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Research Paper

Trip and parking generation at transit-oriented developments: Five US case studies

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HIGHLIGHTS

- Parking demand at the five TODs is generally less than half the US guideline.
- Trip generation at the five TODs is generally less than half the US guideline.
- Automobile mode shares at the five US TODs are as low as one quarter of all trips.
- Results suggest the potential for significant savings in TOD developments.
- Guidelines are provided for using study results in TOD planning.

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ABSTRACT

Guidelines for trip and parking generation in the United States come mainly from the Institute of Transportation Engineers (ITE). However, their trip and parking manuals focus on suburban locations with limited transit and pedestrian access. This study aims to determine how many fewer vehicle trips are generated at transit-oriented developments (TODs), and how much less parking is required at TODs, than ITE guidelines would suggest.

Our sample of TODs is small, which limits our ability to generalize. However, the five cases selected for this study are more or less exemplary of the D variables, at least in comparison with US norms. They are characterized by land-use diversity and pedestrian-friendly designs. They minimize distance to transit, literally abutting transit stations. They have varying measures of destination accessibility to the rest of the region via transit. Three have progressive parking policies, which fall under the heading of demand management. Two have high residential densities, and one has a high intensity of commercial development.

Simply put, our case study TODs create significantly less demand for parking and driving than do conventional suburban developments. With one exception, peak parking demand in these TODs is less than one half the parking supply guideline in the ITE *Parking Generation* manual. Also, with one exception, vehicle trip generation rates are about half or less of what is predicted in the ITE *Trip Generation Manual*. Automobile mode shares are as low as one quarter of all trips, with the remainder being mostly transit and walk trips.

1. Introduction

How best to allocate land around transit stations is a debated topic, with transit officials often opting for park-and-ride lots over active uses such as multifamily housing, office, and retail organized into transit-oriented developments (TODs). The question of how much vehicle trip and parking demand reduction occurs with TOD is largely unexplored in the literature. This study gives hard numbers, albeit for only five TODs in five different regions.

For planned TODs in the same or other regions in the US, our findings may be used in tandem with regional travel model forecasts. Perhaps conservatively, one could set a floor on alternative mode shares and percentages trip and parking reductions equal to the minimum values for our five TODs, or could set a cap on these equal to the maximums from this study. Also, one could look for the best match to a particular TOD being proposed from among our sample of TODs.

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The only way to increase the generalizability of this effort, and increase the likelihood of a good match, is to expand the sample of TODs studied, particularly including larger TODs and TODs on light-rail lines. In this vein, we call for additional research on trip and parking generation at TODs.

2. Literature review

Previous researchers have examined the relationship between urban density and transportation. Low density and separate land uses create high auto dependency (Catalán, Saurí, & Serra, 2008; Clifton, Currans, Cutter, & Schneider, 2012; Reilly, O'Mara, & Seto, 2009). TOD is one of the strategies for planners to mitigate the problems associated with high auto dependency. The basic idea behind TOD is to capture more trips internally and encourage more walking and transit trips by creating an urban form that is relatively high density, mixed in terms of different land uses, served by high quality transit, and with pedestrian-friendly designs.

A large amount of urban land is dedicated to parking, especially in auto dominated cities in the U.S. Davis, Pijanowski, Robinson, and Kidwell (2010) estimate that the states of Illinois, Indiana, Michigan and Wisconsin allocate 1260 km^2 of their land to parking lots. This accounts for approximately 4.97% of urban land use and more than one parking space per adult. Wu and Thompson (2013) found the impervious surface increased rapidly in Iowa in recent decades, with parking lots being one of the most prevalent impervious surfaces. As one of the most common impervious surfaces human created during urbanization, parking lots contribute to many environment concerns, such as urban sprawl, water quality, and the urban heat island effect. Urban lands used for parking lots tend to have lower green coverage (Kremer, Hamstead, & McPhearson, 2013). States that have a higher proportion of their urban land devoted to parking lots are states where urban sprawl is more prevalent (Davis et al., 2010).

First we review the literature on vehicle trip generation at TODs. The ITE *Trip Generation Manual* itself states that its "[d]ata were primarily collected at suburban locations having little or no transit service, nearby pedestrian amenities, or travel demand management (TDM) programs" (ITE, 2012). It goes on to say: "At specific sites, the user may wish to modify trip-generation rates presented in this document to reflect the presence of public transportation service, ridesharing, or other TDM measures; enhanced pedestrian and bicycle trip-making opportunities; or other special characteristics of the site or surrounding area" (ITE, 2012). This kind of modification is seldom done in practice.

Surveying 17 housing projects near transit in five U.S. metropolitan areas, Cervero and Arrington (2008) found that vehicle trips per dwelling unit were substantially below the ITE's estimates. Over a typical weekday period, the surveyed housing projects averaged 44% fewer vehicle trips than that estimated by using the ITE manual (3.754 versus 6.715). Another study by the San Francisco Bay Area Metropolitan Transportation Commission found that residents living near transit generated half as many vehicle miles traveled (VMT) as their suburban and rural counterparts (SFBAMTC, 2006). Nasri & Zhang (2014) found people living in TOD areas reduced their VMT by around 38% in Washington, D.C. and 21% in Baltimore, compared to their non-TOD counterparts. At the same time, residents living in developments near transit are reported to have higher rates of transit trips than residents living at greater distances (Faghri & Venigalla, 2013; Olaru & Curtis, 2015; SFBAMTC, 2006; Zamir, Nasri, Baghaei, & Mahapatra, 2014), especially for commuting trips (Arrington & Cervero, 2008; Cervero, 1994; Faghri & Venigalla, 2013; Lund, Cervero, & Wilson, 2004; Lund, Willson, & Cervero, 2006). However, another study found that new residents in seven TODs in North American adopted more active and transit trips only for amenities and leisure after they relocated to a TOD but that they were less likely to do so for work and shopping (Langlois, van Lierop, Wasfi, & El-Geneidy, 2015). These results are specific to multifamily development near transit. To our knowledge, there is only one previous study of vehicle trip generation at TODs (defined as mixed-use developments – Handy, Shafizadeh, & Schneider, 2013).

Next we review the literature on parking generation at transit-served sites. The ITE *Parking Generation* manual notes that study sites upon which the manual is based are "primarily isolated, suburban sites" (ITE, 2012). ITE (2010) studies show that the vehicle ownership is lower in transit-served areas than those that are not transit-served (Faghri & Venigalla, 2013; Zamir et al., 2014). By comparing parking-generation rates for housing projects near rail stops with parking supplies and with ITE's parking-generation rates, Cervero, Adkins, and Sullivan (2010) found there is an oversupply of parking near transit, sometimes by as much as 25–30%. Oversupply of parking spaces may result in an increase in vehicle ownership (Cervero & Arrington, 2008). This is supported by the strong positive correlation between parking supply and vehicle ownership (Chatman, 2013; Guo, 2013) and auto use (Chatman, 2013; Weinberger, 2012; Weinberger, Seaman, & Johnson, 2009). Again, these studies relate to residential developments. Although Loo, Chen, and Chan (2010) studied rail-based TODs and the connection with variables such as parking and car ownership, they did not examine parking demand. To our knowledge, there is no previous study of parking demand at TODs (again, defined as mixed-use developments), only parking demand at residential developments near transit.

3. Methodology

3.1. TOD definition

TODs are widely defined as compact, mixed-use developments with high-quality walking environments near transit facilities (Cervero, Murphy, Ferrell, Goguts, & Tsai, 2004). For this study, we limited our sample of TODs to sites developed by a single developer under a master development plan. TODs may also include a clustering of development projects near transit facilities developed by one or more developers pursuant to a master development plan.

The first three criteria used to select TODs for this study are consistent with the definition above. TODs must be

(1) Dense (with multi-story buildings),
(2) Mixed use (with residential, retail, entertainment, and sometime office uses in the same development), and
(3) Pedestrian-friendly (with streets built for pedestrians as well as autos and transit).

We have added four criteria to maximize the utility of the sample and data. TODs must be:

(4) Adjacent to transit (literally abutting and hence integrally related to transit),
(5) Built after a high-quality transit line was constructed or proposed (and hence with a parking supply that reflects the availability of high quality transit),
(6) Fully developed or nearly so, and
(7) Self-contained in terms of parking.

By self-contained parking, we mean having dedicated parking, in one or more parking garages or lots, for the buildings that comprise the TOD. This criterion is dictated by our need to measure parking demand for the combination of different land uses that comprise the TOD. The criterion precludes TODs in a typical downtown that share public parking with non-TOD uses. This obviously constitutes a limitation on our study's external validity, but one that is self-imposed. In a typical downtown with public parking, it is impossible to tell which parked cars are associated with which land uses. Thus, our findings will be most applicable to the many proposed, self-contained TODs in less urban or more suburban locations.

3.2. TOD selection

Given our seven criteria, we selected good (arguably the best) self-contained TODs in each of five US regions as our case studies: Denver, Los Angeles, San Francisco, Seattle, and Washington, D.C. These five regions were selected based on the presence of high-quality transit and on sampling convenience. Our consulting partners (Fehr & Peers and Nelson\Nygaard) have branch offices in these regions. This expedited the data collection for the sampled sites.

For each region, we identified TOD candidates from multiple sources in a multi-step process. The first step was to consider mixed-use developments (MXDs) near transit from an MXD database collected for another purpose (Tian et al., 2015). The MXD database includes developments in two of the five study regions: Denver and Seattle. We identified all MXDs in close proximity to transit stations in the two regions.

The second step was to ask our consulting partners with branch offices in our case study regions to identify candidate sites within their regions that meet our seven criteria. Concurrently, we contacted regional transit operators and/or metropolitan planning organizations with the same question. A surprising number of transit agencies and MPOs have staff specifically dedicated to promoting TODs. These were contacted, told our criteria, and asked for the best local examples of TOD.

The third step was to review candidate sites with Google Earth imagery to check for clustering of buildings around transit stations, typically with well-defined boundaries. This was followed by the use of Google Street View to establish that TOD criteria (dense, mixed use, pedestrian-friendly with self-contained parking) were actually met. Several top candidate TODs were ranked in this manner for each metropolitan area.

The final step was to visit each of the metropolitan areas and, once there, take transit from one candidate station area to the next. In each location, we walked around and through the development to determine whether our criteria were in fact met and went to the property management office to get contact information. We also made a photographic record of each development. In virtually all cases, the relative ranking of sites changed with on-the-ground inspections. There were surprisingly few TODs in these regions that met all seven criteria, so the final selection was straightforward.

Ultimately, we identified one TOD in each region that met our criteria and was feasible to study. Here the process of TOD selection got messy. One practical consideration was our decision to obtain approval from property managers to conduct these studies, particularly because we would be going into their parking garages at all hours to conduct parking occupancy counts. We were not able to obtain permission from Del Mar in Los Angeles. This led to the substitution of Wilshire/Vermont for Del Mar.

Fig. 1 shows photos of the five case study TODs. Table 1 provides statistics on the density/intensity of development for the five case study TODs. Floor area ratios (FARs) for commercial development (which are calculated as commercial floor area divided by acreage of commercial and mixed uses) are relatively low, while gross residential densities exceed the guidelines in most transit-oriented design manuals (Ewing & Bartholomew, 2013). The typical TOD has ground floor retail and apartments above, meaning that the commercial FAR is generally limited to 1.0, while the residential density depends on the number of stories. Fruitvale Village TOD, with its heavy concentration of clinics, a high school, a library, etc., is one exception to the low FAR rule. But the very substantial vehicle-trip and parking reductions documented in this study suggest that very high density/intensity of development is not a requirement for success.

3.3. Data collection

The multimodal transportation planning firms of Fehr & Peers and Nelson\Nygaard developed a data collection plan and protocols. The firms also managed data collection in the field and subsequent data entry for three types of travel data: (1) full counts of all persons entering and exiting the buildings that make up the TODs, (2) brief intercept surveys of samples of individuals entering and exiting the buildings that make up the TODs, and (3) parking inventory and occupancy surveys of all parking accessory to the commercial and residential uses of the TODs.

The intent of this approach was to develop an accurate measure of total trip generation associated with the commercial and residential uses at the site, as well as complementary travel survey and parking utilization data that provide a picture of the mode of travel, origin/destination, parking location – if applicable – and purpose for all trips to and from the building throughout the course of the day.

As a first step, surveyors noted whether the subject was observed "coming" or "going" to/from the buildings and the type and location of entrance/exit used, and recorded the time of intercept by checking a box on the data collection form associated with one of four 15-min periods per hour.

People leaving the building were asked: (1) "How do you plan to get to your next destination?" (e.g., by what mode of travel?), and (2) What is the purpose of your trip? (e.g., "Going home," "Going to work," "Shopping," or "other").

People arriving at the building were asked: (1) "How did you get here?" (e.g., by what mode of travel?), and (2) What is the purpose of your trip? (e.g., "I live here/coming home," "coming to work," "shopping," or "other").

Individuals who indicated that they had arrived by or would be leaving by automobile were also asked where they parked their vehicle (e.g., "on-street," "in the garage" or at an "other" location/facility).

Surveyors counted and attempted to intercept only individuals observed walking to or from an entrance to the TOD buildings (or, in observation of the garage entrance, only drivers and passengers in vehicles entering/exiting the garage driveway to/from the public street). Individuals waiting for the bus or train, or walking between the transit stops and park-and-ride garages, were not counted or surveyed.

The data was collected between 7:30 a.m. and 9:00 p.m. on Tuesday, May 28, 2015 for Redmond TOD, between 7:00 a.m. and 9:00 p.m. on Wednesday, September 16, 2015 for Rhode Island Row, between 7:30 a.m. and 8:00 p.m. on Thursday, November 5, 2015 for Fruitvale Village, between 7:00 a.m. and 9:00 p.m. on Tuesday, October 13, 2015 for Englewood TOD, and between 7:00 a.m. and 9:00 p.m. on Thursday, November 17, 2015 for Wilshire/Vermont TOD.

3.4. ITE manual comparison

The Institute of Transportation Engineers (ITE) is an international organization focusing on education and research in transportation planning and engineering. The ITE *Trip Generation Manual* and *Parking Generation* manual are considered "bibles" in transportation planning. Data for the manuals are collected primar-

(a) Redmond TOD

(b) Rhode Island Row

(c) Fruitvale Village

(d) Englewood TOD

(e) Wilshire/Vermont

Fig. 1. TODs Studied.

Table 1
Net and Gross Residential Densities, and Floor Area Ratios for Commercial Uses, for the Five TODs Studied.

TOD	Metropolitan Area	Gross Area (acres)	Gross Residential Density (units per gross acre)	Net Residential Area (acres)	Net Residential Density (units per net acre)	Gross Commercial FAR (for retail and office uses)
Redmond TOD	Seattle	2.5	129	2.5	129	0.11
Rhode Island Row	Washington, D.C.	6	46	6	46	0.27
Fruitvale Village	San Francisco	3.4	14	3.4	14	0.94
Englewood	Denver	30	15	10.7	41	0.25
Wilshire/Vermont	Los Angeles	3.2	140	3.2	140	0.27

ily in the US, with a few Canadian exceptions. The national scale of ITE manual data makes for an appropriate comparison with our US case studies. Our data from TODs are compared to ITE manual rates, in hopes of illustrating the unique nature of trip and parking generation rates at TODs. The distinct characteristics of American infrastructure, tax policy, and mode split make our findings and recommendations applicable only within this limited National context.

4. Results

There is a certain logic or predictability to the summary statistics that follow. See individual case study chapters of our final report, for detailed information on how these summary statistics were derived (Ewing et al., 2016).

Table 2
Average Mode Shares for TODs Studied.

TOD	Count	Mode shares					
		Walk	Bike	Bus	Rail	Auto	Other
Redmond	1981	18.9%	1.7%	13.0%	NA	64.9%	1.5%
Rhode Island Row	8451	16.6%	0.3%	9.3%	27.2%	42.5%	4.0%
Fruitvale	16,558	28.3%	4.3%	15.2%	26.1%	23.0%	3.1%
Englewood	14,073	19.2%	3.8%	3.3%	13.6%	59.7%	0.2%
Wilshire/Vermont	11,043	27.4%	2.2%	21.1%	20.1%	25.9%	3.4%
Simple Averages	NA	22.1%	2.5%	12.4%	21.8%	43.2%	2.4%

4.1. Mode shares

From Table 2, walk mode shares for these five TODs fall within a fairly narrow band, from 16.6% at Rhode Island Row to 28.3% at Fruitvale. They mostly reflect the environment in which the TOD is

Table 3
Average Vehicle Trip Reductions Relative to ITE Rates.

TOD	ITE vehicle trips	Actual vehicle trips	% of ITE trips	% reduction
Redmond	1,767	661	37.4%	62.6%
Rhode Island Row	5808	2,017	34.7%	65.3%
Fruitvale	5899	3,056	51.8%	48.2%
Englewood	13,544	9,460	69.8%	30.2%
Wilshire/Vermont	5180	2,228	43.0%	57.0%

located, and secondarily the number of commercial trip attractions contained within the TOD. Wilshire/Vermont and Fruitvale are in the most urban settings. They have dense neighborhoods nearby and many commercial trip attractions on site. In contrast, Rhode Island Row and Englewood abut big-box retail development, which supports few if any walk trips. Redmond, which also has a relatively low walk mode share, has neighborhoods nearby that should generate walk trips, but also has the smallest number of commercial trip attractions of the TODs surveyed.

Bike mode shares are small for all TODs studied, although all but Rhode Island Row do exceed the national average for bike mode share. The mean bike mode share for this five-TOD study is only 2.5%. For planning purposes, it is safe to assume a small bike mode share for any planned TOD. It will not have much effect on overall vehicle trip and parking generation whether you assume a 1% bike mode share, the national average, or a 4% bike mode share, the highest for our five TODs.

Bus mode shares vary from a low of 3.3% at Englewood to a high of 21.1% at Wilshire/Vermont. All TODs studied, including Englewood, are served by multiple bus lines and have bus transfer operations adjacent to the TODs. All but bus-only Redmond TOD provide relatively seamless transfers from rail to bus and bus to rail. It is a matter of exiting one vehicle, walking a very short distance, and entering another vehicle. The bus transfer area at Englewood is not nearly as amenity-rich as at other TODs; there are no benches or shelters. At the other extreme, Wilshire/Vermont lies at the intersection of two major bus corridors. Density and related vehicle ownership may also have something to do with the contrasting mode shares. To the visitor, three-story Englewood reads very differently than seven-story Wilshire/Vermont; with ground floor retail both places, it is the difference between two stories of residential and six stories of residential.

Finally, rail transit proves its dominance over bus transit at three of the four locations where both are present. The exception is Wilshire/Vermont, where they have nearly identical mode shares. And, of course, there is no comparison for Redmond because it has only bus service. The smallest rail mode share is 13.6% at Englewood. The largest shares are 27.2% at Rhode Island Row and 26.1% at Fruitvale. Not surprisingly, these two TODs are located in Washington, D.C., and San Francisco, the regions with the best rail systems. In terms of ridership, Washington, D.C.'s Metro system ranks second in the U.S. behind New York City, while San Francisco's BART system ranks fifth. In terms of system route miles, they rank second and third in the United States, respectively.

4.2. Vehicle trip generation

Vehicle trip generation at the five TODs occurs at much lower rates than predicted by ITE guidelines. Table 3 shows that the number of vehicle trips at these TODs range from one-third below to two-thirds below ITE rates. The biggest reductions are at Rhode Island Row and Redmond, where the numbers of vehicle trips are, respectively, 34.7 and 37.4% of the number of trips predicted by the ITE *Trip Generation Manual*. These numbers represent a 65.3% reduction and a 62.6% reduction in vehicle trip-making relative to ITE's suburban, auto-oriented developments.

Similarly, vehicle trips at Wilshire/Vermont and Fruitvale are about half what is predicted by ITE. These are the most urban of the TODs in the sample. Off-site retail and housing options abound near both developments, and mode shares for walking are correspondingly high. Mode shares for transit use are also high, and auto mode shares are by far the lowest of the five TODs studied, a fact we will return to momentarily.

The smallest reduction is at Englewood. But even here, vehicle trips fall to 69.8% of the number predicted by ITE, a 30.2% reduction. That is, even in a relatively auto-oriented TOD like Englewood, with an abundance of free parking, vehicle trip reductions are substantial relative to the suburban standard.

When the percentage of ITE vehicle trips from Table 3 is plotted against the percentage of automobile trips from Table 2, the resulting graph, Fig. 2, has two interesting features. First, as one might expect, the percentages rise together in what appears, from certain data points, to be a linear manner from (0,0) to (100,100). If, as the ITE *Trip Generation Manual* itself says, the sites for which ITE trip-generation rates are calculated are overwhelmingly auto-oriented, then the upper right corner of the graph, where both variables are equal to 100%, represents the suburban norm captured by ITE. Conversely, the lower left corner, where both variables are equal to zero, represents a hypothetical development with no auto use at all (perhaps a rare Manhattan development). In such a development, there would likewise be no vehicle trip generation.

But Fig. 2 has another interesting feature. One of the data points, that of Fruitvale Village, lies well above the 45° line. This highly urban and commercial-heavy site seems to generate more vehicle trips than it should, given its mode shares. Why would this be the case? One explanation is that some trips within the development were double counted. People may have been counted entering or exiting one of the garages, then again on the plaza or sidewalk.

There is also another, more interesting, possibility. Development at Fruitvale, and to a lesser extent, Wilshire/Vermont, may be generating more person trips in total than their suburban counterparts, and hence more vehicle trips for any given mode split. It has long been speculated that urban developments might have higher trip-generation rates (by all modes) than their suburban counterparts due to the greater accessibility and hence lower generalized cost of travel at urban sites (Boarnet & Crane 2001). The practical implication is that one cannot simply apply ITE trip-generation rates to highly urban developments, then discount by a percentage for non-auto mode share. The policy implication is that these sorts of urban, transit-served developments may not produce as large a reduction in vehicle trips as a simple mode choice analysis would suggest (although, in terms of vehicle trip reduction relative to ITE rates, they still perform well).

Redmond TOD represents the opposite case. It is well below the 45° line in Fig. 2. It has a high auto mode share, the highest in our sample of TODs, but the second lowest percentage of vehicle trips relative to ITE. Because ITE data represent trip generation in auto-oriented, suburban contexts, we would expect suburban Redmond TOD to have vehicle trip-generation rates very similar to ITE's, perhaps discounted by the percentage of walk and transit trips. Could vehicle trips have been undercounted by our consultant? It is possible but seems unlikely, given that lower volumes of people coming and going created fewer challenges for the counters at this site than at the other TODs. Could person-trip generation rates be lower at Redmond TOD than at the ITE sites, the reverse situation compared to Fruitvale? We speculated that Fruitvale's trip rates were higher than ITE's because of better accessibility. Could the accessibility at Redmond be worse than the ITE norm, and hence the overall person trip rate be lower? This also seems unlikely when comparing suburban development to suburban development. We are left with no explanation for the anomalous Redmond results.

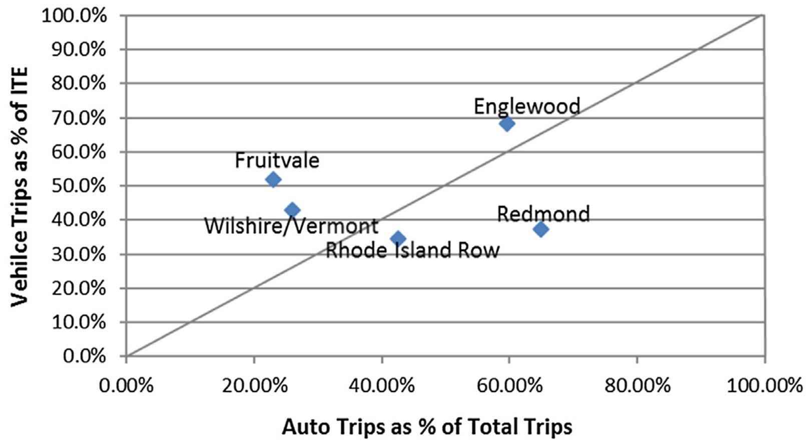

Fig. 2. Vehicle Trip Generation vs. Auto Mode Share.

4.3. Parking generation

Parking generation is much more complicated than vehicle trip generation. There is both supply of and demand for parking. There is residential, commercial, and mixed-use parking. And, of course, there are ITE guidelines and actual parking numbers for our TOD sites. There are also issues such as shared parking between different land uses, bundled parking (guaranteed parking spaces as part of a rent payment) for residential uses, and paid parking for commercial uses. There are so many comparisons that could be made that we risk simply creating confusion, so we will try to keep it as simple as possible.

The bottom line of this section is clear. In almost all cases, the TODs in the sample supply much less parking than is called for in ITE guidelines. Despite these supply restrictions, demand for parking at case study TODs is well below the supply. But there are exceptions, as discussed below. Readers are referred to the individual case study chapters of our final report (Ewing et al., 2016) for more detailed discussions of parking supply and demand at the five TODs.

All of the featured TODs have apartments in multi-story buildings, so that is the land-use category to which we compare TOD residential supplies to the ITE supply guideline. As noted in the individual chapters, supply is relatively easy to measure except where there is shared parking. In Redmond, Englewood, and Wilshire/Vermont, and in the south garage at Rhode Island Row, residential users have their own parking garages or lots, or have sections of garages reserved for them. Only in Fruitvale, and in the north garage at Rhode Island Row, is parking shared with commercial uses. Also, for computing supply per dwelling unit, we use the total number of residential parking spaces and the total number of apartments, not just the occupied apartments. The total number of apartments is easier to determine.

In Table 4, we present supply numbers on a per dwelling unit basis (the common way of representing residential parking). The supply of parking stalls for residential uses at these five TODs ranges from 0.81 stalls per dwelling unit at Rhode Island Row (57.9% of the ITE guideline) to 1.60 stalls per dwelling unit at Englewood (114.3% of the ITE guideline). Englewood actually provides more residential parking than ITE would suggest because of an agreement between the City of Englewood and the big-box retailer Wal-Mart, which was concerned that residential parking would spill over into the retailer's parking lot.

Now for a comparison of actual demand for residential parking at TODs to the supply at these TODs. Peak demand for residential parking is trickier to estimate than parking supply. Unlike supply, we use only occupied apartments to compute the number of parking spaces per dwelling unit. We also make the assumption, where parking is shared, that residential parking demand peaks in the late night/early morning hours when apartment dwellers are presumably all at home, and commercial and transit users presumably have left. The peak demand for parking ranges from 0.44 spaces per occupied dwelling unit at Rhode Island Row (south garage) to 1.29 spaces per occupied dwelling unit at Englewood. From Table 4, the occupancy of residential parking spaces (peak demand divided by actual supply) ranges from 54.3% at Rhode Island Row (south garage) to 80.6% at Englewood.

Now onto commercial parking supplies and demands. As with residential parking, commercial parking supplies are well below ITE guidelines, but peak parking demand uses up most of the reduced parking supplies. For commercial parking, we can only report aggregates, since parking is shared by the individual commercial uses in these multiuse projects. For Redmond, Englewood, and Wilshire/Vermont, commercial parking is separate from residential, and we can therefore compute statistics specific to commercial parking supply and demand. For parking supplies, we apply ITE supply rates to the specific square footage of leased commercial uses present within the development. For parking demand, we do the same with ITE peak demand rates (see individual case study chapters of our final report for examples). Unlike residential parking demand, which peaks at night, commercial parking demand peaks during the day.

For Rhode Island Row (north garage) and Fruitvale, commercial uses share parking with residential uses, and we can only compute statistics for the resulting mix of parking users. For mixed-use parking garages, we apply ITE supply rates to both residential and occupied commercial uses within the development. For mixed uses, we use the actual daily peak parking volume (the one hour across the day when the number of parked cars is greatest) to represent the peak parking demand.

From Table 5, actual parking supplies for commercial and mixed-use garages and lots in our TODs range from 22.6% of ITE supplies at Fruitvale to 61.2% of ITE supplies at Englewood. These are huge reductions relative to ITE supplies. As noted in the Englewood case study, even relatively auto-oriented Englewood TOD conserves on parking.

With these reduced supplies, the TODs in our sample use most of their parking supplies during the peak hour. Peak demand for commercial/mixed-use parking garages and lots ranges from a low of 74.3% of parking supply at Englewood to 140.7% of supply at Wilshire/Vermont. Wilshire/Vermont is able to exceed the actual supply of parking spaces by using tandem, valet parking.

A final set of comparisons captures the potential of these exemplary developments to conserve on parking relative to ITE supply

Table 4
Residential Parking Supplies as a Percentage of ITE, and Residential Peak Parking Demand as a Percentage of Actual Supplies.

TOD	ITE supply (spaces per unit)	TOD supply (spaces per unit)	TOD peak demand (occupied spaces per unit)	TOD supply as% of ITE supply	TOD peak demand as% of TOD supply
Redmond	2.0	1.19	0.86	59.5%	72.3%
Rhode Island Row	1.4	0.81	0.44	57.9%	54.3%
Fruitvale	1.4	NA[a]	1.02	NA	NA
Englewood	1.4	1.6	1.29	114.3%	80.6%
Wilshire/Vermont	2.0	1.10	0.81	55.0%	73.6%
Average	1.55	1.18	0.87	71.7%	70.2%

[a] Fruitvale's east and west garages both have shared residential and commercial parking.

Table 5
Commercial/Mixed Use Parking Supplies as a Percentage of ITE, and Commercial/Mixed Use Peak Parking Demand as a Percentage of Actual Supplies.

TOD	Commercial/mixed use parking supply as% of ITE guideline	Commercial/mixed use peak parking demand as% of actual supply
Redmond	27.5%	85.7%
Rhode Island Row	50.8%	78.9%
Fruitvale	22.6%	84.0%
Englewood	61.2%	74.3%
Wilshire/Vermont	25.4%	140.7%

Table 6
Residential/Commercial/Mixed Use Parking Supplies as a Percentage of ITE Supplies, and Residential/Commercial/Mixed use Peak Parking Demand as a Percentage of Actual Supplies.

TOD	Residential/commercial/ mixed use peak parking demand as% of ITE supply guideline	Residential/commercial/ mixed use peak parking demand as% of actual supply
Redmond	41.6%	73.5%
Rhode Island Row	32.7%	63.6%
Fruitvale	19.0%	84.0%
Englewood	45.8%	58.3%
Wilshire/Vermont	33.0%	66.8%

guidelines. This is the most extreme comparison, comparing peak demand for these mixed-use developments to supplies.

For this final comparison, we sum parking utilization across residential, commercial, and mixed-use parking areas for the hour when occupancy is at its highest for residential and commercial uses. We do not include transit park-and-ride parking in this comparison. At all TODs studied, transit users have their own garages or lots. The one exception is Englewood, where transit users share parking with commercial users in the civic center garage.

The first comparison (aggregate peak demand to aggregate ITE parking supplies) indicates just how wildly over-parked these developments would be if parking were built to ITE guidelines rather than scaled back for alternative mode use (walking and transit use). From Table 6, at the overall peak hour, parked cars would fill only 19.0–45.8% of parking spaces if built to ITE guidelines.

The second comparison (aggregate peak demand to aggregate actual supply) indicates the degree to which these developments are over-parked relative to their theoretical potential. From Table 6, at the overall peak hour, only 58.3–84.0% of parking spaces are filled. The latter is for Fruitvale, which has shared parking for residential and commercial uses. Due to limited shared parking, even these exemplary developments (except Fruitvale) do not achieve their full potential. This fact is discussed in the next section.

5. Discussion and conclusion

Smart growth, as an alternative to auto-oriented sprawling development, encourages mixed residential and nonresidential land uses in walkable communities with transit options and nearby essential destinations. Smart Growth America, the leading group for "smart growth" in the U.S., advocates for TODs because of the common goal of achieving a more compact urban form. Within a European context, planners are more likely to refer to this concept as the compact city (Churchman, 1999) or new urbanism. Increasingly, planners, scholars, innovative developers, and local officials across the world promote smart growth as an antidote to many of the ills associated with urban sprawl (Catalán et al., 2008; MacLeod, 2013; Wey & Hsu, 2014).

5.1. D variables and parking policies

Developments are often characterized in terms of D variables. The Ds all bear a relationship to travel demand. The first three Ds—development density, land-use diversity, and urban design—were coined by Cervero and Kockelman (1997). Two additional Ds—destination accessibility and distance to transit—were included in later research. Other Ds include demand management and demographics.

The five TODs studied in this project are more or less exemplary of the Ds. All contain a diverse land-use mix, though Fruitvale could use more residential development and Redmond, in particular, could use more commercial development. All have public spaces, ample sidewalks, street trees, curbside parking, small building setbacks, and other features that make them well designed from a pedestrian standpoint. All minimize distance to transit, literally abutting transit stations. Fruitvale and Rhode Island Row are served by two of the best rail systems in the nation, and thus have exemplary destination accessibility via transit. Wilshire/Vermont has exemplary bus accessibility as well. Four of five provide affordable housing units (20% of all units), and thus attract the demographics most likely to use transit and walk.

In terms of density, these developments (except Wilshire/Vermont) would be classified as low rise (five or fewer stories). The commercial floor area ratio is moderately high only at Fruitvale (see Table 1). Even density of residential development would be considered high only at Wilshire/Vermont and Redmond (see Table 1). The three-story developments at Englewood, Fruitvale, and Rhode Island Row represent a lost opportunity from a transit-supportive standpoint.

A sixth D, demand management (parking management), is mixed in TODs studied. Only Fruitvale and the north garage at Rhode Island Row share residential and commercial parking in the sense that the same spaces can be used at different hours by different users. In other cases, residential and commercial users may occupy the same garage, but with spaces reserved for one use or another (commercial at Redmond, residential at Wilshire/Vermont). And only Englewood shares parking between TOD and transit park-and-ride users. Again, they may share a garage as at Rhode Island Row, but spaces are reserved for transit park-and-ride users. At all surveyed developments, transit has its own, exclusive park-and-ride garage and/or lot. We are not implying that some reserved parking is not warranted for market reasons, but the extent of reserved parking in these otherwise smart developments comes as a surprise.

A parking space/permit comes with each apartment in Englewood and Wilshire/Vermont, whether the renters want it and use it or not. Parking is effectively free. Fruitvale has a hybrid parking policy, where the first space/permit comes with the apartment. The second space (if renters want one) costs them $90 per month. Very few renters opt for the second space, evidence that unbundled parking suppresses parking demand. Only in Redmond and Rhode Island Row is parking totally unbundled. In Redmond, reserved parking spaces are leased for $95 per month ($90 at the time of our study); and in Rhode Island Row, reserved parking spaces are leased for $150 per month.

Redmond and Englewood have free commercial parking. Of the other three, Rhode Island Row charges commercial parkers $2 per hour or a maximum of $24 per day (or $4.50 for early birds). Comparable charges for Fruitvale Village are $3 per hour and a maximum of $12.50 per day; and for Wilshire/Vermont, the charge is $6 per hour and a maximum of $30 per day. All in all, except at Wilshire/Vermont, parking charges are modest.

In terms of parking policies, Englewood is the least progressive and has the highest vehicle trip generation rate relative to ITE. Imagine how much further parking supplies could be reduced if residential, commercial, and transit parking were shared, residential parking were unbundled, and commercial parking were on a pay basis (Willson, 2005).

5.2. Transit park-and-ride demand

We have focused on trip and parking generation by developments (TODs) as compared to ITE guidelines, not on transit park-and-ride which is a function of transit service quality and park-and-ride supply. Our final report, which is previously referenced, does present figures on park-and-ride usage. But this parking supply and demand has nothing to do with the parking supply and demand of the adjacent TOD. Indeed, park-and-ride is (with two exceptions) provided in parking lots or structures separate from TOD parking. In the final report we suggest that economies could be achieved if TOD and park-and-ride parking were more often shared.

5.3. Study limitations

The limitations of this study are summarized here. The first and most important is the small sample size. These are truly case studies, as opposed to a cross-sectional sample. Due to labor-intensiveness of data collection (two people at each entry point to a TOD, one to count and the other to survey), our sample is limited to five TODs. Only one of our TODs is exclusively bus-based, Redmond TOD. Only one is served by LRT, Englewood TOD. Only one is predominately commercial, Fruitvale Village (although Englewood has ample strip commercial along its southern boundary).

A second limitation is an inability to account for internal capture of trips within these TODs. Internal trips are trips that begin and end within a mixed-use development. Such trips obviously have much less impact on the environment and are generally subtracted from total trip-generation rates in traffic-impact studies. Our TODs are small and, we argue elsewhere, likely have low internal capture rates. It is hard to imagine, except perhaps at Englewood, anyone doing anything but walking within our sample of TODs. But as we expand our sample to larger TODs, we will want to ask a third question in our intercept surveys beyond the current two (those two being mode of travel and purpose of trip). We will want to ask whether the origin and destination are within the development.

A third limitation is related to the phenomenon of residential self-selection. Residential self-selection occurs when people who would use transit anyway elect to live in a TOD. The literature strongly suggests that not everyone living in a TOD does so for the transit connection. But many probably do. If there is ever a case where self-selection is likely to be prevalent, it is at developments that offer immediate, high-quality transit options like our case studies. While the transportation statistics from these case studies can be used to plan individual TODs within the context of the US, which will likewise benefit from self-selection, these statistics probably (due to self-selection) overstate the benefit to the region as a whole in having TODs. Again, these self-selectors would be inclined to use transit anyway, so there is not as much impact on regional mode shares or vehicle trips or perhaps even parking demand as our statistics imply.

There are other limitations, such as the fact that our vehicle counts are typically from 7:00 a.m. until 9:00 p.m., rather than the full 24 h as with ITE. Another is that the seventh D variable, demographics, may be different for these TODs than others because most of the developments in our sample offer some affordable (as opposed to market rate) housing. But we still contend that this study has important practical planning implications, as discussed in the next section.

5.4. Applications to TOD planning

How might the statistics in Tables 3 through 6 be used to plan for other TODs? Our statistics represent default values, to be used when better estimates are not available. If a TOD already exists and is, for example, being expanded (like Fruitvale's), planners would not use our default values but would want instead to conduct the same types of counts and intercept surveys we did to estimate the performance characteristics of the expanded TOD. The same idea would apply to new developments going in near existing TODs. Planners probably would want to conduct studies at those TODs to get the best possible estimates for new developments nearby. Redmond TOD and Rhode Island Row TOD, and their respective transit stations, have spawned nearby developments that may mirror the statistics of these particular TODs, perhaps with small adjustments since the new developments are not directly adjacent to the stations, as our sampled TODs are.

For planned TODs around other stations, in the same or other regions, our statistics may be used in tandem with regional travel model forecasts for a particular TOD or its respective traffic analysis zone. Regional travel models can capture the effects of transit service at a particular site, but typically do not capture the full effects of the D variables on travel demand (authors, 2016). On the other hand, our mode shares, trip generation rates, and parking generation rates are actual (not modeled) values that reflect all the D variables of particular TODs, but are particular to these developments and their contexts. Whether they apply to TODs with different D variables and different contexts will always be debatable. That is why we say that both modeled regional travel model forecasts and actual trip and parking generation rates for TODs should be considered in the planning of other TODs.

In the planning of TODs in an international setting, these figures should not be used as they are presented here. However, one can get a sense of the rate of vehicle trip reduction and parking demand, and apply that to a specific context. The US has exceptionally high vehicle trip rates, low mode shares for transit and walking, and ample cheap parking congruent with our sprawling development patterns. Different development patterns in other nations certainly lead to different travel patterns. If an area is generally more compact with higher transit or walk mode shares than the US, TOD would likely have a smaller impact on changing individual travel behavior.

One other source of travel data for mixed-use developments (MXDs) might be used to obtain independent estimates for TODs. For a sample of 412 MXDs in 13 diverse regions of the U.S., Tian et al. (2015) estimated models relating internal capture rates and external walk, bike, and transit mode shares to D variables for the developments and their surroundings. It would not be difficult to estimate these outcome variables for any given TOD. This would provide a third independent estimate of TOD travel characteristics around which to triangulate.

To go further, we need larger samples of TODs, so what are now case studies become a cross sectional sample. Then, perhaps conservatively, one could set a floor on alternative mode shares and percentages trip and parking reductions equal to the minimum values for a larger sample of TODs, or could set a cap on these equal to the maximums from this sample. Also, one could look for the best match to a particular TOD being proposed from among this larger sample of TODs. The best match would be chosen based on the D variables. As an example, a TOD proposed for a Salt Lake City station area might be matched to Englewood TOD in Denver, since the metropolitan regions are most similar and both regions have LRT (light rail transit) rather than HRT (heavy rail transit). This would be particularly appropriate if the planned TOD were large and relatively auto-oriented, like Englewood TOD. Conversely, if the TOD were compact and pedestrian-oriented, largely commercial, and inclusive of affordable housing, one might match to Fruitvale Village, despite differences in rail systems (LRT vs. HRT) and metropolitan regions (Salt Lake City vs. San Francisco). Obviously, any application of these statistics would ideally involve triangulation in light of regional travel demand model forecasts and MXD model estimates.

It is our hope to continue this work by adding more regions and TODs to our sample. The process of data collection has proven to be exorbitantly expensive, thus limiting our count thus far. We hope to limit the costs going forward by streamlining our collection methods, and involving students in future efforts. An ample cross section of regions and sites will ensure confidence in trip and parking generation rates, providing planners with more firm numbers from which they can make crucial decisions. We also encourage our colleagues outside of the US to undertake similar work.

The preceding discussion leads to a re-acknowledgement of the main limitation of this study, and a partial solution to the problem of finding an appropriate match for any new TOD that might proposed. The only way to increase the external validity (generalizability) of this effort is to expand the sample of TODs studied, particularly including larger TODs with higher internal capture rates. We think it particularly important that more LRT systems be represented in the sample, since these are systems that seem to be generating most of the TOD activity. In addition to sample size, we acknowledge other limitations: sample methodology (convenience sampling based on the availability of consultancy branches) and questionnaire design (e.g., no question on parking duration).

In this vein, we call for additional research on trip and parking generation at TODs. TODs, as we have defined them, are an increasingly common development type. In our home region of Salt Lake City alone, there are plans for nine TODs similar to those studied, including adjacency to rail stations. We are currently seeking funding to estimate trip and parking generation rates for two larger TODs on LRT systems, City Creek Center in Salt Lake City and Orenco Station in Portland. But creating a respectable database of TODs with trip and parking data is too big a task to take on alone.

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