APPENDIX B

ASSESSMENT OF EVALUATION TOOLS

ASSESSMENT OF EVALUATION TOOLS

The research team assessed a variety of evaluation tools that can support transit planning for access to transit stations. This assessment emphasized tools with the ability to support the evaluation of the factors affecting access decisions identified in the research. A total of seven primary categories of tools were identified:

- Travel demand models
- Agency planning and ridership tools
- Economic development/market research tools
- Transit performance measures
- Vehicle emission and sustainability models
- Pedestrian friendliness/safety evaluation methods
- Bicycle friendliness/safety evaluation methods

For most of the categories listed above, some tools had already been assessed through the literature review or identified through stakeholder interviews. For these categories, the team relied on previously gathered information where appropriate, and supplemented as needed with previously unconsidered tools and more detailed consideration of previously considered tools.

The exception is the category of vehicle emission and environmental impact models, which were not previously considered in any detail in the station access literature. While environmental and emissions impacts were mentioned relatively infrequently during the literature review and stakeholders interviews as factors that transit agencies currently consider, the importance of these factors and tools to evaluate them is growing. Greenhouse gas reduction is an increasingly important goal of regional, state, and potentially federal policy, and the ability to assess transit station access alternatives with respect to emissions impacts is needed to support these goals.

Each category of tools is summarized in detail below.

TRAVEL DEMAND MODELS

Travel demand models are a familiar tool for estimating transit ridership and have been used for decades to predict transit ridership for line-haul services, especially large capital projects. Nearly all MPOs have demand models available, and most of these models provide at least some level of ability to estimate transit use. Thus, most transit agencies have access to at least some travel demand model without the need to develop in-house expertise in building and calibrating demand models. In general, high-quality travel demand models can enhance planning for access to transit stations by estimating ridership impacts of a wide range of access alternatives, including:

- Park-and-ride facilities;
- Transit-oriented development;
- Pedestrian network improvements;
- Bicycle network improvements;
- Bicycle parking;
- Transit fare integration;
- Parking pricing strategies; and
- Coordinated transit schedules to reduce transfer times.

However, many existing demand models lack the sensitivity needed to adequately assess the impacts of specific transit station access alternatives. *TRB Special Report 288: Metropolitan Travel Forecasting Current Practice and Future Direction* evaluated the ability of current travel demand models to meet a broad set of needs, including modeling transit demand. This report noted several issues with current travel demand models that impede their ability to accurately assess transit access modes. In particular, many current models have the following structural deficiencies that limit their effective use for assessing transit access strategies:

- **Travel behavior:** Traveler behavior is currently represented in a highly aggregate manner. Factors influencing travel behavior (e.g., value of time or value of reliability) for different sectors of the traveling public are impossible to model with the current four-step process. This makes it difficult to represent travelers' responses to access improvements such as fare integration, changes to parking pricing, fare and parking integration, real-time customer information, and improved transit scheduling to reduce transfer time.
- **Non-motorized access:** Many walking or bicycle trips take place or are affected by features wholly within a travel analysis zone and thus cannot be captured by many current models. One solution is to code a much finer-grained zone system; however, doing so imposes a major burden of labor and computer processing. As a result, many MPOs do not model walking or bicycle travel. This makes it difficult to evaluate the impact of such initiatives as pedestrian and bicycle network improvements, increased bicycle parking, and TOD.
- **Sensitivity to land use:** Many regions wish to consider options other than transportation capital improvements for addressing future mobility needs, including increases to overall density, urban growth boundaries, intensification of development around rail stations, and mixed housing and employment. Travel demand models must be sensitive to these variables to be able to model land use policies.

Partially for the reasons described above, *TCRP Synthesis 66: Fixed-Route Transit Ridership Forecasting and Service Planning Methods* surveyed current transit agency methods for estimating ridership and found that only 51% of agencies of use demand models for ridership forecasting. This result suggests that many transit agencies are unsatisfied with currently available demand models. Further results of *TCRP Synthesis 66* and alternatives to travel demand models are discussed in the Other Ridership Tools section.

A survey of modeling practice identified seven separate efforts to develop modeling procedures that accurately capture transit access mode choice, which are summarized in Table B-1. Each of the models is described in more detail in *TCRP Web-Only Document 44: Literature Review for Providing Access to Public Transportation Stations*. The travel demand models reviewed here do not comprise the full body of knowledge related to transit station access modeling; it describes a subset of the published research. Because travel demand models must be calibrated specifically to local conditions, none of the models reviewed here may be directly applied to model transit station access in other regions, and similar tools may not be generally integrated into current MPO models.

However, these tools demonstrate the feasibility of developing transit access models tailored to local conditions and describe methodologies that have been used successfully to create models sensitive to transit access in the past. In addition, a review of these models suggests several specific factors that appear highly correlated with access decisions and will likely be important in any transit access model:

- Parking cost and supply;
- Quantity and quality of feeder transit service;
- Type and diversity of land uses;
- Residential and employment density;

- Quality of pedestrian facilities;
- Station area demographics;
- Safety;
- Auto ownership; and
- Travel time

Factors that are positively correlated with auto access include parking supply and auto ownership, while factors positively correlated with walking access include density and land use mixing. No one model incorporates all of the factors listed above, and some are used as proxies for other factors. For example, higher densities and a mix of uses tend to be correlated with higher quality pedestrian infrastructure. Each model is also summarized in the literature review.

Table B-1 Travel Demand Model Summary

Travel Demand Model	Line-Haul Systems Modeled	Access Modes Considered	Sensitivity to Access Alternatives	Description
Walk-and-Ride Factors	Heavy Rail (BART, WMATA)	Walk; Other	Auto parking availability; Feeder transit availability and quality; Residential/ Employment density; Land use diversity	Regression and binomial logit analyses predict the probability of a transit passenger choosing to access the system by walking. Useful for comparing relationship between access modes.
Joint Access Mode and Railway Station Choice	Commuter Rail (Dutch National Railway)	Auto; Transit; Bike; Pedestrian	Line Haul service quality; Bicycle parking availability; Auto parking availability; Auto ownership; Feeder transit availability and quality	Aggregate (postal-code level) nested-logit model for both station choice and station access mode based on service quality for each station. Used for comparing alternatives with sensitivity to key factors (demographics, line-haul mode, station design).
Access Journey to Railway Station	Commuter Rail (Dutch National Railway)	Auto; Transit; Bike; Pedestrian	Parking capacity; Feeder transit connections; Bicycle parking; Perception of station	Survey results are used to model passenger satisfaction with access and egress trips to commuter rail stations, and the extent to which the quality of the access/egress journey plays into the perception of the overall rail trip. This quantifies the effect of the access experience on rider satisfaction.
Travel Behavior Analysis	Light Rail (St. Louis MetroLink)	Park-and-Ride; Kiss-and-Ride; Transit; Pedestrian	Station area design; Land use diversity; Pedestrian environment quality; Safety; Demographics	A disaggregate multinomial logit model was estimated with four potential mode choices based on survey results. Key characteristics include age, gender, race, vehicle availability, crime, distance from station, sidewalks, traffic volume, and intersection density.
Design Determinants of Walk Access Trips	Heavy Rail (BART)	Walk; Other	Demographics; Density; Auto parking availability; Land use diversity	Identify determinants for walking trips to the station by combining individuals' socio-economic characteristics and aggregated station area characteristics in the model. Useful for comparing alternatives as it combines many sources of data to provide a comprehensive analysis of station access features.
Commuter Rail Users' Access Mode Choice	Commuter Rail (CalTrain)	Auto; Bike; Pedestrian	Trip purpose/distance; Auto ownership; Intersection density; Proximity of high-volume roadways; Race; Gender	This model estimates access mode choice to the Mountain View, California CalTrain commuter rail station. Two binomial logit models were estimated: one for Auto vs. Walk access and the other for Auto vs. Bike access. Effective in estimating access mode share based on station area demographics, and the potential demand for various types of access improvements.
Metro Station Access Mode Choice	Heavy Rail (Athens Metro)	Auto; Transit; Walk	Auto ownership; Access time and cost; Gender; Age	Disaggregate access mode choice model based on market segmentation accounting for trip purpose and availability of auto. Useful for comparing station area populations and predicting access mode choice.

OTHER RIDERSHIP TOOLS

As described above, numerous travel demand models capable of assessing the impacts of at least some transit access alternatives have been developed. However, these models are not generally available to transit agencies for planning for access to transit stations, as the cost and data requirements of developing such sophisticated demand modeling tools are prohibitive for many MPOs and few transit agencies have resources to develop their own models.

As a result, many transit agencies use other methods to estimate ridership. Table B-2 summarizes the responses collected for *TCRP Synthesis 66*, which collected information on ridership estimation methods currently used by transit agencies. This report found that just over half of all transit agencies use their regional travel demand models for ridership estimating. Instead, the majority of transit agencies rely on more qualitative methods of forecasting ridership, such as judgment or rules of thumb. Relatively few transit agencies use econometric models or regression analyses, with only one out of every five identifying them as a forecasting technique.

Table B-2 Ridership Forecasting Techniques Used By Transit Agencies

Forecasting Technique	No. Agencies Responding	Agencies Responding (%)
Professional Judgment	29	83
Rules of thumb/similar routes	28	80
Service elasticities	22	63
Four-step travel demand model	18	51
Econometric model	7	20
Regression analysis	7	20
Other	7	20
Total responding	*35*	*100*

The following list summarizes some of the key findings from the TCRP synthesis:

- A wide variety of data sources are used in ridership forecasting. The most often used data sources include: ridership data from the farebox and from recent ridechecks; existing and forecast land use; census demographic data; and origin/destination data from onboard surveys.

- Simpler, less formal approaches are used for route-level and other small-scale service changes. Some of these “simpler” approaches have grown more sophisticated as GIS databases are used to assess demographic characteristics and identify similar routes and as APCs and ongoing programs improve the accuracy of ridership data.

- Use of elasticities is widespread for changes to existing service, particularly frequency changes.

In general, most of the tools described in *TCRP Synthesis 66* focus on line-haul ridership and tend not to consider aspects of transit access. This suggests the need for ridership tools that more comprehensively consider access attributes to better understand the ridership implications of proposed access improvements.

The tools described in this section vary from basic to complex depending on the funds and level of effort available to conduct forecasts. Simple tools, such as Metra’s method to assess the impacts of station consolidation on pedestrian access, provide transit agencies with effective approaches that are relatively simple to apply. More complex tools, such as BART’s Direct Ridership and Parking-TOD Trade-off models require significant investments to develop, but can provide valuable insight into a wide range of situations once they are developed.

Overall, transit agencies use a wide variety of forecasting methods that are designed to meet their unique needs. Some of these consider access to transit stations, while others have limited ability to assess access alternatives. The following section summarizes some of tools and methods currently in use and the level of access mode planning they consider.

Traditional/Professional Judgment

According to *TCRP Synthesis 66*, many transit agencies estimate ridership based simply on professional judgment. A typical analysis may consider several factors in developing ridership forecasts, including system ridership, land use, economic trends within the new service area, and consideration of analysis of similar routes serving similar areas.

The forecasting techniques described here include rules of thumb, similar route analysis, and professional judgment. These techniques typically rely heavily on past performance, and thus have limited usefulness in assessing previously untried techniques or accounting for broader policy or demographic shifts.

Service Elasticity

Many transit agencies use service elasticities to forecast the ridership impact of frequency changes. These values are then calibrated upward or downward based on its previous experience, depending on existing route frequency, similar routes, and setting. Service elasticity, when employed as a ridership forecasting tool, generally does not consider access modes. However, where elasticities related to aspects of access services are available, it can be a useful tool for estimating the ridership impacts of various access alternatives.

TCRP Report 95: Traveler Response to Transportation System Changes is a common source for average elasticity values, although many transit agencies supplement this report with agency-specific elasticities based. Related to access planning, *TCRP Report 95* addresses park-and-ride and transit-oriented development: Chapter 3, Park-and-Ride/Pool identifies the relationship between parking supply and demand and a variety of related factors and their impacts on ridership.

Chapter 17, Transit-Oriented Development in *TCRP Report 95* does not identify specific elasticities, but instead offers a general approach to characterizing and evaluating how a project will function as a TOD. It can also be used as a preliminary design-planning guidance tool. The TOD Index identified the following indicators, which are summarized in Table B-3. For each of the indicators identified in Table B-3, the TOD Index targets desired values for successful development projects.

Table B-3 TOD Index

Essential Indicators	Supportive Indicators
Centrally Located Transit	Street Widths and Driveways
Pedestrian Priority	Roadway Access
High-Quality Transit	Housing Types
Mix of Uses	Ground Floor Transparency
Supportive Density	Car Sharing
Parking Management	Transit Support

Transit Agency Ridership Model

Large transit agencies in major cities are able to develop and maintain models of their entire transit network. These models may include multiple service modes in the network as well as walking and driving access links. *TCRP Synthesis 66* cites New York MTA as an example of such model. MTA uses their electronic swipe fare cards to compile boarding and alighting data to generate detailed origin-destination trip tables. The model is used to identify future service changes by using census-based trip tables projected into the future.

Data from electronic fare cards can be supplemented by a variety of sources, including trained traffic checkers, farebox/turnstile data, origin-destination data from travel modes, census and demographic data, existing and forecast land use, and economic trends and forecasts. Short-term forecasts are based on ridership trends and known land uses, whereas long-range forecasts use detailed socioeconomic forecasts. Short-term forecasts can be completed within 1 to 5 days by service planners, including time for supplementary ridechecks. A simple long-term forecast can be completed in one week; however, more complex forecasts of alternatives can take up to a year. Ridership forecasting models are often used as tools to test various scenarios, and this can be an open-ended process until a satisfactory service is planned.

Some transit agency ridership models are powerful enough to adequately model station access modes; however, most agencies do not have such tools available.

Linear Regression Models

Linear regression models are a commonly used tool for ridership forecasting, and can vary considerably in complexity depending on the data available to calibrate the model. Simple regression models are unlikely to be sensitive to changes in access, while more complex regression models will have at least some sensitivity to changes in the quality and quantity of access services to transit stations. In particular, parking availability is a commonly used factor.

According to *TCRP Synthesis 66*, TriMet uses simple regression models that were developed in-house for three different types of service and calibrated using actual route data. Separate equations are used for each service type. Inputs to the regression equations include only population, non-retail employment, and retail employment located within ¼ mile of the transit stop/station. Thus, this particular model is insensitive to nearly any change in access.

Kuby, Barranda, and Upchurch present a more comprehensive linear regression approach for estimating ridership at light-rail stations. Their model is based on both station-area and regional characteristics and was estimated using data for 268 light-rail stations in nine American cities. The model estimation used multivariate linear regression to test the effects of independent variables in five categories: (1) traffic generation; (2) intermodal connection; (3) regional; (4) network structure; and (5) socioeconomic. Several access-related factors were determined to have significant effects on stations boardings, including the amount of parking provided and the number of available bus connections.

In general, the model is not specifically focused on access issues. However, the linear regression coefficients provide a simple method to estimate the impact to ridership for alternative station access and development scenarios. For instance, the ridership coefficients for parking spaces and residents are 0.77 and 0.09, respectively. This indicates that a ridership-neutral TOD strategy would require 8.5 new residents for every lost parking space.

OTHER AGENCY TOOLS FOR PLANNING ACCESS

Several tools have been developed for use by transit agencies specifically in planning for access to transit stations. These tools may incorporate ridership estimates as a portion of the tool's output, but are not solely focused on ridership impacts. This section summarizes these other tools. In some cases, the tools described here may be applied directly to other transit agencies; for others, calibration to insure that model parameters (e.g., elasticities) match local conditions would be required before transferring the tool. The tools relate primarily to planning TOD, park-and-ride, and feeder transit services, and help planners assess the trade-offs associated with each.

Willson and Menotti developed a spreadsheet-based tool for BART designed to weigh the economic and ridership tradeoffs between various station-area development and parking supply alternatives. By studying alternative development scenarios at stations, analysts are able to estimate what level of parking and development investment will yield the greatest level of benefit to BART, partner transit agencies, and local municipalities. Ridership impacts include both riders lost due to reduced parking and new riders gained through transit-oriented development. Financial impacts include changes in parking revenue and the ability of new development to pay for itself through rent.

Thirteen total model inputs are used, including current access mode shares, parking costs, elasticities, and land values. BART uses the model to identify good TOD opportunities, and estimate reasonable replacement parking requirements that match conditions at individual stations. The exercise is not purely mathematical and requires some understanding of the local conditions, context, development opportunity, and community. The scenarios are developed by determining a variety of qualitative characteristics for each station, including station type, population, employment, parking, access modes, and relevant municipal or transit operator plans. Replacement parking possibilities are also address by answering questions on parking utilization, off-site parking supply, nearby station parking supply, and other contextual questions.

BART's model was created through a spreadsheet-based methodology, which makes it relatively easy to apply. While the methodology is applicable to any transit agency, a significant amount of data would be needed to calibrate model parameters to local conditions. The original development costs for the model were approximately $30,000-50,000, which BART was able to attain due to the ready availability of an abundance of data. In particular, BART has been the subject of much research related to regional impacts and TOD. Other transit agencies wishing to adopt BART's tool for their use or implement a similar tool may face significant data acquisition costs, including identifying specific TOD ridership data.

A similar model was employed by Fehr & Peers to assess the effects of TOD on ridership and access mode share. The model forecasts the individual effects of TOD, parking supply, and bus service on BART boardings and modes of access and egress. These were based on statistical analyses of existing BART ridership to correlate station-by-station ridership with station-area parking, bus service, TOD households and employment, and other factors. To evaluate the ridership effects of replacing parking spaces with TOD, the model identified a "balance-point" which represents the parking replacement rate required to maintain the existing number of boardings when adding TOD at the station. On average, this rate was found to be 80 percent parking replacement. When comparing alternatives, this tool is useful to assist an transit agency and its partners in balancing the priorities and trade-offs associated with auto parking and station area density. Using this model, planners can optimize station access provisions according to regional land use and development goals.

Levinson, Adams, and Hoey developed a conceptual model for evaluating the cost-effectiveness of park-and-ride versus feeder (bus) service. The results indicate that feeder service is often more costly in low-density areas than parking, due to the long distances buses must travel to pick-up and drop-off passengers. Levinson also shows how transit facility parking can complement downtown parking supply by setting forth planning procedures for estimating the number and location of park-and-ride facilities. By studying the origins of downtown parkers and the likely growth in the CBD, this analysis identifies the demand for outlying park-and-ride facilities. These demands are then allocated to various geographic sectors based upon their relative future population.

Metra has employed a heuristic model to estimate impacts of station consolidation. Using existing station access data (% walk access mode share and distance walked), and assigning that information to the new station location, planners identified average current walking distances/time, and new walking distances/times. Using that information they then extrapolated the estimated percent decrease in travelers associated with the planned consolidation. This tool can be used to assess impacts associated with station consolidation or other service modifications. Data collection for this analysis is relatively simple and readily accessible, but it provides meaningful results on which decisions can be confidently made. It is designed for agencies and decision-makers to weigh trade-offs and identify optimal solutions, specifically with regard to access mode choice.

ECONOMIC DEVELOPMENT

Many communities and transit agencies are beginning to consider the relationship between transit service and economic development. Transit-oriented development and similar strategies rely on high-quality transit service to stimulate station-area demand for housing and commercial development. Municipalities and transit agencies jointly seek to implement these programs through subsidies and zoning changes for the associated benefits each hopes to realize. For municipalities, the stimulated development has short-term and long-term benefits associated with new and high-intensity development in areas that may have been underutilized. Transit agencies support transit-oriented development as a way to boost ridership and fare revenue.

The balance between the desire for station-area development and maximizing ridership can set up a difficult conflict for transit agencies. TOD is targeted at stations with land available for such new development, which often occurs at stations with high levels of automobile parking. Removing those parking facilities to accommodate new development often means sacrificing existing customers for new ones. The tools identified in this section can be used by transit agencies looking to optimize the benefit of station-area development and parking and maximize ridership and fare revenue.

Access is seldom specifically measured by economic development tools. Rather, the analysis examines general transportation and land use trends within a station area or region. The tools described in this section will help a transit agency determine whether transit-oriented style development policies, accompanied with transit investment, are likely to spur economic development in the station area. These sorts of policies would favor non-auto modes of transportation, and will limit the amount of parking an agency can provide at the station.

Attitudinal Market Segmentation

Attitudinal market segmentation is based on the premise that there are underlying preferences of individuals that can't be explained by demographics. Surveys of residents (riders and non-riders) are used to gain insights into the propensity to use transit and acceptance of transit by examining characteristics of transit and non-transportation lifestyle choices. Statistical techniques are used to create distinct attitudinal groups that can be marketed to through product, pricing, and promotional strategies. For example, a market group could be very "earth-conscious" and willing to bike to a station if that option were made accessible through bike paths.

This type of attitude is inherent in the success of TOD, which appeals to certain types of people who are willing to trade off single family homes and larger lots with the convenience of higher density living, if given a choice. Other populations that may have similar demographics are very auto oriented and will only respond to transit if a parking space is available, even if there is a charge for the space. Understanding these markets and tailoring the access plan around the different customer expectations should result in a stronger overall plan and higher ridership.

Transit agencies with sophisticated market research activities may be able to apply this technique and begin to include this customer perspective into their planning activities. This technique requires local surveys to determine the specific attitudinal markets in which the agency operates, and where the various segments are concentrated. These segments can be related to land use, service, pricing, travel times and other local conditions, to add further depth to the analysis. The "Transit Competitiveness Index" (TCI) developed by Cambridge Systematics, Inc is one example of this technique. This tool uses market segmentation based on demographic data to prioritize locations for transit improvements based on travel corridors with a high number of potential riders.

Land Use Models

Land use models are generally recognized as useful tools for forecasting land use inputs to transportation models and for analyzing the land use effects of transportation projects. Unfortunately, the complexity of most land use models gets in the way of their widespread use by planning agencies. However, land use modeling is evolving to create simpler and more easily applied models. For instance, the Land Use Scenario DevelopeR (LUSDR) is a land use model that incorporates most of the land use behavior and policy sensitivity desired in a land use model and yet has a simple structure and manageable data requirements. LUSDR operates at the level of individual households and employment establishments and microsimulates location decisions of land developments. The model produces a synthetic population of households having the attributes of size, workers, age-of-household-head, income, dwelling tenure, and dwelling type.

The LUSDR model incorporates regional transportation plans in developing its land use models. Using a tool such as this, municipalities and transit agencies can test the effect of creating TOD-style zoning around transit stations. From this analysis, the modeler can determine the potential economic development benefit of higher density zoning around transit stations.

Oregon's Statewide Integrated Model (SWIM2) uses an economic input-output activity allocation framework, an aggregate model of spatial development and micro-simulation models of freight and person transport. Population and employment shift to areas of comparatively better accessibilities, urban densities change, trip lengths and modes change, and floorspace development and prices respond to these changes in patterns that evolve across the state over time. Analysis conducted with this model can identify the potential consequences of different policy, social, or economic conditions on land use and transportation.

SWIM2 is designed for use on a much more macroscopic scale than would be ideal for station-area analysis. However, it may make sense from a regional planning perspective to assess the value of TOD-friendly policies and activities, specifically forecasting the effects of transit on such development.

Economic Impact Analysis Tools

TCRP Report 35: Economic Impact Analysis of Transit Investments: Guidebook for Practitioners studied a variety of methods to evaluate the economic costs and benefits of transit investment. Table B-4 summarizes some of the key tools identified in the report and provides several options for forecasting and measuring the economic impacts of transit investment.

Table B-4 Economic Impact Analysis Tools

Economic Analysis Tool	Sensitivity to Access Alternatives	Description	Limitations
Economic Forecasting and Simulation Models	Employment potential; Public financing availability; Individual income	Models based on the inter-industry production-consumption functions of input-output models, and can account for factors such as business cost, competitiveness, the shifting mix of population, and business characteristics. They also differentiate between the short-term impacts of constructing a transportation investment and the long-term impacts of maintaining and operating it, and the growth and expansion of user benefits over time.	Costly (often $15,000 to $20,000 just to purchase the model) and require substantial economic expertise. Forecasting and simulation models rarely predict impacts below the county level.
Multiple Regression and Econometric Models	Land value; Employment; Transit service quality	Infers causal relationships between a dependent variable, such as employment, land values, or building square footage, and various explanatory variables, including the existence of a transit investment, and transit service levels.	Difficult to fully specify every relevant variable and collect needed data.
Physical Conditions Analysis	Land value; land availability; Ease of station access	Identifies opportunities for development within a proposed transit corridor since transit investment will influence development in a corridor only if land is available and the market conditions within the corridor are competitive with other areas of a region.	Not practical on a region-wide scale.
Real Estate Market Analysis	Land value	Traditional market analysis to identify the competitive position of the corridor, or specific sites within the corridor, relative to other areas within the region. Helps to determine whether existing conditions in the corridor will support new development and the degree to which the location of transit stations might increase the corridor's development potential.	Requires extensive real estate analysis experience and data.
Development Support Analysis	Transportation network operations; Employment density; land use mix	Identifies the total square footage of development that could be supported by the improved transportation capacity provided by a transit investment. It measures the number of additional trips that could access the study area without reducing the roadway level of service below a specified level.	Requires extensive real estate analysis experience and data.

VEHICLE EMISSIONS MODELING

As environmental awareness increases, the benefits of transportation improvements in reducing emissions are of interest to both the public and environmental planners. Analyses of station-related emissions need to serve several distinct purposes:

- To provide transportation planners and the public with an indication of the emissions benefits (or possibly costs) of planned access improvements;
- To feed regulatory processes relating to emissions (in particular air quality conformity determinations) with accurate emissions estimates that often cannot be analyzed within the traditional travel model frameworks; and
- To demonstrate that projects funded through the Congestion Mitigation and Air Quality (CMAQ) program do in fact contribute to emission reduction objectives.

A comprehensive emissions analysis of station access improvements can be a complex undertaking due to the number of potential pollutants involved, and the number of potential emissions sources. For example, sources can include:

- **Passenger car** VMT increases due to park-and-rides, and decreases due to shuttles and other services;
- **General traffic flow changes** resulting from reduced VMT, and potentially from street system and traffic operations changes in the station area;
- **Transit bus** VMT increases due to service changes. Fuel options such as CNG, clean diesel, and other technologies must be accounted for as well, since new equipment purchases often use alternative fuels;
- **Shuttle bus** VMT increases due to service changes. Alternative fuels are less likely, but nonetheless should be considered;
- **Pedestrian and bicycle** activity changes (not a source of pollutants, but should be accounted for in the travel analysis).

The range of pollutants to be evaluated depends on the air quality attainment status of the jurisdiction. Typically the list of pollutants includes ozone precursors (hydrocarbons and nitrous oxide); carbon monoxide; and particulate matter (PM_{10} and $PM_{2.5}$). In addition, while greenhouse gas and energy consumption standards have not been set, impacts on CO_2 and energy are often desired as inputs to climate change policy evaluations. The effect of transit service changes on $PM_{2.5}$ can be particularly troublesome in an analysis of this type, since buses are high emitters of $PM_{2.5}$ and bus VMT increases that drive the amount of $PM_{2.5}$ can be difficult to mitigate.

As of this writing the available tools for computing emission rates are changing. USEPA's family of MOBILE software—most recently MOBILE6.2—has been the principal source of emission factors for decades. However USEPA released a draft of its new MOVES software in April 2009 which provided expanded and more accurate estimates of on-road emission rates. USEPA expected to release the final version for public use in December 2009. While MOBILE6.2 can be used in the interim, MOVES will produce higher estimates of NO_x, $PM_{2.5}$, and CO emissions than MOBILE6.2, and consideration should be given to using MOVES as early as possible.

Forecasting the impacts of transportation improvements on travel behavior is typically the most difficult part of an emissions analysis. Because improvements such as station area access can have a wide range of effectiveness, depending on the details of the strategy and its implementation context, great care needs to be taken to consider data and analytic approaches. Some components of proposed station area access treatments can and should be analyzed with the region's travel demand model, which typically provides the strongest basis for estimating effects on regional travel and mode choice. Other components of proposed station area access treatments are typically too finely detailed to be coded into and analyzed with the travel model; instead, they need to be evaluated using specialized off-model techniques. These techniques can be based on surveys, experience from other areas, elasticities borrowed from the travel model, logit or pivot-point models, or combinations of each. Methods for estimating trip reductions and travel behavior changes are discussed elsewhere in this report. These tools ultimately need to produce estimated changes in VMT and traffic flow conditions for each of the various sources described above.

To calculate the change in emissions that will result from travel changes, emission rates (in grams per vehicle mile) are obtained from the relevant emissions model (MOBILE6.2 or MOVES). These rates are then multiplied by the change in VMT resulting from the project to produce the emissions change.

Emission rates vary by vehicle type or source type (autos, buses, etc.) and should be separately determined for each. Emission rates also vary with vehicle speed, so the effects of the proposed station area access improvements on traffic flow should also be considered. Reductions in the number of vehicle trips (as opposed to the amount of VMT) will reduce the number of trip ends. The "cold start" that occurs at the beginning of a trip produces a higher amount of emissions than the remainder of the trip. However, as new engine technologies emerge these elevated cold start emissions are less significant. If the number of trips diverted from auto to transit is significant, however an analysis should consider the additional benefit of trip-end reductions.

Tools to compute emissions changes can be as simple as a spreadsheet to multiply rates obtained from MOBILE6.2 or MOVES by the change in VMT and trip ends. Or, the tools can be in the form of an integrated package that both estimates travel changes and applies the emission rates. Table B-5 describes several available off-the-shelf and customizable software packages that could be used for this purpose. Note that a significant amount of effort may be needed to customize and adapt any of these tools to a specific region's needs and data/modeling resources.

Table B-5 Off-Model Travel Demand Analysis and Emissions Estimation Tools

Method	Description	Source
TCM/Commuter Choice Model	Analyzes travel and emission impacts of transit, carpooling, vanpooling, employer-based strategies, etc.	USEPA Office of Transportation and Air Quality
TCM Analyst / EPA TCM Methodology	Analyzes travel and emission impacts of transit, carpooling, vanpooling, employer-based strategies, etc.	Texas Transportation Institute
CM/AQ Evaluation Model	Analyzes travel and emission impacts of transit, carpooling, vanpooling, employer-based strategies, etc.	Texas Transportation Institute
PAQONE and the AQ-ONE family of tools	Analyzes travel and emission impacts of transit, carpooling, vanpooling, employer-based strategies, etc. Thoroughly integrated with travel models and MOBILE6.2	Pennsylvania Department of Transportation; Michael Baker Jr., Inc.
Simplified Method for Analysis of Regional Travel (SMART)	Analyzes travel and emission impacts of transit, carpooling, vanpooling, employer-based strategies, etc.	Illinois Department of Transportation

In general, the following steps would be followed to estimate the emission benefits of station-area improvements:

1. Estimate changes in VMT, trip ends, and traffic flow conditions using travel models and/or off-model travel analysis methods, as described elsewhere in this report. These estimates should be developed for each of the vehicle / source types described above.
2. Estimate average speeds or, preferably, a distribution of speeds of each vehicle / source type. Traffic operations analysis techniques may be based on *Highway Capacity Manual* methods, sketch analysis, or simulation depending on the resources and context of the study.
3. Using either MOBILE6.2 or MOVES, obtain emission factors (i.e. grams per mile) for each relevant pollutant, and for the range of speeds developed in Step 2. The setups for these emission models should be consistent with the specifications used by the metropolitan planning organization (MPO) and/or air agency to account for current emissions control programs, meteorology, and other critical factors. Trip-end rates (i.e. cold-start emissions per vehicle start), if needed, may need to be estimated as a separate exercise outside the standard application of MOBILE6.2 or MOVES.
4. Multiply the change in VMT and trip ends (if needed) by their appropriate emission rates. Movement of VMT from one speed to another, due to traffic operations changes or other effects, should be calculated by deducting VMT and emissions at one speed and adding the same at another.
5. Accumulate and report the resulting emissions for each vehicle / source type and overall, and for each pollutant of concern

TRANSIT PERFORMANCE MEASURES

Transit agencies regularly measure system performance for the purposes of reporting, to identify needed improvements, and to communicate the results of those improvements. Performance measurement data provide transit agencies with objective assessments of current circumstances, past trends, existing concerns, and unmet needs. Features measured range from economic performance and service availability to safety and travel time. Several transit performance measures are also useful for measuring station access.

Stop Accessibility

TCRP Report 88: A Guidebook for Developing a Transit Performance-Measurement System is the primary literature resource for performance measurement for transit agencies. The Guidebook comprehensively details the tools and resources available to transit agencies, classified by function, line-haul mode, system size, and purpose. Stop Accessibility is a fundamental measure of transit performance. *TCRP Report 88* classifies the various tools available for transit agencies to measure the portion of the trip between the transit station and origin or destination. Examples of stop accessibility measures are summarized in Table B-6.

Table B-6 Stop Accessibility Performance Measures

Performance Measure	Description
Pedestrian Level of Service	Evaluates quality of pedestrian environment based on density, segment, intersection, and crossing measures. Attributes include geometry, vehicle volumes, vehicle speeds, separation from traffic, and intersection delay.
Bicycle Level of Service	Evaluates bicyclists' experience at intersections and on street segments. Based on traffic volumes, traffic speeds, intersection delay, roadway geometry, facilities, grades, and presence of on-street parking.
Percent of stops/stations ADA accessible	Identifies number of stations compliant with ADA regulations, based on grades, lateral clearance, surface hardness, etc. at or near a station.
Percent of park-and-ride lot spaces filled	Evaluates park-and-ride lot utilization to assess demand with respect to capacity.
Street-crossing difficulty	Evaluates pedestrians' perceived quality of service in crossing roads at midblock locations. Key variables include width of painted medians, signal spacing, turning movements, presence of pedestrian signals, and cycle length.
Number of bicycle rack spaces/bicycle lockers	Assesses opportunity to park a bicycle once a passenger arrives at a station.
Network connectivity index	The number of roadway links divided by the number of roadway nodes. A higher index means travelers have increased route choice, allowing more direct connections. A score of ≥ 1.4 is for walkable community.

Beyond those stop accessibility performance measures, transit agencies also use stop spacing as a gauge of the accessibility of service. Typically used when designing new routes or consolidating existing stations, stop spacing indicates the frequency of transit stations along a route. Spacing represents a trade-off between two competing goals: maximizing access to transit and minimizing travel time after boarding a transit vehicle.

There is currently no comprehensive measure of station access, such as a level-of-service grade, with which to evaluate access alternatives. However, proxy measures are available that can quantify the benefit of service improvements. Station access modes are not equal, and some are more cost-effective than others. Transit agencies invest very little capital or operational funds into accommodating transit riders who arrive by foot. Providing parking for bicycles and autos involves primarily capital costs and feeder transit service has significant operating costs. Cost per passenger or cost per new passenger quantify the level of investment a transit agency must make for each trip it accommodates. Access alternatives that emphasize ridership accessing the station by walking or bicycling will reduce cost per passenger compared with auto- or feeder transit-focused scenarios.

Service Coverage

The *Transit Capacity and Quality of Service Manual* (TCQSM) provides evaluation tools for assessing transit capacity and quality of service for a wide range of transit modes. It identifies several transit quality of service measures and assigns level of service (LOS) thresholds to these measures as part of a quality of service framework. Passenger access to stops is also identified as a factor that influences transit capacity.

One measure evaluated in the TCQSM is service coverage, defined as a measure of the area within walking distance of transit service. The planning-level analysis assumes a 0.25-mile (5-minute walk) radius around each local bus stop and a 0.5-mile (10-minute walk) radius around each rapid transit station. However, the detailed methodology reduces the transit stop service radius as a function of the following attributes:

- Street connectivity factor—reduces a stop's service coverage area in relation to the amount of out-of-direction travel a pedestrian is forced to make to get to a transit stop from the surrounding land uses.
- Grade factor—reduces the horizontal distance that pedestrians are able to travel in a given time decreases as the vertical distance climbed increases.
- Population factor—pedestrian walking speed (and thus distance walked in a given amount of time) is highly dependent on the proportion of elderly pedestrians in the walking population.
- Pedestrian crossing factor—wide, busy streets pose barriers to pedestrian access and pedestrians become impatient when crossing delay exceeds 30 seconds. Delays in excess of 30 seconds reduce a stop or station's service area.

Transit agencies can utilize this measure to more finely evaluate the coverage area of transit service supplied in a region. The TCQSM also provides guidelines for assessing park-and-ride service coverage. Studies indicate that one-half of a park-and-ride lot's users start their trip within 2 to 3 miles of the lot, and that the other half is drawn from an area four or more times as large. The TCQSM suggests a 2.5-mile radius around large park-and-ride facilities (typically 100 or more spaces).

The service coverage performance measure is useful for evaluating alternative station-area development scenarios, as increasing walking distance would affect a transit agency's service coverage population. Many of the factors influencing coverage are external to transit agency control or influence such as topography and population, which are generally fixed values. Understanding these conditions may help an agency plan appropriately. However, factors like pedestrian crossings and street connectivity are controlled at least in part by local and state jurisdictions that may be able to work with the transit agency.

PEDESTRIAN SAFETY AND FRIENDLINESS EVALUATION METHODS

Pedestrian access to transit stations is determined by many factors, including distance, urban design, pedestrian facilities, crime, and characteristics of individual travelers.

Based on the literature review, surveys of walk access trips show that some pedestrians walk between 0.5 and 1 mile to access transit, indicating that the traditional focus on only the first half mile by underestimate the actual potential for walking trips. Regardless of distance, transit riders who are inclined to walk to a rail station will do so if they feel safe from harm by motor vehicles and other people, and if they feel "welcomed" along the way through pedestrian-friendly design.

Pedestrian LOS

LOS is a method for measuring the quality of a transportation facility from the user's perspective. There are many models available to estimate pedestrian level of service (PLOS). These can be generally aggregated into tools measuring capacity or delay versus tools that attempt to measure the pedestrian experience. Tools measuring capacity or delay, such as those used in the *Highway Capacity Manual 2000* are most directly comparable to the traditional automobile level of service tools. The HCM 2000 approach essentially measured the available walking space or density along sidewalks, and the crossing delay at street corners, as these factors determine the speed at which a pedestrian can walk. However, several studies have determined that the independent variables identified in the HCM are inadequate in determining a pedestrian's assessment of the quality of the walking environment.

All models reviewed address pedestrian crossings and segments along the roadway separately. This is because the variables affecting pedestrians in these two situations are different. Along roadways, models generally incorporate factors such as proximity to moving vehicles, the volume and speed of traffic, design of pedestrian facilities and other features related to the sense of safety and comfort. At crossings, many models incorporate variables related to perception of safety such as proximity to traffic and volume of turning/crossing vehicles, presence (or absence) of amenities such as pedestrian signals and crosswalks. Models designed for crossings also address convenience.

NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets presents an approach for measuring pedestrian level of service. Researchers utilized video laboratory surveys to measure the accuracy of several existing PLOS models in calculating a pedestrian's perceptions of level of service provided in several settings. The goal was development of a model that best addressed real world pedestrian environments incorporating both segments and crossings. The resulting tool is an aggregate of existing PLOS models and has been incorporated into the *Highway Capacity Manual 2010.*

Several agencies and communities are incorporating PLOS into their routine planning. Generally, this work is being performed by the entity with responsibility for providing and maintaining pedestrian travelways. Cities are using PLOS in the development of their pedestrian master plans to identify the relative pedestrian-friendliness of different parts of the community. For example, Louisville, KY conducted a city-wide PLOS analysis utilizing the FDOT model in their 2004 study "Suitability of Louisville Metro Roads for Walking and Bicycling." The city used the resulting information in the development of a series of policies aimed at improving the walkability of the community in areas near schools, employment and commercial areas, parks and other areas with higher relative demand for pedestrian facilities.

Alexandria, Virginia developed a PLOS score for "walking along the roadway" and "crossing the roadway." The walking along the roadway scoring system approximates pedestrian comfort based on presence, width and condition of the sidewalk; traffic volume and speed; high speed corridors; presence of a buffer and on-street parking. Crossing the roadway scores reflect how difficult it is to cross a street for both pedestrians and bicyclists based on number of travel lanes crossed, ADT, speed, high speed corridors, presence of a median, signal type, presence of a signal.

Kansas City, Missouri, uses 5 PLOS measures:[1]

- **Directness**—does the network provide the shortest possible route?
- **Continuity**—is the network free from gaps and barriers?
- **Street Crossings**—can the pedestrian safely cross streets?
- **Visual Interest and Amenities**—is the environment attractive and comfortable?
- **Security**—is the environment secure and well lighted with good line of sight to see the pedestrian?

[1] http://www.kcmo.org/planning/walkplan/measure.pdf

Based on these measures, Kansas City developed minimum standards or thresholds for a given area or development type, including transit zones, shown in Table B-7.

Table B-7 Kansas City Pedestrian Level of Service Requirements

Pedestrian Level of Service Requirements by Pedestrian Area Type					
	Directness	Continuity	Street Crossings	Visual Interest & Amenity	Security
Pedestrian Zones, Great Pedestrian Streets	A	A	B	B	B
Mixed Use & Multimodal Transportation Centers, Transit Impact Zones	A	B	B	B	B
Neighborhood Activity Centers & Corridors	B	B	C	B	B
Schools/Parks/Community Centers/Libraries	C	B	B	C	B
Walking To/From Transit Stops	B	C	C	C	B
Other Areas Within City	C	C	C	C	C

Loudon County, VA developed county-wide pedestrian level of service 'target minimum' PLOS scores for different scenarios related to development status, planning area, school proximity and other factors. These PLOS targets are used in the scoping of transportation projects and review of applications for development. Table B-8 illustrates the county's PLOS target minimum scores and decision criteria.

With the exception of the Charlotte model, all of the models reviewed provide a quantitative method of measuring levels of service for pedestrians. When the same model is used within a single jurisdiction, comparisons can be made such as levels of accommodation provided in different areas, effects of different infrastructure improvements on pedestrian safety and comfort and identification of preferred routes to transit or other destinations based on PLOS scores.

However, there are shortcomings of the existing PLOS models that were reviewed for this section. With the exception of the Alexandria and Kansas City models, the models do not incorporate grade, cross slopes, presence of curb ramps or tactile warning strips or other elements related to Americans with Disabilities Act (ADA) considerations in their measurement or prediction of pedestrian LOS. As with any quantitative tool, the results are dependent on accuracy of data inputs. Although communities generally maintain fairly current records for the motor vehicle travelway, pedestrian facility data is frequently not incorporated into a jurisdiction's infrastructure inventory.

Table B-8 Alexandria, Virginia Pedestrian Level of Service Standards

	Applicability	Target Minimum BLOS	Target Minimum PLOS	BLOS Exceptions	PLOS Exceptions
Condition 1	New roads on new ROW, and in new developments throughout the County.	B	B	*C acceptable in certain situations	*C acceptable in certain situations
Condition 2	Improvements to Roads & Streets in Developed Areas: -Suburban Policy Area -Transition Policy Area -Joint Land Management Areas	C	B	*Major Arterials can be D in certain situations; provision of a shared use sidepath is recommended in these cases	*Major Arterials can be C in certain situations
Condition 2a	Roads & Streets within 1.25 mile radius of elementary, middle & high schools within Condition 2 Policy Areas	B	B	*Major Arterials can be C	*Major Arterials can be C
Condition 3	Improvements to Roads in the Rural Policy Area that have been selected for the Countywide Network	C	N/A	Highest BLOS that can be achieved or provision of an off-road pathway	N/A
Condition 3a	Designated Bike Route System within the Rural Policy Area	C	N/A	BLOS D and traffic calming, or route cannot be designated	N/A
Condition 3b	Rural Villages: Aldie, Bluemont, Lincoln, Lucketts, Paeonian Springs, Philomont, St. Louis, Taylorstown, Waterford	C	C	The highest BLOS feasible using traffic calming	The highest PLOS feasible using traffic calming
Condition 3c (When applicable, this minimum prevails over 3, 3a, or 3b.)	All Roads & Streets within a .75 mile radius of all schools within the Rural Policy Area	B or 5 foot paved shoulder	B or 5 foot sidewalk or paved shoulder	Accommodations sufficient to create a "safe walking route" to school, as determined by the LCPS Transportation Dept.	Accommodations sufficient to create a "safe walking route" to school, as determined by the LCPS Transportation Dept.

BICYCLE SAFETY AND FRIENDLINESS EVALUATION METHODS

Bicycle access to transit is determined by many of the same factors that influence pedestrians, including distance, urban design, bicycle facilities, and characteristics of individual travelers. Bicyclists traveling in the roadway are also impacted by pavement condition, traffic speed, traffic volume and heavy vehicles. Surveys of bicycle access trips show that many bicyclists will ride up to 2 miles to access transit, indicating that there is significant potential for increasing the number of passengers accessing transit by bicycle.

Bicycle level of service (BLOS) models provide tools for calculating a bicyclist's perceptions of safety and comfort when riding along a roadway. The BLOS models in widespread use generally measure perceptions of quality of the bicycling environment and not the capacity or volume of a given route. Furthermore, segments and intersections are generally addressed independently.

Bicycle Suitability Criteria: Literature Review and State-Of-The-Practice Survey provides a synopsis of the various tools used to predict the "suitability" of a roadway for bicycling. Drawing from the literature review, the authors propose three classifications of LOS models based on the criteria used:

- *Stress Levels:* simple evaluation criteria based upon curb lane vehicle speeds, curb lane vehicle volumes, and curb lane widths. Bicycle stress levels are easy to calculate because of only three input variables, but they do not incorporate other factors hypothesized to affect bicycle suitability.

- *Roadway Condition Index/Suitability-Based Level of Service:* The variables most common to all criteria were traffic volumes, curb lane width, speed limit, pavement factors, and location factors. Bicycle planners mostly use these types of criteria in urban areas where data can be economically collected for roadways under study.

- *Capacity-Based*: volume-based or similar procedures that have been adapted from capacity analyses common in the 1994 Highway Capacity Manual.

Two of the BLOS models commonly used are the Florida DOT BLOS model included in the state's *Quality/Level of Service Handbook* and the Bicycle Compatibility Index (BCI) developed by FHWA. Both models address level of service conditions along road segments (average midblock locations away from intersections).

NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets identifies an arterial BLOS that is a weighted combination of a BLOS segment model, a BLOS intersection model and the total number of unsignalized conflicts (intersections and driveways) per mile. This model was subsequently incorporated into the *Highway Capacity Manual 2010.*

FHWA's *Pedestrian and Bicyclist Intersection Safety Indices* presents a method for prioritizing intersection crossings for pedestrians and intersection approaches for bicycles in relation to level of safety for each. The analysis incorporates conflicts and avoidance maneuvers (behavioral data) and expert safety ratings (subjective data), to produce safety index values. Researchers used 68 intersection crosswalks selected for the pedestrian analysis from Philadelphia, PA; San Jose, CA; and Miami-Dade County, FL, and 67 intersection approaches for bicyclists from Gainesville, FL; Philadelphia, PA; and Portland and Eugene, OR. In general, factors such as the number of lanes to cross, traffic speed and presence of signals developed in FHWA's intersection safety indices are commonly used by local governments to assess intersection safety. The safety indices do not incorporate grade or weather conditions that may influence a bicyclist's decision to ride or travel use another mode of travel. The FHWA intersections/approaches model was developed at intersections that are not highly unsafe, as enough pedestrian and bicyclists traffic needed to be present to collect sufficient conflict and avoidance maneuver data. In addition, because the data were collected during the day, the models do not reflect the effect of darkness on intersection safety.