the continuity of street systems that reduces the number of difficult large vehicle movements.

Enhance safety:

Safety and security are broad topics and are impacted by a wide range of measures. Most communities track major vehicle incidents and crash rates. However, safety and security can also be significantly improved through increases in activity that accompanies improved connectivity within the pedestrian realm. Areas that have high amounts of pedestrian activity have more people watching for security threats. Therefore, the activity that comes from connected street and pedestrian systems, short distances to transit service and well-lit pedestrian networks can significantly impact the security of the area. The provision of transit service outside of peak hours reduces the risk of transit users being stranded. Assuring that a significant percentage of students have a safe accessible route to school reduces their risk of being in a vehicle crash and increases the opportunity for children to walk. Assuring that there is adequate funding to maintain high quality bicycle and pedestrian systems in good condition also reduces the chance for incidents on those facilities. Safety issues can also become an alternate source for funding facility improvements.

Reduce air pollution:

One of the primary uses of regional travel demand models is to provide input to air quality analysis. Factors that directly impact air quality are largely tied to the amount of time vehicles use the roadway, regardless of which criteria pollutant is considered. Therefore, both vehicle hours of delay and vehicle hours traveled can provide important information regarding air quality while simultaneously providing an indication regarding other environmental consumption issues like fuel consumption. Reduction in vehicular trips due to mode shift or TDM strategies will also reduce emissions.

2.2 Classification by Application Context

In addition to classifying measures based on the objective addressed, it is also useful to classify them based on the nature and applicability of the measures to specific contexts and modes (See Table 1 on the next page). *Measure classification* identifies whether a performance measure can be obtained directly from the observed field data or indirectly as an output from a (statistical/simulation) model, or represented as an index (combination of multiple measures). *Scale* relates to the context that a measure can be applied and ranges from project level to system level (network, local, or regional scale). *Target Mode* indicates the primary mode for which the measure is appropriate. Elefteriadou et al (2012) present an extensive classification of all measures along all these dimensions.

Table 1 Classification by Application Context

Performance Measure Characteristics	**Description**
Measure Classification	- **Measured** (**M**) performance measures can be directly measured in the field, but they may also be estimated using calibrated models or approved calculation procedures especially for future conditions. - **Estimated (E)** measures are generally data extrapolations generated from a limited data set. - **Index (I)** measures are collections of multiple individual measures that are aggregated and calibrated to provide a broad assessment of the quality of a system from multiple points of view. - **Model-generated (G)** measures are estimates that are extrapolated from detailed system-wide models of land use and transportation systems. Many of these model-generated measures have correlates in smaller-scale, measured variables, but take into account system level changes that could impact specific operations in specific locations.
Scale	Level of scale at which a indicator is typically applied: **Project (P), Network (N), Local/Jurisdictional (L), or Region (R)**
Target mode	Target modes for which an indicator measures influence: **Auto (A), Transit (T), Bicycle (B), Walking (W), or Multimodal (M)**

2. 3 Classification by Practical Applicability

The final classification is to assess the overall usability and usefulness of the measures based on the agency's needs and constraints. A review of the literature resulted in the identification of several major criteria for performing this assessment. These criteria are: (1) Technical feasibility, (2) Agency feasibility, (3) Affordability, (4) Technical usefulness, (5) Agency acceptability, (6) Multimodal effectiveness, and (7) Robustness. A detailed description of these criteria is shown in Table 2 below.

Table 2 Classification by Practical Applicability

Evaluation Criteria	Description
Technical feasibility	**Data availability and reliability**: The degree to which data to calculate, estimate, measure or model a specific measure is readily available or can be obtained at a reasonable cost **Methodology:** The degree to which tools or analysis methods are acceptable, measurable, and understandable, as well as interpretable **Predictability:** The degree to which an indicator produces outcomes that are predictable and consistent to infrastructure service providers, such as planners and developers
Technical usefulness	**Sensitive to changes that are significant to the system**: The degree to which an indicator is sensitive to the change of system such as new development

Evaluation Criteria	Description
	Measurable, target-oriented: The degree to which a measure produces quantitative outcomes that can be compared with a target level or benchmark **Trendable and predictive**: The degree to which a measure show trends over time and is predictive for future conditions
Agency acceptability	**Intelligible and credible**: The degree to which the political decision makers, property owners and/or the development industry can easily understand and trust the process or believe that the outcome is fair enough to meet the goals of measurement **Political acceptability:** The degree to which an indicator is acceptable to various political constituencies such as local government officials, regional government officials, the development community, business owners and executives, environmental groups, community groups, and various transportation advocacy groups **Market signals:** The degree to which an indicator encourages private sector to build projects with desirable characteristics in desirable areas as identified by a jurisdiction and discourages undesirable project characteristics in areas that are inappropriate or not yet ready for development.

Evaluation Criteria	Description
Agency feasibility	**Compatibility:** The degree to which an indicator is compatible with existing planning processes, including the degree to which an indicator requires a revision of the governance and/or decision making structure of existing transportation and planning agencies; and/or the degree to which the data required to perform the required analytical tasks are already being produced by existing transportation planning efforts **Legal, financial and structural sustainability**: The degree to which an indicator is sustainable legally, financially, and structurally **Applicability to funding process**: The degree to which an indicator can be used to generate funds for multimodal transportation improvements
Multimodal effectiveness	**Encourages transportation options:** The degree to which an indicator successfully encourages the deployment and use of well-functioning transportation facilities that serve multiple modes of travel **Mode neutrality:** The degree to which an indicator encourages person mobility without prescribing one specific transportation mode over another **Appropriate detail to reflect scale of the mode**: The degree to which an indicator includes adequate detail to assess the performance of a system at an appropriate scale for the mode considered (i.e. smaller scale and finer resolution for pedestrian and bicycle modes, larger scale and less resolution for vehicular travel)
Robustness	**Scalability:** The degree to which an indicator can be applied across multiple scales (project, local, or region) within an analysis area

Evaluation Criteria	Description
	Context sensitivity: The degree to which an indicator is sensitive to urban, suburban, or rural areas
Affordability	**Cost to implement and manage for public/private:** The degree to which an indicator increases the burden of doing business to the public and private sectors.

3. Project Level Case Study

To fully understand how these measures are implemented, it is also important to examine how they work within the context of evaluating an individual project. The objective of this paper is to apply some of these performance measures to an illustrative project. This will provide an avenue to describe the computational procedures associated with each measure, as well as highlight how the context, form and design features of a project can change the outcome of each measure, particularly as it relates to multimodal mobility. Also, the analyses can help identify where measures have the capacity to demonstrate the differences generated by these contexts as well as agency goals, and where they cannot.

3.1 Description of the Development of Regional Impact Project

The case study is a project at the scale that has regional impact, a so-called Development of Regional Impact (DRI), which is defined by the fact that it is likely to have impacts beyond a single jurisdiction. The site is located on land purchased for the reclamation of Lake Apopka in Orange County, Florida, just north of the City of Apopka. The portion of the parcel to be used is approximately 9,365 acres and is located along the northeast shore of Lake Apopka, near the Orange County/Lake County line.

The prototypical DRI is intended to replicate the scale of a small new town with a mix of residential, office, retail, civic and industrial land uses. Specifically, the following summarizes the development used in both scenarios:

- 3,647 Single Family Dwelling Units
- 1,353 Multifamily Dwelling Units
- 1,000,000 square feet of Retail Commercial Space
- 2,000,000 square feet of Office Commercial Space
- 500,000 square feet of Light Industrial Space
- 400,000 square feet of Civic Uses
- 750 student Elementary School (K-6th grade)
-

The land uses have been arranged into two configurations on the same land parcel. This is intended to contrast the typical suburban patterns seen within much of Florida with a land use form that is intended to strongly support multimodal travel. The first configuration uses a transit-oriented, traditional neighborhood development (TOD/TND) pattern. The second configuration uses the same land uses in a fairly suburban pattern typical of current development patterns throughout Florida (See Figure 1)

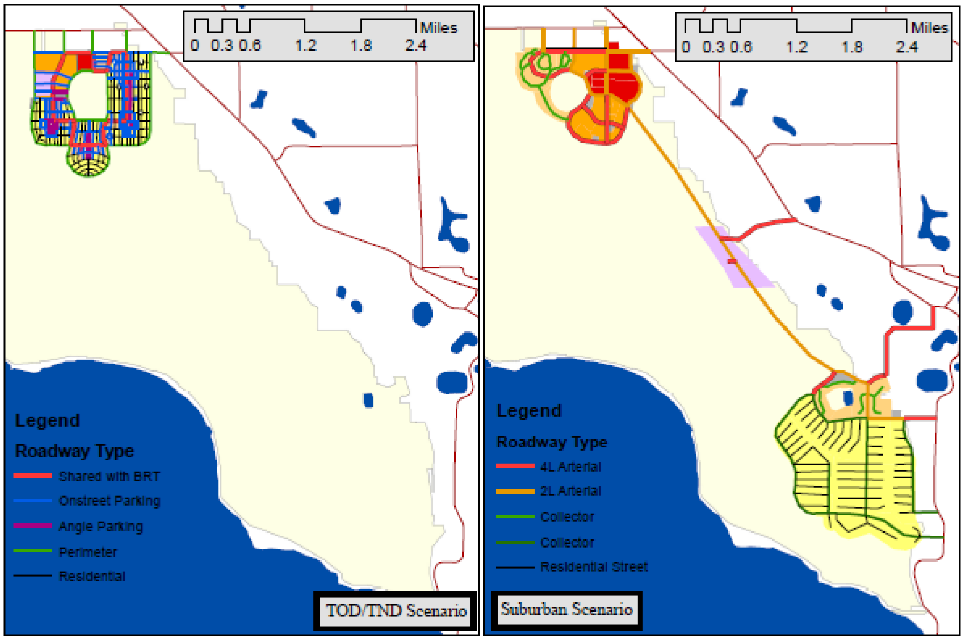

Figure 1 Scenario Comparison

TOD/TND Development

The first configuration uses a transit-oriented, traditional neighborhood development (TOD/TND) pattern. Regional-scale office and retail uses are clustered in their own ¼ mile radius, walkable districts on the northwest side of the project. The remainder of the development configuration consists of four, ¼ mile radius villages. The design for these villages is based on the land development code standards identified within the Alachua County TOD/TND Land Development Code requirements, because they are consistent with the typical TOD/TND design principles espoused within the new urbanist movement. The center of each of the 6-7 clusters are connected using a Bus Rapid Transit (BRT) system that operates within dedicated lanes. The BRT system is planned to operate with 5 minute headways during the peak hours and 12 minute headways off-peak. This system also connects to a commuter rail station located on the north side of the project.

The roadway network for the TOD/TND plan was laid out in a grid pattern with four residential villages that have commercial amenities located at the center of each village. Three (3) additional commercial villages are also created with a single land use type and within walking distance of a BRT stop. The design also includes a park and ride lot, also within walking distance of the regional rail station and BRT. Although Alachua County's design parameters intend for land use mix to occur vertically as well as horizontally, each zone is limited to one land use type. This is a simplifying assumption that is not likely to directly impact the results. The neighborhood village office and retail land uses occur in immediate proximity of each other, well within reasonable walking distance. The elementary school would be located immediately adjacent to one of the village centers. Therefore, nearly all of the students within the village adjacent to the school could comfortably walk to school, and arrangements for student passes could be negotiated with Lynx for the remainder of the villages. School bus service could not be provided for any of the students who live within the project because they are within the state mandated 2 mile radius.

Suburban Development

The second configuration uses the same land uses in a fairly suburban pattern typical of current development patterns throughout Florida. In the north of the parcel is a cluster of retail, office and multifamily uses adjacent to the major roadway system. This area is connected to a regional commuter rail station and has bus service operating at 20-minute headways. Near the center of the parcel is an industrial/office cluster supporting a local airport. A third cluster, to the south, contains residential uses and a Kindergarten-6th grade school. This cluster is in the vicinity of several other residential subdivisions and the regional highway system, and as such, would be considered a compatible continuation of the existing land use patterns. Transit service is not provided for either the center or southern clusters.

The suburban plan is assumed to have roadway cross-section features that are typical in Central Florida, and laid out in three large clusters. Rather than mixing land uses, each land use has a specific geographic concentration and is relatively consistent with the land uses adjacent to it in the surrounding area.

The northern cluster is located near the historic town of Zellwood. From a developer’s point of view, a commercial center would be an appropriate use adjacent to the intersection of Jones Road and US 441, although it would be a better site if it were actually in the corner of the intersection itself, rather than buffered by other property owners. The intersection has several commercial properties consistent with a future retail expansion. The closest full service grocery stores are approximately 5 miles to the south and 7.7 miles to the north. The office and multifamily cluster would also be considered good land uses to place in proximity to a commuter rail station. They are laid out in typical suburban fashion with a strong vehicle orientation and little clustering. A circulating transit line connects to the rail service but with 30-minute headways in the peak hours and 60-minute headways in off peak periods. In many areas of Florida, even suburban development forms are required to provide at least some transit service, particularly if a regional transit station is included as a part of the plan. These headways are consistent with the transit service provided in most suburban areas within the Lynx system.

Near the center of the suburban scenario is a cluster of industrial uses. This cluster would include all three industrial parcels and would access US 441 via the existing driveway for the local airport. This airport has recently undergone significant expansion and can provide limited service for small scale jet traffic. The industrial parcels would be an asset to the airport, which has sufficient length to support limited cargo deliveries. The zonal structure for this area was relatively simple and consisted of just 3 zones connected to the supporting through road.

The southern cluster includes some of the multifamily and all of the single family dwelling units as well as the elementary school. Potential access to the regional highway system and the surrounding land use pattern would make a suburban residential cluster a common development scheme in this area. It would be designed to have access, if possible, to the John Land Parkway, a component of the western beltway which includes SR 429 and the proposed Wekiva Parkway.

Based on local standards derived from the City of Orlando school concurrency regulations, the project’s residential development program would be expected to generate approximately 750 students in Kindergarten through 6th grade. The location of the elementary school indicates that a handful of the single family units and many of the multifamily units would be within walking distance of the grade school. However, the majority of the units within the southern cluster of the project would not be provided bus access because they are within the 2-mile radius dictated by the State of Florida. Therefore, as in many areas in the state, the majority of the students would arrive by car because they live beyond the comfortable ½-mile walk distance but under the 2-mile bus radius.

3.2 Analysis Results

The fundamental purpose of this analysis is to look beyond the typical performance measurement framework (i.e., auto-based LOS) and identify additional measures that would support multimodal transportation solutions. This section provides a description of many of the performance measures identified within this study and a comparison of the outcomes for each of the two scenarios.

Some of the differences between the values of performance measures are a direct result of the assumptions made within the scenario. For instance, where a set of cross-sections are assumed, the resulting square footage of sidewalks is a direct outcome of that assumption. Mostly, these measures can be directly calculated using GIS tools without the explicit need for a travel-demand forecasting model. Other measures need the application of a travel-demand model. For this purpose, the design layouts were then translated into a travel demand model zonal structure and added to the FDOT District 5 Central Florida Regional Planning Model (CFRPM) 5.2 Florida Standard Urban Transportation Model Structure (FSUTMS) model. Both models use 66 zones with identical socioeconomic data characteristics, although the zones were arranged and connected differently. Thus, all analyses were performed according to state-of-practice demand forecasting/impact assessment methods using the currently operational demand model for the region.

Measures that do not need a travel-demand model are discussed first followed by measures that do need a run of the region’s four-step travel forecasting model.

3.2.1 Measures that do not need a Travel-Demand Model

Density can be defined as the number of persons per acre or the number of dwelling units per acre. Table 3 below summarizes several density calculations for the two scenarios. Development Intensity is the equivalent measure for non-residential development. It is usually measured in terms of either employees per acre or Floor Area Ratio (FAR), which is the ratio of the building square footage to the square footage in the development. In general, it can been seen that the TOD/TND scenario leads to lesser amount of land consumed and a greater density/intensity of development.

Table 3 Density and Intensity of Development

	TOD/TND scenario	Suburban scenario
Development area (acres)	737.47	1994.90
Percent of land Consumed	7.9%	21%
Residential area (acres)	514.31	1421.90
Non-Residential area (acres)	223.16	573.00
Dwelling Units	5,000	5,000
Non-residential size (ksf)	4,000	4,000
Population (person)	12,760	12,760

Employment (persons)	7,492	7,492
Density (person/acres)	17.3	6.4
DU/acre, project	6.8	2.5
DU/acre, residential	9.7	3.5
Density (employees/acre)	33.5	13.1
FAR	0.411	0.160

A land use balance identifies the diversity of land use for a zone by segregating into different land-use categories. Developing Sustainable Transportation Performance Measures for TXDOT's Strategic Plan (2009) developed a formula for measuring land use balance as:

$$Land\ use\ balance = \frac{\sum |P_i \times lnP_i|}{lnN}$$

Where,

P_i = the proportion of total land area allocated to each land-use classification; and

N = total number of land-use categories considered (residential, commercial, industrial, and institutional)

The balance value ranges between zero (worst, a single-land use) and one (best, equal-land use). The values of land use balance for the entire development area are 0.60 for both the TOD/TND and suburban scenarios. This means that the percentage of land allocated to each of the land uses is nearly identical between the two scenarios. Dividing the suburban scenario into the major three development clusters, the lack of land use mix becomes obvious. The mix in the northern cluster appears to be best of any of the scenarios. However, the balance of land consumed does not take into account the balance of population and employment, which is strongly tilted toward employment in the northern cluster.

Table 4 Land Use Balance Calculations

Acres by land use types	TOD/TND scenario	Suburban scenario	
Institutional	20.70	Northern	21.72
		Southern	17.92
		Total	39.64
Industrial	32.97	Central	181.86
Retail	47.36	Northern	148.94
Office	122.13	Northern	202.01
Residential	514.31	Northern	176.46
		Southern	1245.44
		Total	1421.90
Total	737.47	1994.90	
Land use balance	**0.60**	Northern	**0.88**
		Central	**0**
		Southern	**0.11**
		Entire	**0.60**

Transit-Oriented Residential/Employment Density

To calculate this variable, a ¼-mile buffer was created around all transit stops, and the population within that buffer was estimated. As Table 5 shows, nearly all of the housing and employment within the TOD/TND development is considered "transit supported," while less than 15% of the housing within the suburban plan can be considered "transit supported." The TOD/TND scenario has double the residential and employment density of the suburban scenario. Because most of the employment in the suburban plan is in the northern cluster, the percent employment with access to transit is fairly similar for the two scenarios. As the table shows, there is a significant increase in the potential for transit to be useful to a resident or employee in the TOD/TND project. The residential and employment densities within the ¼-mile buffer are significantly higher as well. The higher densities are more likely to support significant ridership for the transit service.

Table 5 Transit-Oriented Residential/Employment Density/Intensity

		TOD/TND scenario	Suburban scenario
Residences	Dwelling units within ¼ mile buffer (5,000 total)	4,362	751
	Acres within ¼ mile buffer	456.3	152.21
	Residential density (DU/acres)	9.56	4.93
	% of DU within ¼ mile buffer	87.3%	15%
Employment	Employees within ¼ mile buffer (7,492 total)	7,492	5,471
	Acres within ¼ mile buffer	216.9	336.74
	Employment density (jobs/acres)	34.54	16.24
	% of employees within ¼ mile buffer	100%	73%
	Employment square footage within ¼ mile buffer	4,000	3,156
	FAR[1] within ¼ mile buffer	0.412	0.215

Connectivity Index

Connectivity index can be defined in several ways. One simple way is to identify the number of intersections per acres, where intersections that only end in cul-de-sacs are not counted. A second way to calculate connectivity index is to calculate the ratio of links to nodes. Links are defined as a segment between nodes and nodes are defined as the ends of the segments (see Figure 2). All intersections are considered nodes and a cul-de-sac end is considered a node. A third way to calculate connectivity index is to identify the number of closed polygons per square mile. Using these measures, the TOD/TND development provides better connectivity than the suburban development as shown in Table 6, on the next page.

Table 6 Connectivity Indices

	TOD/TND scenario	Suburban scenario
Development areas (acres)	737.47	1994.90
Number of intersections	265	54
Links	466	155
Nodes	266	140
Number of polygons	211	29

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37. FAR=Floor Area Ratio=floor area/development acres/(43.56 ksf/ac)

Connectivity (intersection per acres)	0.359	0.027
Links/Nodes	1.75	1.071
Polygons per mile	183	9.3

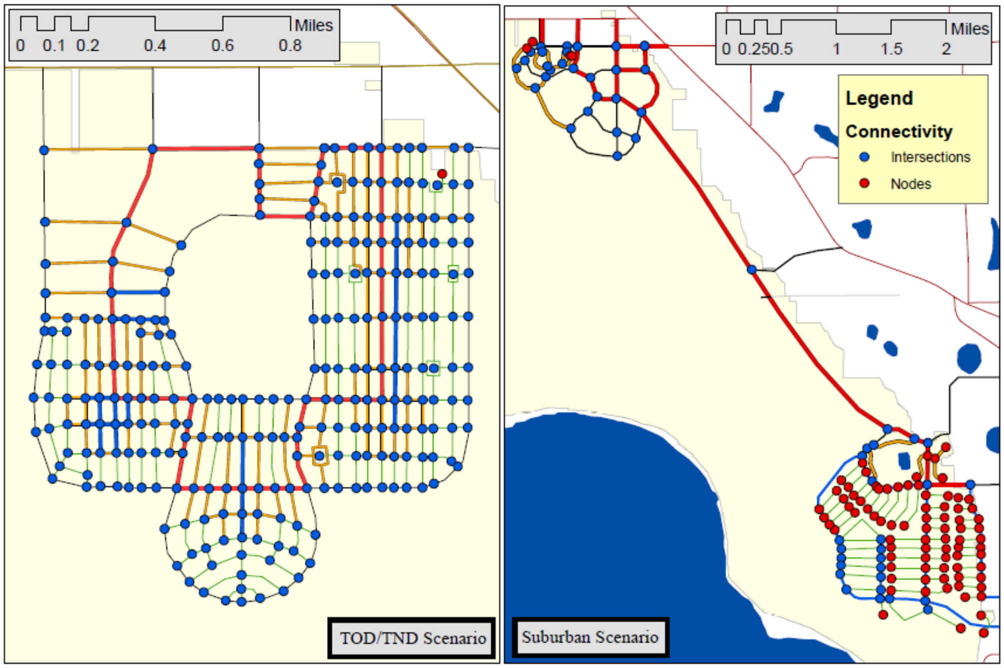

Figure 2 Intersections and Nodes for Connectivity Calculation

Percent of Network that is "Effective"

"Effective" roadways are defined as paths that are not cul-de-sacs. In other words, it is the roadway network that can be used to effectively move from one area of a community to another. In the suburban development, 72.6% of the network is effective, and there are no ineffective roadways on the TOD/TND development due to the grid structure.

Lane Miles per Capita

The suburban plan has approximately 96.7 lane miles of new roadway provided by the project (both within the project and as improvements to the surrounding area) while the TOD/TND project provides only 75.44 lane miles of new roadway. This corresponds to 6.66 lane miles per 1,000 population in the suburban plan and 6.07 lane miles per 1,000 population in the TOD/TND plan. This is an interesting result in that the roadway construction needs are fairly similar. However the earthwork for each of the two projects will be substantially different since the TOD/TND scenario uses only 37% of the land used in the Suburban scenario.

Percent Miles Bicycle Accommodation

Percent miles bicycle accommodation is defined as the percent of the roadways that have bicycle path. Within the TOD/TND development, the entire network provides bicycle accommodations of some kind, while only 72% of the network in the suburban development accommodates bicycle use.

Percent of Residential Areas within 1 Mile of an Elementary School

Figure 3 compares the 1-mile buffer around the elementary school site in each scenario, at the same scale. The TOD/TND plan has 99.6% of its residential areas within 1-mile of the school, while the suburban plan has 43.6% of its residential areas within 1 mile. One mile is a long distance for students to walk to school, but is half of the state mandated 2 mile bus service exclusion area and a reasonable distance for bicycle travel. All of the roadway facilities within the TOD/TND scenario are walk and bicycle-friendly. As can be seen from Figure 3 below, nearly all of the students in the suburban single family development will not be within a reasonable walking or bicycling distance from school and over half of the students in the multifamily portions of the project are not within the 1 mile radius.

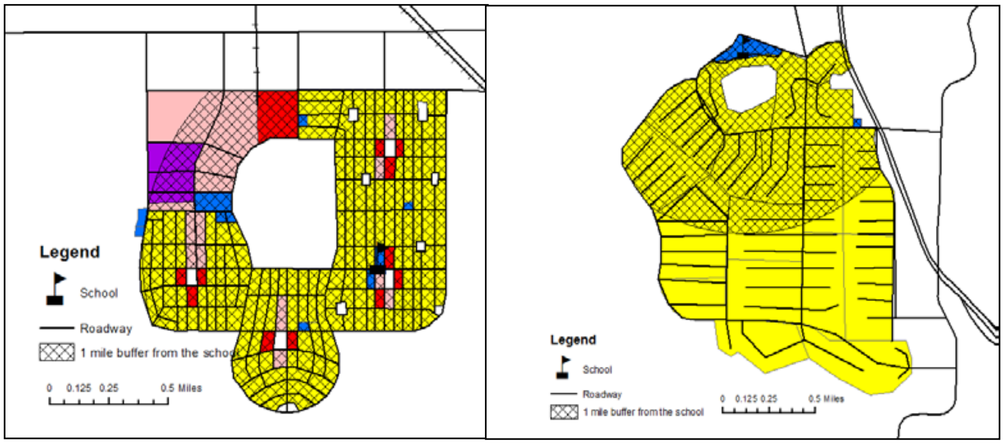

Figure 3 Residential Areas within 1 Mile of an Elementary School

Square Feet of Pathways/Sidewalks, Bicycle Lanes, Roadways

Designing Sidewalks and Trails for Access (FHWA, 2006) provides the definition and design widths of sidewalks. Design width is defined as the width specification the sidewalk was intended to meet; it extends from the curb or planting strip to any buildings or landscaping that form the opposite borders of the sidewalk. Sidewalk design widths are required to be at least 60 in (5 foot). Based on this information, within the suburban plan, all sidewalk widths were designed to be 5 feet wide.

However, the TOD/TND plan is intended to have increased sidewalk widths in all of the cross-sections and lane widths that are directly tied to the street type. Table 7 shows the geometric parameters for each of the different specified cross-sections for both the TOD/TND plan and the Suburban Plan. Most communities are moving toward complete streets implementation, therefore bicycle lanes are included on most arterial streets and most local residential streets accommodate bicycle use. However, collectors often create a missing link in this system because they aren’t as accommodating to bicycle use as typical residential streets.

Within the TOD/TND plan, much of the parking is shifted on-street, though not entirely. A detailed parking calculation is beyond the scope of this analysis, but it is interesting to note how much of the parking needs for the TOD/TND plan have been met through on-street parking. In contrast, the Suburban Plan assumes wide swaths of parking fields that can be a barrier to pedestrians and bicyclists.

Table 7 Square Feet of Roadways/Pathways/Sidewalks

	Total (mile)	ROW (ft)	Road width (ft)	Bicycle width (ft)	Sidewalk width (ft)	Road (ksf)	Sidewalk (ksf)	Parking (ksf)	Parking spaces
TOD/TND	**37.72**	–	–	–	–	**4,194**	**2,454**	**2,267**	**7,754**
BRT	3.94	100	42	10	25	874	520	–	–
Angle parking	1.85	103	29	10	12	287	117	377	1,332
On street parking	12.81	80	12	12	12	812	812	1,082	4,058
Perimeter street	6.53	66	22	12	6	759	207	276	1,034
Residential street	12.59	60	22	–	12	1,462	798	532	1,330
Suburban Plan	**39.82**	–	–	–	–	**5,989**	**2,102**	**551**	**1,378**
4 lane divided	8.53	100	48	8	10	2,162	450	–	–
2 lane arterial	7.29	55	24	8	10	924	385	–	–
SF/MF collector	10.95	47	24	–	10	1,388	578	–	–
Residential street	13.05	54	22	–	10	1,516	689	551	1,378

SF=single family, MF=multifamily, KSF=thousand square foot

3.2.2 Measures that need a Travel-Demand Model

The remaining performance measures discussed are products of the travel demand model and are subject to the strengths and weaknesses of the model. The currently operational four-step travel demand model was used in this study. Therefore, the model is indeed limited in its ability to determine the sensitivity of travel behavior to detailed land-use characteristics.

Work Accessibility

Destination accessibility can be influenced by the land-use type around the residential areas. Work accessibility is measured as one of destination accessibility types. The gravity-based measure discussed by Hansen (1959) is still the most widely used method for measuring accessibility, which is defined as:

$$A_{im} = \sum_{j} O_j C_{ijm}^{-2}$$

Where,

A_{im} = Accessibility at centroid i to potential work centroid j using mode m
O_j = Number of jobs at centroid j, and
C_{ijm} = Cost function to travel between i and j using mode m

We assume the cost is equal to the vehicular travel time between *i* and *j* by automobile (determined by a run of the travel demand model). Figure 4 compares different levels of work accessibility at every residential zone. Overall, the TOD scenario has roughly double the work accessibility as the Suburban Scenario (679,088 vs. 377,631).

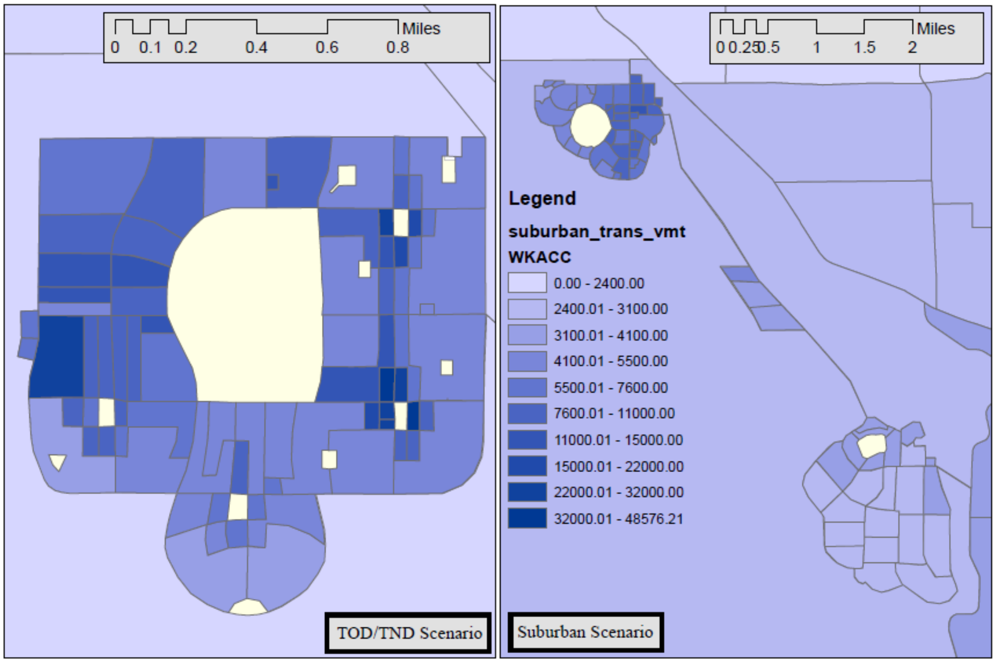

Figure 4. Work Accessibility

Projected transit ridership

The FSUTMS model produces an estimate of the projected ridership within the transit systems that have been programmed within the model. Table 8 summarizes the number of person trips and the number of person miles anticipated to be served on the transit systems available within each scenario.

Table 8 Transit Ridership Projections

	TOD/TND scenario	Suburban scenario
Local Transit (BRT or bus—whole line)		
Peak ridership	275.2	273.6
Off-peak ridership	31.4	187.8
Peak person-miles	541.02	565.9
Off-peak person miles	72.47	388.2
Rail Transit (project only)		
Peak ridership	154.2	28.9
Off-peak ridership	29.2	8.8
Peak person-miles	3154.93	591.29
Off-peak person miles	597.43	180.04

Travel Time Ratio

The travel time ratio is the ratio of time it takes to travel from an origin to a destination via transit, compared to the time it takes via passenger vehicle. For a typical work trip, one of the multifamily zones (Zone 1054) that is served by the local transit circulator system is used as the origin and the zone for Orlando City Hall is used for the destination (Zone 720). Table 9 summarizes the comparison:

Table 9 Peak (Work) Travel Time Ratio

	TOD/TND scenario	Suburban scenario
Transit trip (commuter rail, 2 transfers)	55.47	53.38
Transit Fare	$2.00	$2.00
Roadway Trip (27.88 miles)	39.72	36.37
Gas Cost [2]	$8.67	$8.67
Travel Time Ratio	1.40	1.47
Out of pocket cost ratio	0.23	0.23

The suburban plan makes up for the difference in transit accessibility through increased roadway accessibility, lowered congestion on US 441 and auto-access park and ride at locations closer to downtown.

Local Traffic Diversion

The internal roadway within the suburban plan, parallel to US 441, may divert some traffic from US 441, particularly any traffic using both the beltway and Jones Road. Based on the model results, the total roadway volume on US 441 without the parallel facility is 29,769 while with the parallel facility, the volume is 26,622. Therefore, the parallel facility diverts approximately 3,147 daily trips from US 441.

Vehicle Miles Traveled, Vehicle Hours Traveled, and Average Trip Length

One of the most powerful tools that the travel demand model provides is the ability to estimate travel distance and time between the Traffic Analysis Zones (TAZs) within the model. This information can be tabulated by zone within a relatively simple model script to generate the Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT) and the Average Trip Length (ATL) within each zone. VMT and VHT are calculated by multiplying the congested skims (either distance or time, respectively) with the output trip table. The average trip length can then be computed by dividing by the VMT by the number of trips produced by the zone. Furthermore, each zone has estimates for residential population and employment. Dividing the vehicle miles traveled by the population in the zone gives the miles traveled per capita in each zone. Table 10 compares the average VMT, VHT and ATL for the project zones. Although the internal circulator doesn’t make a significant difference in the VMT or VHT for either of the two scenarios, the development form does. The TOD/TND scenario is has saves roughly 11% to in VMT and 8% in VHT.

Table 10 Scenario Summaries for VMT, VHT, ATL

	TOD/TND scenario		Suburban scenario	
	No Transit	With Transit	No Transit	With Transit
VMT	534,682 miles	544,901 miles	601,527 miles	608,237 miles
VHT	252.95 hrs	264.80 hrs	279.38 hrs	279.18 hrs
ATL[3]	10.25 miles	9.79 miles	11.45 miles	11.18 miles

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38. Assuming 22.5 mpg (2009 National Avg) and $3.50 per gallon~~.~~.

Finally, Figure 5 compares the 2020 estimated LOS for the roadways (the classical performance measure) within a 5 mile radius of the project for the Suburban and TOD/TND plans, respectively. Based on these figures, it appears that the only deficiencies within a 5 mile radius are in downtown Mt. Dora or within specific interchanges. One segment of US 441 shows LOS “E” conditions. It would be expected that a more detailed analysis would identify intersection deficiencies in several locations.

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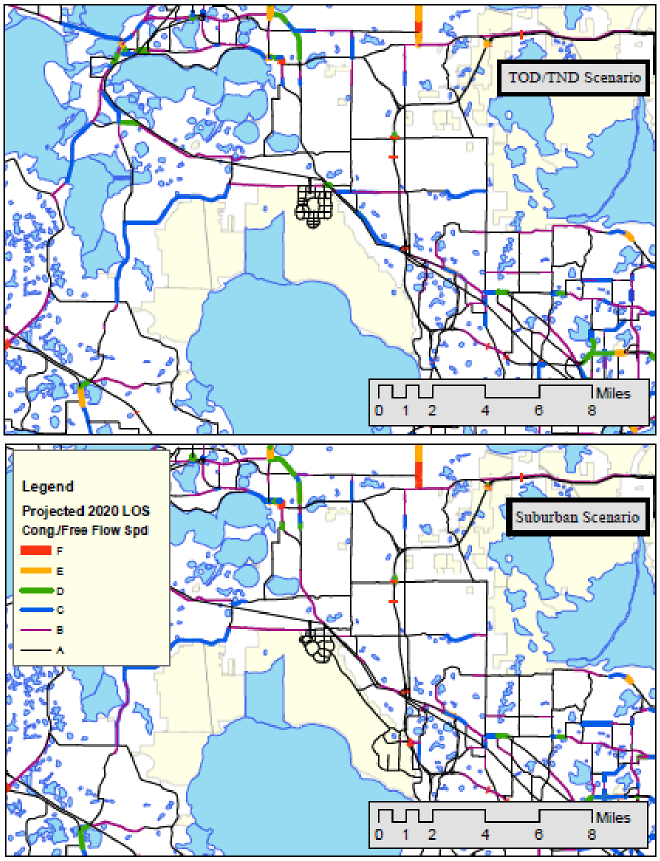

Figure 5 Estimated LOS

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3.4 Selection of Performance Measures and Implications for Practice

An agency’s goals will directly impact the performance measures that are selected and therefore provide a significantly different evaluation of the outcomes for a specific project design. Reviewing the case study land use scenarios from that perspective, if an agency’s goals are focused on congestion management, the two scenarios result in similar performance. The performance measures chosen would include measures such as trip generation, internal capture, LOS (segment and intersection level, which are based on trip generation), local traffic diversion, VMT and ATL. The addition of the new parallel facility in the suburban plan offsets the additional capacity needs that could have resulted from the lower internal capture rate.

Indeed, the offsite LOS impacts are nearly identical between the two scenarios. Even though the capacity relief to US 441 is minimal, a small relief can provide big changes in LOS and the connectivity to the western beltway would be seen as a plus, removing traffic from the interchanges on US 441. The majority of the mitigation required of the project would come in terms of turn lanes at intersections and interchanges within the study area. The small decreases in VMT in the surrounding community shown by both scenarios would be seen as a positive outcome, but would not significantly favor either project because the differences between them are so small. If transit ridership were considered, the low ridership levels indicated by the model results would seem to say that transit would not be a significant factor in mitigating any local congestion. Indeed, the expansion of bus service would be likely to increase congestion with minimal compensating mode shift. Land use balance might be considered in an effort to minimize vehicle trip lengths. However, the land use balance and ratio of employment to dwelling units are identical across the entire project regardless of the scenario, so these metrics would not favor either scenario as well.

On the other hand, an agency with goals related to mobility options is likely to choose an entirely different set of metrics and view the two scenarios as dramatically different. These include transit-oriented densities and intensities, connectivity, roadway network effectiveness, bicycle use, and number of residences within walking distance of a school. Land use balance would be considered important, but since mobility options are their goal, land use balance would be calculated based on the balance available within a walk distance or transit trip from the residences. This modification would highlight the segregated nature of the land uses in the suburban plan, showing where the segregation would inhibit pedestrian or transit interaction.

The transit ridership projections from the model would be examined critically to assess whether they are realistic in light of the services proposed and to determine if minor modifications to the service outside of the model parameters would make a significant difference in its use. At a minimum, the trip cost ratio tends to support the idea that transit would be more strongly utilized than shown in the model projections performed for this study.

The shift within roadway construction from drive lanes to bicycle and sidewalk construction would also be seen as supporting the goal of mobility choice. The on-street parking provided in many of the cross-sections would allow for land uses to be clustered at walkable distances rather than buffered by large parking fields that are unfriendly to pedestrians.

4. Summary and Conclusions

This paper identifies and discusses a wide range of multimodal measurement tools available to planners, transportation engineers and government officials. Although transportation professionals will continue to build roads and bridges, the scale at which we can do so is limited both by the immediate construction costs and the long-term maintenance costs generated by these facilities. Expanding our metrics to support a wider range of mobility options increases our ability to respond to travel demand in a more resilient and cost-effective manner.

This paper identifies and characterizes a large number of performance measures based on an extensive review of the literature. Starting with a list of objectives, an agency can select a broad set of potential performance measures. Next, a set of evaluation criteria are proposed to further reduce the list of performance measures that are appropriate for an agency based on its capabilities and resources, as well as existing transportation planning framework.

To examine how various performance measures could be applied at a project level, a theoretical development project is created and arranged in two scenarios. The TOD/TND scenario includes compact mixed-use development laid out in a gridded roadway network with a complete network of sidewalk, transit, and bicycle facilities. The suburban scenario includes a conventional single-use zoning strategy that incorporates limited transit, bicycle, and pedestrian facilities. From a congestion management point of view, the impacts of the two projects are quite similar. They are projected to have similar roadway infrastructure needs, both internally and externally, and similar offsite impacts. From a multimodal choice perspective, the two scenarios show marked differences that are likely to synergistically interact with travel impacts beyond what can be shown based on typical suburban-based review processes. A comparison of the two scenarios shows that a jurisdiction that focuses on congestion management alone would miss the distinction between the way the two forms function, while a jurisdiction focusing on the provision of multimodal choice would be able to see significant differences between the two scenarios. Examining a broader set of measures provided a broader view of the project’s potential outcome.

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