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Research Partners
This research project was conducted by the Dukakis Center for Urban & Regional Policy in collaboration with the Center for Transit-Oriented Development (CTOD), particularly Chris Yake and Jeff Wood at Reconnecting America. Al Benedict at the Center for Neighborhood Technology (CNT) supplied much of the data and variable formulations. In addition, the eTOD Score data was incorporated into Metropolitan Area Planning Council (MAPC)’s Information Station project in collaboration with Tim Reardon, Armin Akhavan, and other staff at MAPC. Information Station is available at http://tstation.info/ and provides easy access to demographic, economic, transportation, and development information for over 300 existing and planned MBTA transit station areas.

Equity Advisory Committee
An Equity Advisory Committee was convened to provide feedback throughout the development process of the eTOD Score rating system. The committee met four times during the course of the research and provided invaluable feedback at all stages of the process.

Kitty and Michael Dukakis Center for Urban & Regional Policy
The Kitty and Michael Dukakis Center for Urban & Regional Policy conducts interdisciplinary research, in collaboration with civic leaders and scholars both within and beyond Northeastern University, to identify and implement real solutions to the critical challenges facing urban areas throughout Greater Boston, the Commonwealth of Massachusetts, and the nation. Founded in 1999 as a “think and do” tank, the Dukakis Center’s collaborative research and problem-solving model applies powerful data analysis, a bevy of multidisciplinary research and evaluation techniques, and a policy-driven perspective to address a wide range of issues facing cities and towns. These include affordable housing, local economic development, workforce development, transportation, public finance, and environmental sustainability. The staff of the Dukakis Center works to catalyze broad-based efforts to solve urban problems, acting as both a convener and a trusted and committed partner to local, state, and national agencies and organizations. The Center is housed within Northeastern University’s innovative School of Public Policy and Urban Affairs.

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EXECUTIVE SUMMARY

eTOD Station Area Rating System

INTRODUCTION: PURPOSE AND NEED FOR A TOD RATING SYSTEM

Planners and policymakers working to encourage high-performing transit-oriented development (TOD) that can effectively reduce driving and increase transit ridership have long been working to understand what factors best predict the performance of TOD. The task is even more difficult for those who want to ensure that TOD simultaneously improves social equity. The Dukakis Center for Urban & Regional Policy at Northeastern University, Reconnecting America, and the Center for Neighborhood Technology (CNT) worked in collaboration to create a rating system that measures the capacity for equitable TOD within a transit station area.

Unlike rating systems that assess the quality of individual TOD projects, this proposed eTOD Score rating system seeks to measure the capacity for equitable TOD within a given public transit station area. It identifies easily quantifiable and comparable built, social, and transit attributes that reduce driving, encourage higher transit ridership, and promote transit equity and accessibility.

This research focuses on daily household Vehicle Miles Traveled (VMT) as the key performance metric for transit-oriented development and sees areas with already low VMT as optimal locations for TOD. The eTOD Score was piloted in Massachusetts, where household VMT data was available for use in analyzing which attributes to include in the rating system and in validating the resulting rating system.

The resulting rating system—as well as each of its three sub-scores—has a very strong and inverse relationship to VMT, so regions without available VMT data can adopt this rating system with confidence that it accurately predicts which station areas are likely to demonstrate the best TOD performance as measured by reduced household driving.

CONSTRUCTING THE eTOD SCORE RATING SYSTEM

The eTOD Score rating system is based on the concept that successful and equitable transit-oriented development should focus on all three of the words in the acronym TOD:

• The availability, quality and use of public transit (as well as other non-automobile means of transportation);
• Orientation toward “transit-oriented neighbors” who make up the core of transit ridership;
• The characteristics of development in the neighborhoods surrounding the transit station.

The rating system was built by evaluating different metrics to characterize each of these areas (Transit, Orientation, Development). The goal was to generate a rating system that allows for comparisons of station areas across the region, while also identifying the strengths and opportunities presented within individual station areas.

Transit metrics capture the frequency of service, quality, and use of the available public transportation network, factors that have been shown to influence the success of TOD. Transit service, for example, needs to be sufficiently frequent, fast, and connected to useful destinations. The better the quality of transit, the more interested residents are in making use of the service, resulting in decreased driving.

The least-understood word in the phrase TOD, “Orientation,” raises the question, “What or who is TOD oriented toward?” The Dukakis Center’s research supports the conclusion that TOD should be oriented toward those most likely to use transit, a group the center calls “core riders.” If both “Transit” and “Development” are oriented toward core riders, the resulting TOD would be both high performing and equitable.

The orientation element of this equitable TOD framework builds on prior research identifying a set of “core riders,” i.e., demographic and socioeconomic groups who are over-represented among transit riders compared with their proportion of the population. Core riders are important to TOD performance because they have been demonstrated...
both to drive less and use transit more. Station areas with more of these “transit-oriented neighbors” are more likely to produce the travel characteristics associated with successful TOD. At the same time, a number of the socioeconomic and demographic groups who constitute a disproportionate share of transit users are also important from an equity perspective, so ensuring that TOD is “oriented” toward these groups also ensures that the TOD will further the objectives of equitable regional development.

As for development and the built environment, proximity to a station in and of itself does not necessarily encourage less driving or more transit use, which is why some nearby development is simply transit-adjacent rather than transit-oriented. Elements of the built environment, such as walkability and density, can influence the travel choices of both residents and visitors of the station area. This rating system incorporates measures of the types of development in the station area that encourage less driving.

MEASURES
The eTOD Score was piloted in Massachusetts due to the availability of household VMT data for validation. The Massachusetts Bay Transportation Authority (MBTA) transit system mainly consists of three different modes: commuter rail, rapid transit, and bus routes, which allow for the development of a rating system that applies to different types of transit.

All MBTA rapid transit stations as well as select bus stops on high-frequency “key routes” were included in the construction of the eTOD Score. In total, we analyzed 345 station areas, including 276 rapid transit station areas and 69 bus stop areas. Neighborhoods outside of the station areas are not eligible for rating under this system.

Following extensive analysis of a variety of potential scoring attributes, 10 station area attributes (see Figure 1) were selected for inclusion in the rating system based on their relationship to VMT and were divided among three different subscales. In order to create an easily understandable rating system, each attribute received a score of up to five points (for a total possible rating of 50 points across the 10 measures). Points are assigned based on the quintile distribution of that attribute across all of the transit station areas in the system. Those in the lowest quintile received one point, with one point added per quintile, for a maximum of five points.

Transit Subscale
The three selected measures that constitute the transit subscale are:

- **Transit Accessibility**: The Transit Access Shed Index (TAS), developed by the CNT, is a 100-point scale that calculates the size of the area that passengers who board at a given station area can easily access using transit in 30 minutes, scaled by the frequency of transit service at that station;
- **Transit Connectivity**: The Transit Connectivity Index (TCI), also developed by the CNT, is a 100-point scale measuring access to and the frequency of transit service at a bus or rail stop location and within the surrounding neighborhood;
- **Transit Use**: Transit use is considered as non-automobile commuting, measured as the percentage of workers who use transit, bike, or walk to work in the station area, as reported by the American Community Survey (ACS).

Transit ratings for MBTA station areas vary from a low score of 3 (in the bottom quintile of station areas for all categories).
three measures) to a high score of 15 (top quintile for all three measures). The 36 station areas scoring the maximum possible transit score consist mostly of rail and bus station areas located in the downtown core. The 48 station areas scoring the minimum possible transit score are all commuter rail stations. By selecting only the key bus routes, our methodology overemphasizes the “well-performing” bus areas. Nonetheless, it is notable that the best-performing bus station areas are indistinguishable from the best-performing rail station areas on these three measures.

Orientation Subscale
The four selected measures that constitute the orientation subscale are:

- **Transit Dependency**: The percentage of zero-vehicle households in the station area (because persons living in households without a car are far more likely to use transit than those in households with cars, and because serving transit-dependent populations is an important component of equity);
- **Lower Income**: The percentage of households with incomes under $25,000 in the station area (because lower-income households are more likely to use transit, and because serving lower-income residents is an important component of equity);
- **Rental Housing**: The percentage renters in the station area (because renters are more frequent users of public transportation than home owners).
- **Affordability**: Affordability is derived from the H+T® Index developed by CNT, which measures the percentage of income spent on transportation in the station area.

Orientation ratings for MBTA station areas vary from a low score of 4 (mostly commuter rail stations but also several stations on the Green “D” Line in affluent suburbs) to a high score of 20 (found at many bus stops, as well as surface Green “B” and “E” Line station areas). On average, bus stop areas have more residents in zero-vehicle households, more low-income residents, and more renters than rail station areas.

Development Subscale
The three selected measures that constitute the development subscale are:

- **Walkability**: The independently developed WalkScore® of the station’s location (using latitude and longitude), because it measures important destinations within walking distance of the station as well as urban form, and because it correlates well with lower household driving;
- **Residential Density**: The number of households per acre in the station area is used as a measure of how many people live in the station area;
- **Employment Gravity**: The Employment Gravity measure, developed by the CNT, assesses the quantity of and the distance to all employment destinations, relative to any location within the region.

The development rating varies between MBTA station areas, from a low score of 3 to a high score of 15. Most of the lowest-scoring areas are commuter rail station areas, and the highest-scoring are mainly bus stop areas.

THE RATING SYSTEM AND RESULTS
The three subscales can also be added together into a final combined score, establishing a comparable eTOD Score for each station area. The overall score ranges from a minimum of 10 points to a maximum of 50 points. The score is then divided into four groups, which correspond to changes in average VMT measures (see Figure 2).

Using these measures, it is possible to compare a given area’s performance relative to other stations by comparing the scores. The final combined score of each station area reflects its quality of transit, its orientation toward transit users, and the development of the station area. Figure 3 presents a map of the Boston region that shows how the station and stop areas break out by their eTOD Score, and Figure 4 provides examples of each type of station area.

![FIGURE 2](image)

Ranges for eTOD Scores for Station Areas
The highest-rated Transit-Oriented station areas share a combination of built, social, and transit attributes that reduce driving, increase transit ridership, and promote equity. Given the rating system’s strong correlation with average daily household VMT within station areas, the combined eTOD Score provides a holistic measure of those conditions that contribute to less driving and more transit ridership, both now and likely into the future.

While the combined scores provide important information about the suitability of the station area for high-performing equitable TOD, the three separate subscales on Transit, Orientation, and Development can be used to clarify the strengths and weaknesses of different station areas and focus attention on the types of measures that can improve an area’s eTOD Score and thereby the performance and equity of TOD in that station area.

While this rating system focuses on transit station areas rather than individual TOD projects or proposals, it can be used to determine whether a TOD project provides what is “missing” in a station area. For example, the Lynn station area shown below is well-oriented toward core transit riders but scores poorly on transit (as it is commuter rail rather than more frequent bus or rapid transit service) and has a mixed record with respect to development/built environment attributes. TOD projects that build on the identified strengths or address the weaknesses in a station area should “rate” highly as equitable transit-oriented development.
Planners and policymakers concerned with reducing auto dependence have long worked to identify the factors that best predict the performance of transit-oriented development (TOD). The task is even more difficult for those who want to ensure that TOD improves social equity. Improving equity matters, not only as a matter of basic fairness, but also as an essential means of realizing the underlying goal of TOD: to offer more densely settled, lower-carbon alternatives to expanding car-based suburban land use. After years of trial and error, TOD rating systems comprise several reasonably reliable performance measures, most notably Vehicle Miles Traveled (VMT). Metrics for projecting equity outcomes within such projects, however, are vague to nonexistent. To fill the breach, the Dukakis Center for Urban & Regional Policy at Northeastern University and the Center for Transit-Oriented Development (CTOD) collaborated on a rating system called the eTOD Score. Constructed from the unusually rich well of data available for the Boston, Massachusetts, metropolitan region, it identifies quantifiable and comparable built-structure, social, and transit attributes that reduce driving, encourage higher transit ridership, and promote transit equity and accessibility. The eTOD Score quantitative model establishes a replicable common baseline for high-quality equitable TOD planning, and it is our hope that it will be disseminated widely throughout transportation policy circles.

Rating systems commonly used to assess the quality of TODs include GreenTRIP (Cohen & Cheng, 2013), the U.S. Green Building Council's LEED-ND (Ewing, Greenwald, Zhang, Bogaerts, & Greene, 2013), and CTOD's Performance-Based Transit-Oriented Development Typology (Austin, et al., 2010). Each of these systems considers a development’s location in a broad way, focusing on the “as built” project or its site. For instance, LEED-ND includes “smart location,” street pattern and neighborhood design in its model, combining both area and project characteristics in the same rating system. Oakland-based TransForm’s GreenTrip certification places a premium on a well-designed transportation infrastructure, including appropriate parking arrangements.

Unlike these project- and design-based rating systems, the eTOD Score is geography based: It seeks to measure capacity within and among public transit station areas, defined as areas within one-half mile of a transit station (Guerra, Cervero, & Tischler, 2012). These areas are where what we call “core riders” of transit, who often consist of historically underserved demographic groups, are likely to reside. By capturing station area data, the eTOD Score more closely approximates equity measures for transit-oriented development.

Like these (and other) rating systems, the eTOD Score’s key performance metric is Vehicle Miles Traveled. But here, too, the eTOD Score differs in two methodologically significant
ways. First, rather than drawing from modeled VMT, as is customary, the *eTOD Score* uses far more accurate, granular household data, available through the Massachusetts Registry of Motor Vehicles, to derive the critically important VMT number. Second, where other rating systems use VMT primarily to measure performance outcomes (i.e., assessing whether a project helped reduce driving and increase transit use), the *eTOD Score* uses the metric to determine which station areas are likely to generate the most transit riders, promote walking and biking, lower household transportation costs, and reduce greenhouse gas emissions. Our research shows that areas with an already low VMT are likely to generate the most transit riders in the future.

The *eTOD Score* not only helps equity-minded TOD planners determine where scarce resources could be most effectively targeted to increase transit use, it also helps them determine which kinds of resources are needed for each station area. In other words, it scores both individual station areas in total, making possible quantified comparative analysis, as well as the three TOD components, or "subscales," of each one: transit, development, and orientation (with which equity considerations are most closely aligned). By providing specific measures of high-performing, equitable TOD, this system can be used to foster and direct rapid policy change in support of both specific development projects and broader initiatives intended to plan or improve transit-rich neighborhoods.

The *eTOD Score* was piloted in the Greater Boston metropolitan area, which is served by the MBTA. The MBTA transit system consists primarily of three different modes: commuter rail, rapid transit, and bus service, which allows for the development of a rating system applicable to different types of transit station areas. Massachusetts also collects household VMT data, which was essential to determining which attributes to include in the rating system. Because the resulting rating system—as well as each of its three subscales—is shown to have a strong and inverse relationship with VMT, regions without available household VMT data can adopt this rating system with confidence that it accurately predicts which station areas are likely to demonstrate the best TOD performance.

This rating system builds on CTOD’s national experience in developing TOD typologies consisting of “place types” and “transit zones,” and incorporates the Dukakis Center’s efforts to better measure—and understand—transit and TOD equity. We set out to determine whether a set of measurable station area characteristics could be shown to contribute both to TOD performance in the traditional sense (lower VMT, greater transit usage, catalytic investment) and to improved social equity as reflected in mixed-income housing, enhanced access to transit, and availability of neighborhood-based service amenities. Figure 5 illustrates our conceptual framework:

**FIGURE 5**
The *eTOD Score* Rating System Framework

The key to our methodology lay in focusing on the middle and least-understood word in the acronym TOD: Orientation. Toward what or whom is TOD oriented? Drawing on prior research by the Dukakis Center, our answer is that equity-based TOD should be oriented toward those most likely to use transit, whom we refer to as “core riders,” or demographic and socioeconomic groups who are over-represented among transit riders compared with their proportion of the population. Core transit riders, even when not referred to as such, have been identified by analyzing travel survey data (Chu, 2012), public transit on-board surveys (Neff, John; Pham, Larry, 2007), and Census and American Community Survey (ACS) data on public transportation commuters (Pollack, Bluestone, & Billingham, 2011).

Core riders are important to TOD performance because it has been demonstrated that they both drive less and use transit more. Station areas with more of these “transit-oriented neighbors” (Pollack, Bluestone, & Billingham, 2011) are more likely to produce the travel characteristics associated with successful TOD. At the same time, as Figure 6 shows, a number of socioeconomic and demographic groups who constitute a disproportionate share of transit users are also important from an equity perspective and so ensuring that TOD is oriented toward these groups also ensures that the TOD will further the objectives of equitable metro-regional development.
A variety of demographic groups have been shown to be overrepresented among transit riders, including the working-age population (25–54 year olds) (Neff, John; Pham, Larry, 2007), people of color (Blumenberg, et al., 2007; Lin & Long, 2008), low-income people (Neff, John; Pham, Larry, 2007; Gilat & Sussman, 2003), people in zero-vehicle households (Cervero, Transit oriented development's ridership bonus: a product of self-selection and public policies, 2007), immigrants (Chu, 2012), and renters (Pollack, Bluestone, & Billingham, 2011). Figure 6 uses data from the American Community Survey to demonstrate some of these core ridership groups in metropolitan Boston who are disproportionately represented among those who report using transit for their work commutes. These groups include renters, members of zero-vehicle households, immigrants, people of color, and lower-income households. Equity-based TODs should seek to retain these transit-oriented populations in their station areas (Pan, Shen, & Liu, 2011), which means they should strive to keep housing affordable rather than allowing development to price them out.

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Another important methodological decision bears explanation. While constructing this equitable TOD rating system, we focused on core rider groups associated with attributes that could be affected by public policy in general and development choices in particular, such as vehicle ownership (which is affected by parking management strategies), housing tenure (rental vs. ownership), and income (which can be influenced through the inclusion of affordable housing). Perhaps the most difficult choice made in constructing the orientation subscale of the rating system was whether or not to include data on racial and foreign-born groups. Racial diversity measures (including percentage Black, percentage Hispanic, and dissimilarity measures) and foreign-born status were analyzed and found to be related to VMT (areas with more racial and ethnic minorities and foreign-born had lower household VMT). However, both because this relationship was not as strong as the other relationships in the rating system and because the racial composition of a station area is difficult to influence through policy, planning, and development tools, attributes designed to measure racial diversity were not included in the rating system. While the racial/ethnic composition of a station area may change due to changes in transit service and TOD development, it is far more difficult to “orient” TOD toward accomplishing such changes. The factors chosen for inclusion in the rating system can be influenced by specific planning and policy decisions (e.g., less parking and the presence of car sharing programs can influence the number of zero vehicle households and use mix and policies can promote production of rental housing and of housing affordable to lower-income families).

In addition to assessing what core riders need from station area development, we incorporate measures of the quality of transit toward which a TOD is oriented. Transit service, for example, must be sufficiently frequent, fast, and connected to useful destinations. The better the quality of transit, the more interested residents are in making use of the service (Lund, Cervero, & Willson, 2004). Both of these factors have been shown to influence the success of TOD. If both Transit and Development are Oriented toward core riders, we theorized, the resulting TOD would be both high performing and equitable.

In sum, high-performing equity-based TOD consists of three elements:

1. It is locally and regionally equitable;
2. It is oriented toward people who use transit; and
3. It changes travel behavior in the station area.

Because proximity to a station in and of itself does not necessarily encourage less driving or more transit use, we have also identified four transit station area types, based on their eTOD subscale scores, and made recommendations for how to improve the eTOD score performance in each (Cervero, Ferrell, & Murphy, 2002; Renne, 2009). As will be shown, elements of the built environment, such as availability of parking, high density, pedestrian and cycling infrastructure, and mixed land uses can influence the travel choices of both residents in and visitors to a station area (Cervero & Kockelman, 1997; Lund, Cervero, & Willson, 2004; Frank & Pivo, 1994), thus affecting its eTOD Score.
CONSTRUCTING THE eTOD SCORE RATING SYSTEM

The eTOD Score rating system rests on the principle that successful and equitable transit-oriented development should focus on all three of the words in the acronym TOD:

- The availability, quality, and use of public transit (as well as other non-automotive means of transportation);
- Orientation toward “transit-oriented neighbors” who make up the core riders of transit;
- The characteristics of development in the neighborhoods surrounding the transit station.

The rating system measures each of these thee areas. Its purpose is to generate scores that will allow for station area comparisons across a given metropolitan region, while also identifying the strengths, weaknesses, and opportunities presented within individual station areas. We have delineated the latter subscales, which measure transit, orientation, and development performance for a given station area.

This pilot study analyzed the Greater Boston area covered by the MBTA. The MBTA system includes more than 250 rapid transit and commuter rail station areas and more than 1,000 additional bus stops that cover a service district of 175 municipalities; equal to 3,244 square miles and a serviceable population of over 4.6 million residents. The system mainly consists of three different modes: commuter rail, rapid transit, and bus routes, which allow for the development of a rating system that applies to different types of transit. Since high-frequency bus routes can also support TOD (Dunphy, Myerson, & Michael, 2003), the eTOD Score rating system is also designed to evaluate TOD suitability along high-frequency bus routes using a similar half-mile buffer around selected bus stops.

All MBTA rapid transit and commuter rail stations as well as select bus stops on the MBTA’s 15 high-frequency “key bus routes” were included in the construction of the eTOD Score. In total, we analyzed 345 station areas, including 276 rapid transit and commuter rail station areas and 69 bus stop areas. Neighborhoods that lie beyond station areas are not eligible for rating under this system.

The extent to which both transit and development in TOD are oriented toward strong transportation and equity outcomes cannot be distilled in a single factor. Instead, it is a function of activity-based, demographic, and accessibility-related characteristics in a given station area. The eTOD Score rating system therefore includes a blend of metrics linked to desired public outcomes (e.g., lower VMT, equitable access to transit). These measures of the built and social environments are then combined in a composite index for each station area. For purposes of transparency, consistency, and longevity, we have selected elements that can be readily understood and available for ongoing analysis to accommodate changing conditions in the future.
For each of the three rating system subscales, we identified those station area characteristics that most effectively drive successful and equitable TOD. We focused on measurable attributes statistically associated with less driving (measured as VMT) per household in each station area. This data, from 2008-2010, was available from the Massachusetts Registry of Motor Vehicles from annual odometer readings taken during mandatory safety inspections. VMT per household varies from a low of 15.6 daily miles in the downtown core station areas to a high of 91 daily miles per household in some of the suburban commuter rail station areas. The mean daily household VMT is 37 miles.

Since VMT data are not available nationally, the system does not rely directly on the availability of such data. Instead, it consists of attributes that we found to be strongly correlated with stations areas where residents drive less. These attributes can be used as predictors of VMT in places where VMT data are not available.

Following extensive analysis of a variety of potential scoring attributes (see Appendix: Methodology Details), we selected 10 station area attributes for inclusion in the rating system based on their relationship to VMT. The 10 selected scoring attributes were then divided among the three different subscales, as pictured in Figure 1.

To arrive at easy-to-understand scores, we assign each attribute a score of up to five points (for a total possible rating of 50 points across the 10 measures). Points are received based on the quintile distribution of that attribute across all of the transit station areas. Those station areas in the lowest quintile receive one point, with one point added per quintile, for a maximum of five points. For the distribution of points among quintiles for all selected variables within the MBTA, see Appendix: Methodology Details.

Following are descriptions of each the three subscales, their attributes, and the method and sources we used to measure each attribute.

**TRANSIT SUBSCALE**

Transit access is measured through General Transit Feed Specification (GTFS) data collected from all of the transit agencies that serve the Boston area. The GTFS data includes the location of every bus stop and rail station, how each is connected by what service including the travel time for adjacent stations/stops, and the frequency of service. The three selected measures that constitute the transit subscale are:

- **Transit Accessibility**: The Transit Access Shed Index (TAS), developed by the CNT, is a 100-point scale that calculates the size of the area that passengers who board at a given station can easily access using transit in 30 minutes, scaled by the frequency of transit service at that station;
- **Transit Connectivity**: The Transit Connectivity Index (TCI), also developed by CNT, is a 100-point scale that measures access to and the frequency of transit service at a bus or rail stop location and within the surrounding neighborhood;
- **Transit Use**: Transit use is the non-automobile commute share, measured as the percentage of workers who use transit, bike, or walk to work in the station area as reported by the American Community Survey (ACS).

Transit ratings for MBTA station areas vary from a low score of 3 (in the bottom quintile of station areas for all three measures) to a high score of 15 (top quintile for all

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**FIGURE 1**

**Final eTOD Score Attributes**

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<td>Transit Use</td>
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<td>Orientation</td>
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<td>Lower Income</td>
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* Figure repeated from Executive Summary for reference only
three measures). 36 station areas received the maximum possible transit score, mostly rail and bus station areas located in the downtown core. 48 station areas received the minimum possible transit score; all of them are commuter rail stations. By selecting only the key bus routes, our methodology overemphasizes “well-performing” bus areas. Nonetheless, it is notable that the best-performing bus stop areas are indistinguishable from the best-performing rail station areas on these three measures.

**ORIENTATION SUBSCALE**

The orientation aspect of TOD refers to a project’s ability to orient travel behavior toward public transportation. When analyzing a specific TOD project, for example, planners may point to a reduced number of residential parking spaces in successful TOD projects that discourage automobile travel to these destinations. At the station area level, we believe that the best way to describe a station area’s transit orientation is to consider characteristics of the area’s residents and take into account how “transit-oriented” the residents’ travel behaviors are. The four selected measures that constitute the orientation subscale are:

- **Transit Dependency**: The percentage of zero-vehicle households in the station area, because persons living in households without a car are far more likely to use transit than those in households with cars and because serving transit-dependent populations is an important component of equity;
- **Lower Income**: The percentage of households with incomes under $25,000 in the station area, because lower income households are more likely to use transit and because serving lower income residents is an important component of equity;
- **Rental Housing**: The percentage of renters in the station area, because renters are more frequent users of public transportation than homeowners;
- **Affordability**: Estimated percentage of income spent on transportation in the station area, derived from the H+T® Index developed by CNT.

Orientation ratings for MBTA station areas vary from a low score of 4 (mostly commuter rail stations but also several suburban stations on the Green “D” Line) to a high score of 20 (found at many bus stops, as well as surface Green “B” and “E” Line station areas). On average, bus stop areas have more residents in zero-vehicle households, more low-income residents, and more renters than rail station areas.

**DEVELOPMENT SUBSCALE**

The remaining three station area attributes are related to the built environment or development within the station area. The three selected measures that constitute the development subscale are:

- **Walkability**: The independently developed WalkScore® of the station’s location (using latitude and longitude), because it measures important destinations within walking distance of the station as well as urban form, and because it is well-correlated with lower household driving;
- **Residential Density**: The number of households per acre in the station area, because it measures population density in the station area;
- **Employment Gravity**: The Employment Gravity measure, developed by CNT, assesses the quantity of and the distance to all employment destinations relative to any location within the region.

The development rating varies between MBTA station areas from a low score of 3 to a high score of 15. Most of the lowest-scoring areas are commuter rail station areas and the highest-scoring are primarily subway station and bus stop areas in the downtown core and surrounding neighborhoods.
TOTAL SCORES
The three subscales can also be summed into a final combined score, thereby establishing an eTOD Score for each station area that can be used for the sake of comparison. The overall score ranges from a minimum of 10 points to a maximum of 50 points. The score is then divided into four groups (Transit-Oriented, Transit-Supportive, Transit-Related and Transit-Adjacent) which correspond to changes in average daily miles driven by households in the station area (see Figure 2). Residents of the best performing station areas drive less than half as much as those in the worst performing station areas.

**FIGURE 2**
*The eTOD Score Ranges for Station Areas*

Using these measures, it is possible to compare a given station area’s performance relative to other station areas. The final combined score of each station area reflects the quality of its transit, orientation toward users, and development practices. The three subscales (Transit, Orientation, and Development) together explain 82% of variance in VMT, with Development having the strongest effect, followed by Orientation, and Transit quality. Increasing the Development score by one point reduces a station area’s daily VMT by approximately 1.4 miles per household. Increasing the Orientation score or Transit score by one point reduces VMT by approximately 1.3 and 1 daily miles respectively. The explanatory power of the subscales is similar between bus and rail station areas; bus station areas show a stronger effect of Transit and Orientation while rail station areas show a stronger effect of Orientation and Development on VMT.

TOTAL SCORE AND SUBSCALE RADAR GRAPHS
While the combined scores provide important information about the comparative suitability of a station area for high-performing equitable TOD, the three subscales on Transit, Orientation and Development can be used to better understand the strengths and weaknesses of different station areas.

To visualize the overall eTOD Score together with the subscales, the score can be presented in the form of a “radar graph.” Each axis of the radar graph represents one of the three subscales: Transit, Orientation, and Development. Transit and Orientation are on scales with a maximum of 15 points; Development is on a scale with a maximum of 20 (since it has one more attribute than the other two). The maximum possible score (15/15/20) is portrayed in the outside triangle; the filled-in shape within the triangle shows what proportion possible score the station received. This representation allows for a quick analysis of the strengths and weaknesses in the transit station area. Two stations with the same total score can have very different shapes on the radar graph composed of the subscale scores. Figure 7, for example, compares the radar graph for Longwood on the left, which has a lower subscale score for Orientation than that for Maverick, on the right, which has a lower subscale score for Transit. Both have a total score of 41 out of 50.

Although this rating system focuses on station areas rather than individual TOD projects, its easy-to-use radar graphs make clear that it can be used to quickly assess the extent to which a proposed TOD project provides what is “missing” in a station area. Figure 8 is another example of two station areas with the same score evaluated based on their individual metrics.
Jackson Square on the Orange Line performs relatively well from Transit and Orientation perspectives, but not in terms of Development. On the other hand, a station like Coolidge Corner on the Green has a higher Development score because of the area’s walkability, density, and nearby employment opportunities, but it lacks orientation toward transit-oriented neighbors. Both station area residents are relatively well-served by transit. The rating system methodology is designed to identify these opportunities and strengths under existing conditions and can be updated as communities change.

Figure 4 presents several different radar graphs representing the eTOD Scores of different MBTA bus, rapid transit, and commuter rail station area types. The Transit-Oriented example is a busy bus station at Dudley, the Transit-Supportive example is a commuter rail station in the Lynn urban center and the Transit-Related and Transit-Adjacent stations are rapid transit stations in lower density urban/suburban communities. Here it is easy to see how the radar graphs and sub-scores provide a more detailed view than the combined score alone. For example, the Lynn station area is well-oriented toward core transit riders but scores poorly on Transit (as it is commuter rail rather than more frequent bus or rapid transit service) and has a mixed record with respect to development/built environment attributes.

The eTOD Score rating system employs subscale measures to help prioritize for TOD those station areas with strong existing assets as well as inform decision-makers of future opportunities (e.g., development, access improvements, mixed-income housing). For example, places that are high on Development and Transit, but low on Orientation should be prime places for new affordable or workforce housing projects given their high levels of accessibility. Other areas may exhibit high proportions of transit-oriented populations, yet lack adequate transit or neighborhood-serving retail and services. These communities would be best suited for enhanced service and potential mixed-use or commercial development. Based on the sub-scores that make up a station area’s eTOD Score, development projects can also be “tweaked” in order to better meet the needs of that neighborhood and improve its overall score. In the future it may be possible to develop a complementary project-level equitable TOD rating system that builds from the eTOD Score station area system and more explicitly weighs and scores different components of TOD projects and the extent to which they are responsive to the strengths and weaknesses of their host station area as presented in the eTOD Score for that station area.
TRANSIT-ORIENTED STATION AREA TYPE
Station areas that are Transit-Oriented (eTOD Score of 41 and above) should be considered places where new development would best optimize the existing network by bringing more users to transit-rich neighborhoods. Furthermore, those new households would enjoy reduced transportation costs, through making less or no use of cars, and greater accessibility to regional destinations. Some examples of Transit-Oriented stations include Yawkey Station on the Framingham/Worcester Commuter Rail, Dudley Station on the Silver Line, and Maverick Station on the Blue Line.

FIGURE 9
Transit-Oriented Station Area Type
TRANSIT-SUPPORTIVE STATION AREA TYPE

Although Transit-Supportive station areas (eTOD Score between 31 and 40) do not perform at the level of the Transit-Oriented areas, their moderate-to-high subscales in the Transit, Orientation, and Development categories make them prime locations for future development. Each station area, however, should be carefully evaluated to determine what kinds of projects are appropriate—that is, how much parking to provide and where to place it, what housing types and level of density to encourage, what kinds of amenities to plan for, and whether to introduce additional transit service. Some examples of Transit-Supportive stations include Jackson Square on the Orange Line, Lynn Station on the Newburyport/Rockport Commuter Rail, and Morton Street Station on the Fairmount Commuter Rail.

FIGURE 10
Transit-Supportive Station Area Type

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Station Type</th>
<th>Transit Score (x/15)</th>
<th>Orientation Score (x/20)</th>
<th>Development Score (x/15)</th>
<th>eTOD Score (x/50)</th>
<th>eTOD Score Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackson Square</td>
<td>Rapid Transit: Orange Line</td>
<td>12</td>
<td>16</td>
<td>10</td>
<td>38</td>
<td>Transit-Supportive</td>
</tr>
<tr>
<td>Lynn</td>
<td>Commuter Rail: Newburyport/Rockport</td>
<td>6</td>
<td>18</td>
<td>10</td>
<td>34</td>
<td>Transit-Supportive</td>
</tr>
<tr>
<td>Morton Street</td>
<td>Commuter Rail: Fairmount Line</td>
<td>9</td>
<td>15</td>
<td>8</td>
<td>32</td>
<td>Transit-Supportive</td>
</tr>
</tbody>
</table>
**FIGURE 11**  
Transit-Related Station Area Type

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Station Type</th>
<th>Transit Score (x/15)</th>
<th>Orientation Score (x/20)</th>
<th>Development Score (x/15)</th>
<th>eTOD Score (x/50)</th>
<th>eTOD Score Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roslindale Village</td>
<td>Commuter Rail: Needham Line</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>29</td>
<td>Transit-Related</td>
</tr>
<tr>
<td>Melrose Cedar Park</td>
<td>Commuter Rail: Haverhill Line</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td>24</td>
<td>Transit-Related</td>
</tr>
<tr>
<td>North Quincy</td>
<td>Rapid Transit: Red Line</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>22</td>
<td>Transit-Related</td>
</tr>
</tbody>
</table>

In many of these station areas, it might be appropriate to focus on affordable housing solutions due to low Orientation scores. Some examples of Transit-Related stations include Roslindale Village on the Needham Commuter Rail, Melrose Cedar Park on the Haverhill Commuter, and North Quincy Station on the Red Line.
TRANSIT-ADJACENT STATION AREA TYPE

Transit-Adjacent station areas (eTOD Score between zero and 20) have very low VMT scores and might be strong on one metric of the Transit, Orientation, and Development categories, but are likely to be very deficient in others. TOD investments in these areas are not likely to have much effect on existing VMT, equity, or transit-use patterns, so unless a major neighborhood change takes place, TOD efforts would be better focused on higher-scoring station areas. Some examples of Transit-Adjacent stations include Newton Center on the Green Line, Stoughton Station on the Providence/Stoughton Commuter Rail, and West Concord Station on the Fitchburg Commuter Rail.

FIGURE 12
Transit-Adjacent Station Area Type

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Station Type</th>
<th>Transit Score (x/15)</th>
<th>Orientation Score (x/20)</th>
<th>Development Score (x/15)</th>
<th>eTOD Score (x/50)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newton Center</td>
<td>Rapid Transit: Green Line</td>
<td>6</td>
<td>5</td>
<td>8</td>
<td>19</td>
<td>Transit-Adjacent</td>
</tr>
<tr>
<td>Stoughton</td>
<td>Commuter Rail: Providence/Stoughton</td>
<td>3</td>
<td>8</td>
<td>7</td>
<td>18</td>
<td>Transit-Adjacent</td>
</tr>
<tr>
<td>West Concord</td>
<td>Commuter Rail: Fitchburg Line</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>13</td>
<td>Transit-Adjacent</td>
</tr>
</tbody>
</table>
Figure 3 and 13 show how the Boston metro region transit station and bus stop areas break out based on their combined \textit{eTOD Scores}. Scores for all of Greater Boston’s station areas can be accessed on the Dukakis Center’s website (see http://www.northeastern.edu/dukakiscenter/transportation/etodscore/).

The highest-rated Transit-Oriented station areas share a combination of built, social, and transit attributes that reduce driving, increase transit ridership, and promote equity. Not surprisingly, the highest scores are concentrated in the highly developed and populated downtown core of the system, with scores trending downward with increased distance from the core. This decrease in score with increased distance is due to a range of circumstances including less dense suburban development patterns with more focus on the car as a means of transport, less availability of transit service, and less orientation toward “core riders.” Given the rating system’s strong correlation with average daily household VMT within station areas, the combined \textit{eTOD Score} provides a holistic measure of those conditions that

\* Figure repeated from Executive Summary for reference only
contribute to less driving and more transit ridership, both now and almost certainly into the future.

**TRANSIT-ORIENTED STATION AREAS**
The map in Figure 14 zeroes in on the station and stop areas with eTOD Scores above 41. These stations have shown that they are strong in each of the Transit, Orientation, and Development categories and are thus prime spots for future equitable development to promote walking, biking, transit, and a reduction in driving, with lower transportation costs and greater access to lower- to middle-income employment. As would be expected, transit-oriented stations are centered in the heavily developed and populated downtown core of the system.

**TRANSIT-SUPPORTIVE STATION AREAS**
The map in Figure 15, below, shows the station and stop areas with eTOD Scores between 31 and 40. Given that they lie beyond central Boston, Cambridge, Somerville, and Brookline, in most cases they are more affordable. Their lower housing costs make Transit-Supportive station areas ideally suited for workforce housing and, potentially, new employment centers. Each station area however, should be evaluated to determine what kinds of projects are most suited to them.

**TRANSIT-RELATED STATION AREAS**
Figure 16 shows the station and stop areas with eTOD Scores between 21 and 30. These are located further out from the center of the system, often in nearby cities and towns. These station areas should be evaluated on individual subscale scores prior to targeting them for investment. Carefully considered strategies could elevate them to Transit-Supportive. In many of these station areas, it might be appropriate to build affordable housing due to low Orientation scores.

**TRANSIT-ADJACENT STATION AREAS**
Figure 17 shows the station and stop areas with eTOD Scores between zero and 20. A majority of these station areas host commuter rail stations with less frequent all-day service, which limits their potential to promote alternatives to automotive travel. They also tend to be located in affluent bedroom communities with smaller shares of transit-dependent populations and suburban built environments less conducive to higher transit ridership. As the population of Greater Boston grows, however, municipalities in these areas might alter their zoning ordinances in anticipation of growing housing and transit needs.
FIGURE 16
Greater Boston Transit-Related Station Areas

FIGURE 17
Greater Boston Transit-Adjacent Station Areas
Once a station area is identified as a possible target for policy intervention or development, Transit, Orientation, and Development categories can be analyzed, and specific targeted interventions can be identified for implementation. This process might proceed as follows:

1. Choose a station for evaluation;
2. Determine its eTOD Score;
3. Determine its Transit, Orientation, and Development scores;
4. Identify the appropriate suite of implementation strategies.

The eTOD Score for the frequent Route #66 bus stop at the corner of Verndale and Harvard Streets is 40 points, or Transit-Supportive, just one point from qualifying as Transit-Oriented. On the subscales, the Verndale Street at Harvard bus stop scores 16/20 in Orientation, 13/15 in Development, and 11/15 in Transit. The radar diagram in Figure 19 illustrates its individual TOD scores compared with one another, while the chart shows the scores for individual metrics. This more detailed analysis highlights deficiencies or areas for improvement. The access to transit is relatively low since there are only two lines serving the area—the #66 bus and the Green Line. The number of regional jobs that a station area resident can get to in a 30-minute period is also limited. Reflecting this constrained transit access, the percentage of income spent on transportation (38%) is relatively high here as well. These findings suggest that the area may be a lower priority for near-term development. A more appropriate near-term intervention could be enhanced transit service. With greater regional accessibility, Verndale stop’s scores would improve and elevate its priority status for development to Transit-Oriented.
The Dukakis Center and the Center for Transit-Oriented Development designed the eTOD Score as a quantitative method for assessing the relative suitability of specific transit station areas for high-performing, equitable transit-oriented development. The methodology was built not only from unusually detailed Massachusetts-specific data but also from additional nationally available data sets, so it can be replicated and applied to other transit systems and metropolitan areas.

Local officials, developers, and community stakeholders face numerous challenges when trying to ensure that transit-oriented development succeeds in simultaneously achieving transportation, land use, and social-equity goals. Developing and validating the eTOD Score sheds new light on a number of these challenges.

First, station areas that succeed from the perspectives of both transportation (as measured by lower daily household VMT) and social equity are those filled with people most likely to use transit, including low-income households, renters, and people without automobiles. Orienting equitable TOD toward these core riders or “transit-oriented neighbors” is an effective strategy for making it both high-performing and equitable.

The eTOD Score system also addresses a longstanding debate within the TOD community over the extent to which neighborhoods served solely by high-frequency bus service can support TOD. In fact, some of the highest scoring transit areas, whose neighborhoods scored well on the Transit, Orientation, and Development subscales, were those served by the MBTA’s high-frequency key bus routes.

Finally, we came to the conclusion that it is difficult to provide a single answer to the question of whether a proposed TOD project is a “good” equitable TOD project. The answer is context-specific: If a TOD project builds on the strengths of a station area or addresses its weaknesses, that project should “rate” highly as equitable transit-oriented development. The rating system’s Transit, Orientation, and Development subscale scores can be used to better assess which station area attributes to focus on in efforts to improve the eTOD Score and, thereby, the performance and equity of TOD in a given station area.
REFERENCES


The eTOD Score rating system is based on the concept that successful and equitable transit-oriented development should focus on all three of the words in the acronym TOD:

- The availability, quality and use of public transit (as well as other non-automobile means of transportation);
- Orientation toward “transit-oriented neighbors” who make up the core of transit ridership;
- The characteristics of development in the neighborhoods surrounding the transit station.

Each of the three concepts is measured by several metrics, selected based on the strength of their correlation with Vehicle Miles Traveled (VMT). The selected metrics are listed in the table below (see Figure 1), followed by more information about each metric.

Multiple measures were considered for each metric; for instance, although the selected income measure was percentage of households with income under $25,000, other income measures—such as median income, change in income from 2000 to 2010, and income diversity—were also considered. These measures had a weaker relationship with VMT and were, therefore, discarded. Similarly, for the walkability metric, WalkScore® had the strongest relationship with VMT, but other measures, such as average block size, were considered too. In this case, since WalkScore® includes block size, it is unsurprising to find that WalkScore®’s relationship with VMT was stronger than block size alone.

Additional variables under consideration included the age distribution in the station area (both median age and percentage of residents over 60 and under 18, to focus on age groups less likely to be driving), household size (which was not significantly related to VMT in our data set once other variables were considered), and average number of cars per household (a significant predictor of VMT, but not as correlated as percentage of zero-vehicle households). In addition, since some of the selected measures had curvilinear relationships with VMT, we also considered logged versions of the variables during selection. Ultimately, the logged versions did not perform substantially better, so for the sake of simplicity, the final selections consist of untransformed variables.

**TRANSIT SUBSCALE**

Transit access is measured through General Transit Feed Specification (GTFS) data collected from all of the transit agencies that serve the Boston area. The GTFS data includes the location of every bus stop and rail station, how each is connected by what service, including the travel time for adjacent stations/stops, and the frequency of service. The three selected measures that constitute the transit subscale are: transit accessibility, transit connectivity, and transit use.

<table>
<thead>
<tr>
<th>Category</th>
<th>Metric</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit</td>
<td>Transit Accessibility</td>
<td>Transit Access Shed Index (TAS)</td>
</tr>
<tr>
<td></td>
<td>Transit Connectivity</td>
<td>Transit Connectivity Index (TCI)</td>
</tr>
<tr>
<td></td>
<td>Transit Use</td>
<td>Percentage workers who use transit, bike, or walk to work (ABC)</td>
</tr>
<tr>
<td>Orientation</td>
<td>Transit Dependency</td>
<td>Percentage of zero-car households</td>
</tr>
<tr>
<td></td>
<td>Lower Income</td>
<td>Percentage of households with income &lt;$25,000</td>
</tr>
<tr>
<td></td>
<td>Rental Housing</td>
<td>Percentage of renters</td>
</tr>
<tr>
<td></td>
<td>Affordability</td>
<td>Percentage of income spent on transportation</td>
</tr>
<tr>
<td>Development</td>
<td>Walkability</td>
<td>WalkScore®</td>
</tr>
<tr>
<td></td>
<td>Residential Density</td>
<td>Households per acre</td>
</tr>
<tr>
<td></td>
<td>Employment Gravity</td>
<td>Employment gravity measure</td>
</tr>
</tbody>
</table>

* Figure repeated from Executive Summary for reference only
Transit Accessibility

The Transit Access Shed (TAS) index, developed by the CNT, is a 100-point scale derived from GTFS schedules. The TAS is defined as the optimal accessible area from any block group within 30 minutes by public transportation, scaled by the frequency of service. For each transit stop, all stops that can be reached within 30 minutes were identified. One transfer within 600 meters of a stop was allowed, and all transfers were padded with 10 minutes of walking or waiting. The stops reachable within 30 minutes were all based on the minimum travel time between the two stops, allowing the inclusion of more distant stops that are reachable within 30 minutes via express service. For each origination stop, a quarter-mile buffer was created around the destination stops. Based on the location of the origination stop, the access shed was then aggregated for each stop to the block group and multiplied by the frequency of service (trips per week). Finally, the accessible area scaled by frequency of service was then renormalized such that the minimum value is zero and that maximum value is 100, in order to create the TAS index. The TAS index and VMT in our data set have a negative linear relationship; as TAS increases, VMT decreases (r=.851). In the data set, the minimum TAS value was zero; the maximum was 99.3. The total mean was 70.2. On average, the bus stop areas have higher TAS values than rail station areas (the bus stop area mean was 83.3, the rapid transit station area mean was 66.9).

The distribution of station areas’ TAS scores (Figure 19) shows clustering at the high end for areas with high transit accessibility and, unsurprisingly, low VMT. Approximately half of the stations in our data set scored above 70 on TAS, showing a high amount of accessibility on the transit system as a whole. On the low end, where access to destinations via transit is virtually non-existent, transit is not really an option despite its nominal availability; the VMT is correspondingly higher. At a certain point of accessibility, above 90 TAS, there is virtually no spread in VMT, as driving is limited to approximately 20 daily VMT per household.

Transit Connectivity

The Transit Connectivity Index (TCI), developed by CNT, is also a 100-point scale that measures access to and the frequency of transit service at a bus or rail stop location and within the surrounding neighborhood. To calculate this measure, a buffer was constructed around each transit access point (one-quarter mile radius for bus stops and one-half mile radius for rail stations and all other access points). Next, five concentric annuluses were constructed, each with the width of the initial buffer. These six access areas were then assigned a service frequency value (total trips per week) for the transit access point they surround. Next, at the block group level, six access values were calculated. These were calculated as:

\[
\text{Area (intersection)} \times \text{Service (frequency)} \times \text{Weight (annuluses)}
\]

\[
\text{Area (blockgroup)}
\]

The weighting multiplier identified in the above equation is calculated using regression analysis.

The value of all of the annuluses’ access values are then summed to form the raw TCI. This raw TCI is renormalized such that the minimum value is zero and that maximum value is 100 in order to create the TCI. The TCI and VMT also have a negative linear relationship (r=.899). The minimum TCI value in our data set was 29.1; the maximum was 99.5. The total mean was 79.9. On average, the bus stop areas have higher TCI values than rail station areas (the bus stop area mean was 90.9, the rapid transit station area mean was 77.1).

As with the TAS, the TCI distribution (Figure 20) shows tight clustering on the high end of TCI values (and low end of VMT), and more spread in the top quintile. The middle ranges of TCI values (50-70) show a wide spread of corresponding VMT values, suggesting that where transit is accessible from the neighborhood but perhaps inconvenient, different station areas make different choices about transportation. In contrast, where TCI is very high, there is no spread at all between different station areas in VMT, reflecting the use of transit where it is a viable option.

Transit Use

In addition to the previous measures of transit access and service frequency, we wanted a measure that accounted for actual travel behavior within the station area. The best available proxy for this is measured as the percentage of workers who use transit, bike, or walk to work in the station area, as reported by the American Community Survey (ACS) for years 2005-2009. This measure of non-automobile commuting has a negative relationship with VMT (r=.859). In our data set, the lowest value for non-automobile commuting was 3.3% of the station area residents. The highest value was 78.8%. The mean was 39.1% overall, with the bus stop area mean of 45.1% and the rapid transit station area mean of 37.6%.

The plot of non-automobile commuting versus VMT (Figure 21) shows a drop in VMT for the station area around 30% of commuting residents. While there is still some spread...
in the second-highest quintile, there are virtually no station areas in the top quintile of non-automobile commuting that have a high VMT.

The transit subscale was calculated using these three measures. All three transit measures are correlated with each other, but they are not identical; together, they explain 85.1% (F=649.4, p<.001) of the variance in station area VMT.

Transit ratings for MBTA station areas vary from a low score of 3 (in the bottom quintile of station areas for all three measures) to a high score of 15 (top quintile for all three measures). 36 stations score the maximum possible transit score; unsurprisingly, most of them are rail and bus stations located in the downtown core. 48 stations score the minimum possible transit score; all of them are commuter rail stations.

FIGURE 19: TRANSIT ACCESSIBILITY
Relationship between transit access and VMT

FIGURE 20: TRANSIT CONNECTIVITY
Relationship between transit connectivity and VMT

FIGURE 21: TRANSIT USE
Relationship between percentage of non-automobile commuting and VMT

FIGURE 22: TRANSIT SUBSCALE
Transit subscale’s relationship to VMT
The differences between bus and rapid transit are all significant; the selected bus areas perform better than the rail areas (TAS: t=9.943, p<.001; TCI: t=9.740, p<.001; Transit Use: t=3.054, p=.003). By selecting only the key bus routes but all rail station areas, our methodology overemphasizes the “well-performing” bus areas. Nonetheless, the best-performing bus station areas are indistinguishable from the best-performing rail station areas on these three measures.

The final transit subscale’s relationship to VMT (Figure 22) shows that the quality of transit is important to predicting its use; just being adjacent to transit is insufficient. The station areas that score low on this subscale have higher VMT and more spread in VMT values between station areas. The station areas that score high on the transit subscale generally have very low VMT and not a lot of variation in VMT among station areas.

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**FIGURE 23: TRANSIT DEPENDENCY**
Relationship between proportion of zero-vehicle households and VMT

**FIGURE 24: LOWER INCOME**
Relationship between income and VMT

**FIGURE 25: RENTAL HOUSING**
Relationship between percentage of renters and VMT

**FIGURE 26: AFFORDABILITY**
Relationship between percentage of income spent on transportation and VMT
The orientation aspect of TOD refers to a project’s ability to orient travel behavior toward public transportation. When analyzing a specific TOD project, for example, planners may point to a reduced number of parking spaces in successful TOD projects that discourage automobile travel to these destinations. At the station area level, we believe that the best way to describe a station area’s transit orientation is to consider characteristics of the area’s residents and take into account how transit-oriented the residents’ travel behaviors are. The four selected measures which constitute the orientation subscale are: transit dependency, lower income, rental housing, and affordability.

Transit Dependency
Transit dependency is measured by the percentage of zero-vehicle households in the station area. This measure was chosen because persons living in households without a car are far more likely to use transit than those in households with cars and because serving transit-dependent populations is an important component of equity. Higher transit dependence, measured as the proportion of zero vehicle households, correlates with lower VMT ($r=.834$). In our data set, the minimum percentage of zero-car households in a station area was 0%. The maximum was 62%. The mean for all station areas was 26.2%, with the mean for bus stop areas (31%) higher than the mean for rapid transit station areas (25%).

The relationship between proportion of zero-vehicle households and VMT (Figure 23) is curvilinear and, aside from a very few outliers, tightly clustered around the curve. Since residents living in zero-vehicle households contribute very little to VMT, the proportion of such residents has a very predictable effect on average daily VMT. It is important to note that, while VMT continues to decrease with higher proportion of zero-vehicle households, above a certain proportion (around 30%), the effects on VMT are less pronounced.

While the bottom three quintiles have different average VMT values, the average VMT values for the top two quintiles of station areas are quite similar, an effect of the curvilinear relationship between the two measures. In this case, as far as driving behavior is concerned, it appears more important to reach the threshold value of 30% (which is reached by half of the bus stop areas but fewer of the rail station areas) than it is to reach the top quintile.

Lower Income
Lower income households are more likely to use transit and serving lower income residents is an important component of equity, so one component of the orientation scale involves income distribution in the station area. Several income measures were considered, including median income and income disparity/diversity. The measure ultimately selected was the percentage of households with incomes under $25,000, the measure with the strongest (negative) relationship to VMT ($r=.631$). The percentage of households with incomes under $25,000 ranged from 2.49% to 60.9% in the selected station areas. The overall mean was 24%, with the bus stop areas mean (28.9%) higher than the rail station areas mean (22.7%).

The relationship between income and VMT (Figure 24) is not as strong as some of the other measures, evidenced in the larger spread of values along the curve. As with transit dependence, however, it seems that the effect on VMT is more of a threshold that occurs around 30%. When 30% or more of households make less than $25,000 per year, virtually no station areas see average VMT values of more than 40 miles per day. Conversely, when there are very few low-income households in a station area (less than 10%), virtually no station areas see average VMT values of fewer than 40 miles per day. Between 10% and 30%, while many station areas have low VMT, the VMT averages vary a lot and so the effect is not consistent.

Rental Housing
Since renters are more frequent users of public transportation than home owners, the percentage of renter-occupied housing units in the station area is included as the third
measure of orientation. This measure also correlates with lower VMT \((r=.807)\). The percentage of renters in a station area ranges from a minimum of 2.3% to a maximum of 97.7%, with an overall mean of 57.7%. Bus stop areas have more renters on average than rail station areas (66% versus 55.7%).

The relationship between percentage of renters and average daily VMT (Figure 25) is generally strongly negative: the higher the proportion of renters, the lower the average daily household VMT. However, there are a number of outliers on the high end that have extremely high proportions of renters and fairly high VMT. These outliers are almost all along one transit line (SL2) which serves the Innovation District, an area with many rental and very few buying options. Aside from the high proportion of renters, these station areas have little in common with other high-scoring station areas (e.g., relatively low proportion of low-income households: around 16%; relatively low WalkScore®, etc), and it is unsurprising that their VMT remains elevated.

**Affordability**

Affordability is derived from the H+T® Index developed by CNT. The component used here estimates the percentage of income spent on transportation in the station area. The index is based upon a set of equations that model household transportation behavior. This includes autos per household, annual VMT and transit use. Since cars are more expensive to purchase and maintain than transit or non-motorized modes of transportation, it is not surprising that higher transportation costs are strongly correlated with higher VMT \((r=.903)\).

There is a strong curvilinear relationship between the percentage of income spent on transportation and the average daily VMT in a station area (Figure 26). Since car costs are a higher percentage of (even a high) income than other modes of transportation, percentage of income spent on transportation is a good predictor of daily VMT. The values at the upper end are more dispersed than at the lower end, probably due to the variability in the costs of cars (owning a used car vs. a luxury vehicle, for instance) and incomes (owning the same car on a lower income results in a higher percentage of income spent on the car). At the low end, there is virtually no dispersion because transit costs are fixed and likely do not reflect a significantly variable proportion of income even for low-income households.

The orientation subscale was calculated using these four measures. All four orientation measures are somewhat correlated with each other; together, they explain 87% of household driving differences \((F=571.1, \ p<.001)\).

Orientation ratings for MBTA station areas vary from a low score of 4 (again, mostly commuter rail stations but also several stations on the Green “D” Line that goes to affluent suburbs) to a high score of 20 (found at many bus stops, as well as surface Green “B” and “E” Line stops). As with the transit subscale, the differences in the orientation measures between bus and rapid transit are significant; on average, bus stop areas have more residents in zero-vehicle households, more low-income households, and more renters than rail station areas. Rail station areas have a higher average percentage of income spent on transportation than bus stop areas.

The final orientation subscale's relationship to VMT (Figure 27) shows that “core rider” characteristics of low income, renting, non-car owning households correlates strongly with lower VMT. As with the transit subscale, the station areas that score low on this subscale have higher VMT and more spread in VMT values between station areas. The station areas that score high on the orientation subscale generally have very low VMT and not a lot of variation in VMT among station areas. Optimal VMT averages are reached with a sub-score of 16 or 17 out of 20, suggesting that a certain proportion of “core riders” in the area is necessary to reliably expect low VMT.

**DEVELOPMENT SUBSCALE**

The remaining three station area attributes are related to the built environment or development within the station area. The three selected measures that constitute the development subscale are: walkability, residential density, and employment gravity.

**Walkability**

Walkability is measured by the independently developed WalkScore® of the station's location (using latitude and longitude), because it measures important destinations within walking distance of the station as well as urban form, and because it is well-correlated with lower household driving \((r=.725)\). The WalkScore® values in the data set range from 6 to 100 (the maximum possible WalkScore®); the mean for all station areas is 76.5. The mean for bus stop areas is higher (79.1) than the mean for rail station areas (75.9).

In general, the relationship between WalkScore® and VMT (Figure 28) shows a lot of variation. Although overall the station area VMT decreases with increasing WalkScore®, a station area with a WalkScore® of 60 could have anywhere from 30 to 80 average daily household VMT. The exception is very high WalkScore® values (over 90), where the variation in VMT drops, implying that a certain (very high) level of walkability is necessary to ensure less driving.
Residential Density

The number of households per acre in the station area is used as a measure of how many people live in the station area; generally, higher density is associated with lower household VMT ($r=.687$). This measure of residential density was selected over others (population, population per acre, households per residential acre, etc.) due to its stronger relationship with VMT. The lowest density was 0.11 households per acre; the highest 36.2 households per acre.

The mean for the data set was 9.2 households per acre, with bus stop areas denser than rail station areas (10.8 vs. 8.8 households per acre respectively).

Residential density and average daily VMT (Figure 29) have a very strong curvilinear relationship. At a certain threshold (approximately 10 households per acre), driving drops dramatically. There is very little variation along the curve, suggesting that density is one of the strongest predictors of VMT in this analysis despite the fairly low correlation value.

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FIGURE 28: WALKABILITY
Relationship between WalkScore® and VMT

FIGURE 30: EMPLOYMENT GRAVITY
Relationship between access to employment and VMT

FIGURE 29: RESIDENTIAL DENSITY
Relationship between residential density and VMT

FIGURE 31: DEVELOPMENT SUBSCALE
Development subscale’s relationship to VMT
of the unlogged variable. With a different analysis strategy (reliance on quintiles means that data transformation would not change the assignment of scores), the variables with curvilinear relationships with VMT, especially residential density, would have to be logged for its true influence to become apparent.

**Employment Gravity**
The employment gravity measure, developed by CNT, is determined using a gravity model, which considered both the quantity of and distance to all employment destinations, relative to any given station area. Using an inverse-square law, an employment index was calculated by first summing the total number of jobs (obtained from data set derived from Dunn and Bradstreet business database) and then dividing by the square of the distance to those jobs. This quantity allows us to examine both the existence of jobs and the accessibility of these jobs for a given station area. Because a gravity model enables consideration of jobs both directly and not directly in a given station area, the employment gravity gives a better measure of job opportunity, and thus a better understanding of job access, than a simple employment density measure. Higher employment gravity is correlated with lower VMT \( (r=.657) \). Unlike many other measures, there is virtually no difference between the average employment gravity scores between bus stop areas and rail station areas.

Like residential density, employment gravity (Figure 30) has a curvilinear relationship with VMT. Higher employment opportunities in the area mean less driving. The outliers with relatively high employment gravity and relatively high VMT are the same Silver Line outliers identified in Figure 25.

The development subscale was calculated using these three measures. The development measures explain 87.9% of the variance in station area household VMT \( (F=615.0, p<.001) \). The development rating varies between MBTA station areas from a low score of 3 to a high score of 15. Most of the lowest-scoring stations are commuter rail station areas, and the highest-scoring are mainly bus stop areas.

Unlike the other two subscales, the development measures do not show a clear difference between the average bus station area and the average rail station area. The only significant difference at the 0.05 level is that bus stop areas have higher residential density than rail station areas \( (t=2.479, p<.05) \).

The final development subscale’s relationship to VMT (Figure 31) follows a similar pattern to the other two subscales. The station areas that score low on this subscale have higher VMT and more spread in VMT values between station areas. The station areas that score high on the development subscale generally have very low VMT and not a lot of variation in VMT among station areas. VMT drops reliably around 12 of 15 total points, suggesting that an area need not be completely and perfectly developed in order to receive the reduced driving benefits of development.

Descriptive information for all attributes is available in summary form in the table below (Figure 32).

<table>
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<tr>
<th>Category</th>
<th>Metric</th>
<th>Measure</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Mean (Rapid Transit)</th>
<th>Mean (Bus)</th>
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<tbody>
<tr>
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<td>Transit Access Shed</td>
<td>Transit Access Shed Index (TAS)</td>
<td>0</td>
<td>99.3</td>
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<td>Transit Connectivity Index (TCI)</td>
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<td>Non-Automobile</td>
<td>Percentage workers who use public transit</td>
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<td>78.8</td>
<td>39.1</td>
<td>22.6</td>
<td>37.6</td>
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<td></td>
<td></td>
<td></td>
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<td>Orientation</td>
<td>Orientation</td>
<td>Percentage of zero-car households</td>
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<td>Percentage of households with income less</td>
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