

Trip and parking generation at transit-oriented developments: a case study of Redmond TOD, Seattle region

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Abstract The decision on 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). In this study, we identify the ten best self-contained TODs in ten regions across United States based on seven criteria: dense, mixed-use, pedestrian-friendly, adjacent to transit, built after transit, fully developed, and with self-contained parking. We measure trip and parking generation at one of these TODs, the Redmond TOD in the Seattle region, as a pilot study, using an onsite count and intercept survey. The results show that the Redmond TOD has 1.7 times more trips made by walking and 3 times more trips made by transit than Seattle's regional average. The actual vehicle trips we observed are only 37 % of the Institute of Transportation Engineers' (ITE) expected value. The actual residential peak period parking demand is only 65 % of the ITE's peak demand, and the actual commercial peak period parking demand is only 27 % of the ITE's peak demand. Additionally, the peak period of transit parking was daytime, while the peak periods of commercial and residential were evening and nighttime. There is a real opportunity for sharing parking spaces among these different uses, something which is not realized at present.

Keywords Transit oriented development · TOD · Trip generation · Parking generation

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Introduction

The decision on 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). Providing large park-and-ride lots has been the default strategy to maximize transit ridership in the short-run. But is it the best strategy in the long run? The debate continues when land is developed, with officials usually assuming that TODs require the same number of parking spaces as conventional development and that transit stations require the same number of park-and-ride spaces as non-TOD stations, even if much of the travel demand is captured internally and much of the transit demand is generated by TODs themselves. Transit operators often require one-to-one parking replacement when surface parking lots are redeveloped as mixed-use development projects with structured parking.

Balancing the amount of parking at TODs with the need to create a pedestrian-friendly environment and encourage mixed-use development can be complicated. There are only a few studies of vehicle trip generation (Arrington and Cervero 2008; Cervero and Arrington 2008; Zamir et al. 2014) and parking demand (Cervero et al. 2010; Rowe et al. 2011; Serafin et al. 2010) at multifamily development near transit. And, to our knowledge, there is only one study of vehicle trip generation at TODs (defined as mixed-use developments—Handy et al. 2013) and no study of parking demand at TODs (again, defined as mixed-use developments). The question of how much vehicle trip and parking demand reduction occurs with TOD is largely unexplored in the literature. Everyone agrees that there should be some reduction, but is it 20 or 30 or 40 %? This study gives an answer, albeit for only one TOD. And the reduction is huge. We hope these findings will spur additional research.

In this study, we define TODs with seven criteria and identify the 10 best TODs that meet these criteria in 10 metropolitan areas as an initial pool, and as a benefit to other researchers—Atlanta, Boston, Denver, Los Angeles, New York, Portland, Salt Lake City, San Diego, Seattle, and Washington, D.C. We measure trip and parking generation at Redmond TOD, Seattle region, using a methodology that is the most robust published to date. We want, in particular, to test whether TODs generate as many vehicle trips as the Institute of Transportation Engineers (ITE) Trip Generation Manual estimates and need as much parking as the ITE Parking Generation manual suggests.

A consulting partner, Nelson\Nygaard, helped with data collection, analysis, and report and article writing. Specifically, they conducted parking supply and occupancy studies and building access counts as well as intercept surveys at Redmond TOD. We used these data to analyze travel modes and parking use at Redmond TOD, which allow us to develop numerical models of trip and parking demand and recommendations for land use and parking policies at new TOD developments.

Literature review

The Trip Generation Manual and Parking Generation, an informational report by the ITE (2010, 2012), are key sources of analysis of traffic impacts and parking demands of new development projects for planners, engineers, developers, and government decision makers in the United States (Shoup 2003; Millard-Ball 2015). ITE's trip and parking generation manuals provide estimates of the number of vehicle trips and parking demand generated by

a specific land use based on trip and parking surveys of suburban developments constructed after the 1960s. The trip and parking rates given by ITE are mostly generated in single-use suburban developments dominated by automobile travel.

First we review the literature on trip generation at TODs. The ITE Trip Generation Manual itself states that “Data were primarily collected at suburban locations having little or no transit service, nearby pedestrian amenities, or travel demand management (TDM) programs” (ITE 2004, p. 1). 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 2004, p. 1). This kind of modification is seldom done in practice.

Surveying 17 TODs 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 TOD housing projects averaged 44 % fewer vehicle trips than that estimated by using the ITE manual (3.754 vs. 6.715). Another study by the San Francisco Bay Area Metropolitan Transportation Commission found that residents of the Bay Area living near transit generated half as many vehicle miles traveled (VMT) as their suburban and rural counterparts (SFBAMTC 2006).

At the same time, residents living within developments near transit are reported to have higher rates of transit trips than those who are living at greater distance (Faghri and Venigalla 2013; SFBAMTC 2006; Zamir et al. 2014), especially for commuting trips (Arrington and Cervero 2008; Cervero 1994; Faghri and Venigalla 2013; Lund et al. 2004, 2006).

Next we review the literature on parking generation by properties within TODs. The ITE Parking Generation manual notes that study sites upon which the manual is based are “primarily isolated, suburban sites” (ITE 2010). Rowe et al. (2011) found that the parking demand in an urban center abutting downtown Seattle and exhibited higher levels of transit service is about 50 % less than the parking demand in a growing mixed-use suburban center in Seattle. Other studies also show that the vehicle ownership is lower in transit-served areas than those that are not transit-served (Faghri and 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 et al. (2010) found there is an oversupply of parking at TODs, sometimes by as much as 25–30 %. Serafin et al. (2010) found the oversupply of parking of transit related residential projects in Santa Clara County too. Oversupply of parking spaces may result in an increase in vehicle ownership (Cervero and 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 et al. 2009).

The literature shows that a barrier to create TODs in many areas is “parking replacement policies” from transit agencies that require the developer to replace park-and-ride spaces on a one-to-one basis at a cost of \$10,000 to \$15,000 per parking space (Arrington and Cervero 2008). These policies increase the cost of TOD development substantially, especially because some estimates peg the price of a single parking stall even higher, at \$20,000 to \$40,000, or as much as \$60,000 in high-value real estate markets (i.e., San Francisco) (Reconnecting America 2009). According to Cervero and Landis (1997), “An oversupply of park-and-ride lots at transit stations...can undermine regional land-use benefits.” Developers and policy makers should agree upon parking supply and pricing policies that support the overall objectives of TODs (Willson 2005). The Bay Area Rapid

Transit (BART) system previously had a one-to-one parking replacement requirement, but came to realize that this policy was discouraging transit-oriented development around stations (Knepper 2015).

Our review of the Transportation Research Board's (TRB's) Transportation Research Information Services (TRID) database found few resources on parking at TODs. One team of researchers sought to "understand the tension between access (parking and otherwise) and transit-oriented development (TOD) and learn how practitioners successfully resolved these tensions" (Edgar et al. 2013). The team performed a scan to learn of parking policies and TOD practices in five regions: San Francisco/Oakland, Denver, Los Angeles/South Pasadena, San Diego, and Boston. They found that parking could be a source of tension in areas where land value is at a premium, density is high, and where transit riders are accustomed to large park-and-ride lots. Too much parking may interfere with the human design of a TOD and compromise what should be a pedestrian-friendly environment.

The parking policy recommended by Martin and Hurrell (2012) is one of "constrained" parking that is not included in lease or other TOD operational costs. This will result in the greatest line-haul ridership for the TOD. In addition, they recommend that transit riders pay for parking once parking capacity is reached in order to cover maintenance costs for the parking lot or garage. The idea here is that when riders have to pay for parking, they demand less of it.

Because data are difficult and expensive to collect, much of the research on parking at TODs presents more general findings. Our study will ultimately quantify trip and parking generation at TODs in 10 diverse metropolitan areas. For now, this study is limited to a single pilot study, of the Redmond TOD in Seattle.

TOD definition

TODs are widely defined as compact, mixed-use developments with high-quality walking environments near transit facilities (Calthorpe 1993, p. 56; Cervero et al. 2004, p. 7; ITE 2004, pp. 5–7). For our purposes, TODs are developed by a single developer under a master development plan, and can also include a clustering of development projects near transit facilities that are developed by one or more developers pursuant to a master development plan. This definition excludes mixed-use catchment areas around transit stations in the typical downtown. These mixed-use areas are too large for such a study, and do not have dedicated parking, one of the criteria for project selection.

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

- (1) dense (with mid-rise or higher multifamily housing),
- (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 additional criteria to maximize the utility of the sample and data. TODs must be

- (4) adjacent to transit (literally abutting—transit passengers spill out into the TOD),
- (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) with self-contained parking.

By self-contained parking we mean having dedicated parking for the buildings that comprise the TOD, in one or more parking lots or garages. 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 was 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 and self-contained TODs in less urban or more suburban locations.

Since the TODs of interest to us are self-contained, and are under a single development plan, they will necessarily be small compared to a typical downtown or even relative to the typical quarter mile buffer around a transit station. They are likely to have small internal capture rates. This too is a limitation. The sizes of the TODs in our initial sample are discussed below.

TOD selection

Given our seven criteria, we selected the best self-contained TODs in each of 10 regions. For each region, we tried to identify 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 six of the 10 study regions: Atlanta, Boston, Denver, Portland, Salt Lake City, and Seattle. We identified all MXDs in close proximity to transit stations in the six regions.

The second step was to ask our teaming partners' branch offices to identify candidate sites within their regions that meet our seven criteria. Concurrently, we contacted regional transit operators and/or metropolitan planning organizations in the ten regions 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, as we defined it.

The third step was to review candidate sites with Google Satellite Imagery to see if there was 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 in turn, 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 if 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.

Finally, we identified the 10 best TODs, one in each region, that meet our criteria. Indeed, it proved hard to find TODs that met all of our TOD criteria. In the typical region, there were only one or two. The process we used rank them was, firstly, they needed to meet the "yes-and-no" criteria, including (4), (5), (6), and (7). And then the TODs that

Table 1 The journey to work mode share for the CBGs that contain our TOD sites

TOD	Metropolitan area	Area of TOD (acres)	GISJOIN (census block group ID)	Area of CBG (acres)	Journey to work	
					Walk share (%)	Transit share (%)
Lindbergh City Center	Atlanta	38	G13012100094021	184	2.43	14.03
Station Landing	Boston	17	G25001703398011	227	0	23.99
Englewood	Denver	38	G08000500057002	294	2.55	18.10
Del Mar	Los Angeles	4	G06003704636021 G06003704636021	60	2.72	14.05
Orencia Station	Portland	50	G41006700326071	1554	5.68	6.98
City Creek Center	Salt Lake City	20	G49003501140001	780	13.51	8.42
Redmond TOD	Seattle	5	G53003300323092	300	3.00	13.28
City College Trolley Station	San Diego	2	G06007300052002	43	16.08	9.71
Fruitvale Village	San Francisco	3	G06000104061001	133	13.90	23.22
Rhode Island Row	Washington, D.C.	7	G11000100091022	355	1.86	31.00

were denser, more diverse in their land uses, and with more pedestrian-friendly designs were ranked at the top.

Table 1 provides descriptive statistics of mode share for work trips for the census block groups (CBGs) that contain these TODs. Generally, the CBGs containing TODs have fairly high walk or transit mode shares on the journey to work.

A case study: Redmond TOD, Seattle region

We identified the ten TODs as an initial pool, and as a benefit to other researchers. We then selected one as a pilot study, the Redmond TOD in the Seattle region. The choice was a matter of convenience, considering the relatively small size of the Redmond TOD and the immediate availability of consulting staff to conduct the study. We plan to eventually study them all, but the cost of these labor intensive studies exceeds our current budget.

The Redmond TOD is our choice in the Seattle region, which is served by local and commuter buses. The King County Department of Transportation, the City of Redmond, and Sound Transit jointly developed a new Redmond Downtown Transit Center and adjacent TOD. The westbound bus stops of the Transit Center and Redmond Skate Park are on the north side of NE 83rd Street, while the TOD, eastbound bus stops, and Park-and-Ride Garage are on the south side. With NE 83rd Street having low traffic volumes and a pedestrian-friendly design, the four components form a unified whole.

The Transit Center was built on the site of the existing bus transfer facility, while the TOD was built on Metro's Redmond Downtown Park-and-Ride Lot (Fig. 1). The former replaced a smaller, cramped set of bus stops originally constructed in 1978. The \$7.2

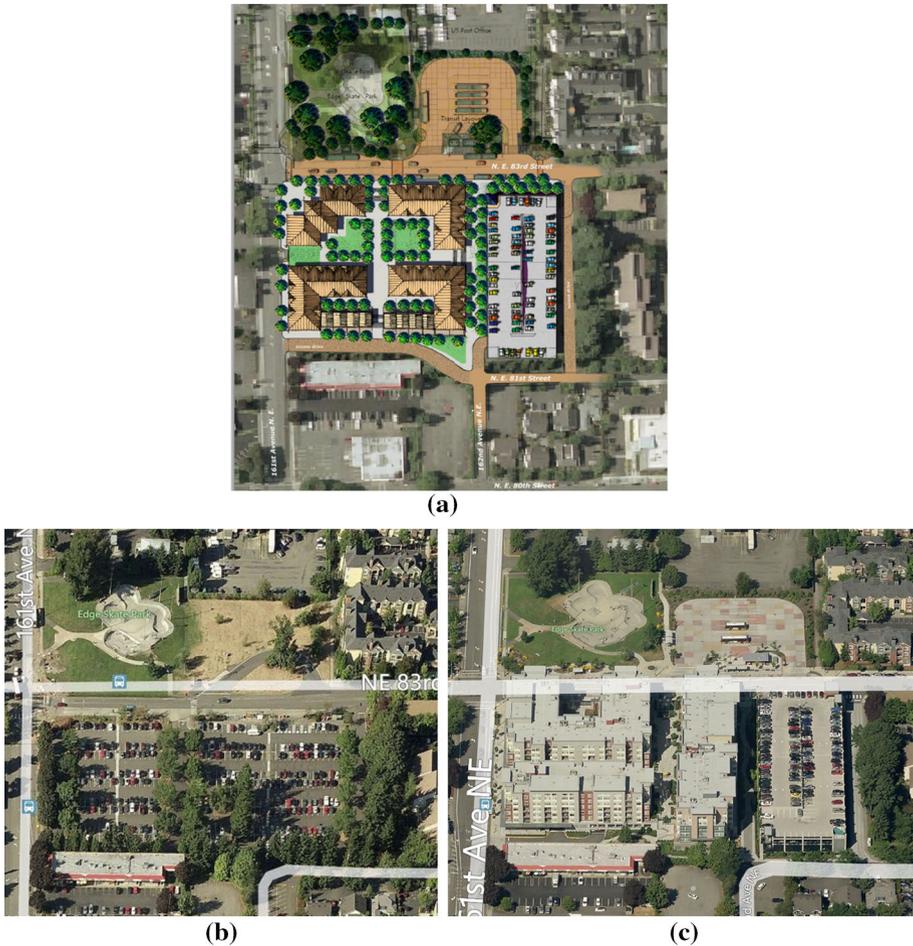
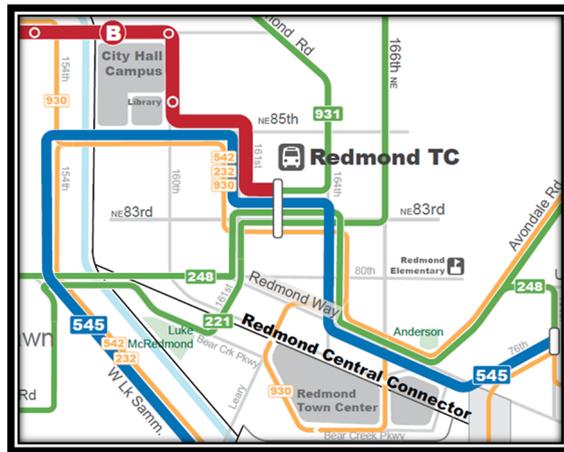


Fig. 1 Redmond Transit Center and TOD. **a** Site plan (source <http://www.kingcounty.gov/transportation/kcdot/PlanningAndPolicy/RegionalTransportationPlanning/TransitOrientedDevelopment/Projects/Redmond.aspx>), **b** before the project, **c** after the project

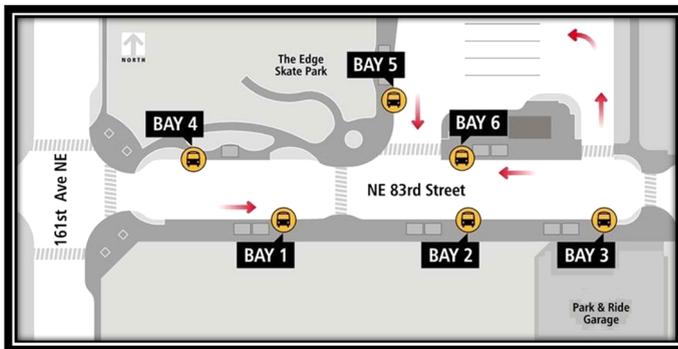
million transit center was designed and constructed by Metro, with \$6 million from Sound Transit and the remainder from a federal grant. The transit center was constructed on county property and city street right-of-way. Metro designed, constructed, and funded the new garage, while private developer Trammell Crow Residential built the TOD project. The city reviewed and permitted all of the projects, which were designed to meet goals of Redmond’s Downtown Transportation Master Plan. The Transit Center officially opened in 2008, while the TOD was completed in 2009.

The Redmond Downtown Transit Center is served by Metro bus lines 221, 224, 232, 248, 930 DART, 931 DART, and RapidRide B Line; and Sound Transit Express 542 and 545 lines (Fig. 2). Sound Transit doubles midday service on ST Express 545, adding extra peak period trips during times when loads are heaviest.

The new transit center has six bus bays and a separate bus layover area that concentrates transit service into a central downtown location. Improvements to the preexisting bus



(a)



(b)

Fig. 2 Transit services at Redmond. **a** Buses that go through Redmond Transit Center (source <http://www.redmond.gov/common/pages/UserFile.aspx?fileId=160128>). **b** Redmond Transit Center Boarding Locations (source <http://metro.kingcounty.gov/tops/parknride/boarding/redmond-tc.html>)

transfer facility increased transit passenger loading capacity, expanded the bus loop north of NE 83rd Street to improve transit operations, and added bus layover capacity to the loop. Features include custom architectural transit passenger shelters and a streetscape design that complements the existing City of Redmond Skate Park.

The new transit center improves safety by providing continuous sidewalks on both sides of NE 83rd Street. Other improvements include more visible pedestrian crossings, better site distances for buses using the turnaround, and fewer vehicle/bus/pedestrian conflicts due to removal of the middle park-and-ride driveway. The addition of off-street layover space and the transit turnaround significantly improves transit efficiency. These two elements allow King County Metro Transit to invest service hours in carrying passengers instead of “deadheading” empty buses to satellite layover locations.

Redmond TOD (called Veloce Building) is a 322-unit multifamily mixed use project that is the focal point of the transit oriented core of the city. Twenty percent of the units are affordable at 80 % of the area’s median income. The podium style building has street level retail and two levels of parking below the 3–5 story apartment buildings. The project caters

Table 2 Development summary of Redmond TOD project

Land uses	Description	Unit	Occupancy (%) ^a
Commercial	Ground floor	11,740 square feet (sq. ft.)	56.8
Residential (called Veloce Building)	5 stories above commercial	322 units (37 studio units, 173 one bedroom units, and 112 two bedroom units)	96.9
Parking	Description	Unit	Occupancy (%) ^b
Transit parking-and-ride	3-level parking structure	383 stalls	96.9
Veloce development parking	2-level underground parking	415 stalls (66 stalls for retail customers and employees; 379 stalls for residents)	69.6

^a On May 28, 2015

^b The peak occupancy at May 28, 2015

to young professionals, who desire urban living, as well as to commuters. Light rail will eventually run next to the building, making it the hub of downtown Redmond. This project won the City of Redmond's 2012 Outstanding Design Award in recognition of its exceptional architectural contribution to the City.

The multifamily units were almost fully leased at the time this study was conducted (Table 2). More than half of the retail space was leased to a restaurant, an animal hospital, and a financial services office. The two-level parking garage/structure has 415 stalls located below the residential component of the project. The parking garage includes 379 stalls for building residents, and 36 public parking stalls, with 3 signed for "new residents," 3 for "guests," 4 for "carpools," and 26 for "retail" customers and employees. The residential parking is leased at \$90/month for the reserved parking in the lower level, and \$80/month for access to non-reserved/resident shared parking in the upper level. Retail, guest, and carpool parking are separated from the residential parking (outside the gates), and available at no charge. Street parking with short-term parking capacity for up to eight vehicles in front (west frontage only) is free, but limited to 2-h, from 9:00 am to 5:00 pm, Monday to Friday, except holidays, as posted. In addition, a 40' short-term loading zone is provided at the curb on the west frontage, immediately in front of the main pedestrian entrance to the building. Additional parking is provided for commuters; the Redmond Park-and-Ride Garage is a three-story structure with 383 free parking stalls and 12 Bike Lockers (Fig. 3).

Data collection

The multimodal transportation planning firm of Nelson\Nygaard developed a data collection plan and protocols, and managed data collection in the field and subsequent data entry for three types of travel data: (1) a full count of all persons entering and exiting the Veloce Building, (2) a brief intercept survey of a sample of individuals entering and exiting the building, and (3) parking inventory and occupancy surveys of all off-street parking accessory to the commercial and residential uses of the Veloce building, and the co-located, but separate off-street parking facility owned and operated by King County Metro Transit for all day use by transit riders.



(a)



(b)



(c)



(d)



(e)



(f)



(g)



(h)



(i)

◀ **Fig. 3** Redmond TOD. **a** Apartment building and park-and-ride garage. **b** Apartment building with ground floor retail. **c** Apartment building with underground parking. **d** Park-and-ride garage. **e** Redmond Transit Center. **f** Transit users. **g** Redmond edge skate park. **h** Unleased space. **i** Spillover bike parking at the apartment garage

The intent of this approach was to develop an accurate measure of total trip generation associated with the commercial and residential space at the site, as well as a complementary sample of travel survey and parking utilization data that could be weighted by hour to 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.

All survey and trip count data were recorded on location in Redmond TOD, between 7:30 am and 9:00 pm on Tuesday, May 28th, 2015. Parking utilization was surveyed at each facility approximately every 2 h, during this same period. In addition, to determine parking occupancy during the anticipated period of peak utilization associated with the predominant residential use, an “overnight” count of parking occupancy was conducted at both the Veloce Building garage, and the Redmond Transit Center Park-and-Ride lot, from 1:00 to 2:00 am on Tuesday, June 2, 2015.

For the purpose of counting person trips generated and recording travel patterns, separate teams of surveyors were employed to (a) count people entering/exiting at each building entrance, and (b) conduct intercept surveys (most intercept surveys were completed by undergraduate and graduate students at the University of Washington Colleges of Environmental Design or Engineering). All parking inventory and occupancy counts were conducted by Nelson\Nygaard planning staff, who also supervised survey workers at building entrances.

Throughout the survey period, four people were employed to conduct trip counts. These surveyors were stationed on the public sidewalk in fixed positions where they could easily and continually observe all primary entrances to the building. Counters on the north and west sides, and the northeast corner of the building tallied the number of people entering and exiting each door by hour. The counter on the southwest corner recorded pedestrians entering/exiting the lone south door, in addition to people entering/exiting the Veloce parking facility by bicycle, or motor vehicle—noting vehicle occupancy when visible.

A separate team of surveyors—four all day, with a fifth added during peak periods (7:30–9:30 am, and 4:30–7:30 pm)—were employed to intercept and survey people entering and exiting the building.¹ These surveyors were initially stationed to the north, west, northeast and southwest of the building, covering all primary pedestrian entrances to the Veloce building, but were instructed to leave their stations, as necessary to intercept and attempt to survey individuals seen moving toward an entrance, or away from a building exit.

As a first step, surveyors noted whether the subject was observed “coming” or “going” to/from the building, 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.

¹ Note that for up to 4 h—7:30 to 9:30 am, and 6:00 to 8:00 pm—a single surveyor positioned at the southwest corner of the building was tasked with both counting and intercept surveying of people entering and exiting the Veloce Building. This surveyor was responsible for observing people entering/exiting the little used South entrance, as well as counting and surveying people on the driveway to/from the parking garage.

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, or would be leaving by automobile were also asked where they parked their vehicle (e.g. “on-street,” “in the [Veloce Building] garage,” or at an “other” location/facility).

Surveyors counted and attempted to intercept only those individuals observed walking to or from an entrance to the Veloce building (or, in observation of the garage entrance, only those drivers and passengers in vehicles entering/exiting the garage driveway to/from the public street). Individuals waiting for the bus, or walking between the bus stops and other trip origins/destinations, including the Redmond Transit Center Park-and-Ride Lot, were not counted or surveyed. The intercept survey received 428 respondents.

Mode choices and trip generation

Mode choices

In the intercept survey, we had one surveyor at each entrance to the development to ask people questions. We received 428 valid responses out of 437 respondents. One question in the survey was which transportation mode was used to get to this development. The mode shares from the intercept survey are presented in Table 3. We then applied these mode

Table 3 Mode shares in Redmond TOD

Intercept survey						
Entrance	Count	Mode share (%)				
		Walk	Bike	Transit	Auto	Other
Parking garage	115	2.61	1.74	0.87	93.04	1.74
Residential north	90	21.11	2.22	65.56	10	1.11
Residential west	124	54.03	0.81	9.68	34.68	0.81
Commercial (west)	99	18.18	2.02	13.13	64.65	2.02
Trip generation counts						
Entrance	Count	Count for modes				
		Walk	Bike	Transit	Auto	Other
Parking garage	852	22	15	7	793	15
Residential south	173	65	3	65	39	2
Residential north	145	31	3	95	15	2
Residential west	324	175	3	31	112	3
Commercial (west)	446	81	9	59	288	9
Parking garage street exit	41	1	1	0	38	1
Final mode share	1981	18.93 %	1.67 %	13.01 %	64.85 %	1.54 %

shares to the total trip generation counts by entrance to compute the final weighted mode shares.

There is no sample for entrances of Residential South and Parking Garage Street Exit in the intercept survey. We used the mode shares from the entrances that were within the same building structures. The average mode shares of Residential North and West were applied to Residential South and the mode shares of Parking Garage were applied to Parking Garage Street Exit.

The final mode shares for Redmond TOD are 19 % walk, 2 % bike, 13 % transit, and 65 % auto (Table 3). According to the 2014 Puget Sound regional household travel survey, the regional mode shares are 11 % walk, 1 % bike, 4 % transit, and 82 % auto (PSRC 2015). Comparing with the regional mode shares, Redmond TOD has a significant mode shift, a shift from auto to walk and transit, even bike. Redmond TOD has 1.7 times more trips made by walking and 3 times more trips made by transit than the regional average.

Trip generation

Our actual trip generation counts from the survey did not distinguish residential trips and commercial trips. To compare the actual trip generation with ITE's benchmarks, we will combine all estimated trips for different uses into a total that can be compared to ITE.

There were 1981 person trips and 661 vehicle trips observed for the whole day of the survey. Those trips were generated by the occupied residential units, which are 312 units (322×0.969), and leased commercial spaces, which are 1905 sq. ft. for an office, 2682 sq. ft. for a restaurant, and 2081 sq. ft. for an animal hospital.

For the trip generation rate of the residential building at Redmond TOD, we used the value for "223 Mid-Rise Apartment" in ITE Trip Generation Manual, which is defined as "apartments (rental dwelling units) in rental buildings that have between three and ten levels (floors)". The ITE manual reports a trip generation rate for the peak hour but does not report a daily trip generation rate for mid-rise apartment. However, the ITE manual reports the daily trip generation rate for all apartments ("220 Apartments"). We used this rate to compute the daily trip generation rate for mid-rise apartments. Here was the process: (1) the average daily vehicle trip generation rate for "220 Apartments" is 6.65 per dwelling unit on a weekday, 0.55 per dwelling unit at the AM peak hour on a weekday, and 0.67 per dwelling unit at the PM peak hour on a weekday; (2) the average vehicle trip generation rate for "223 Mid-Rise Apartment" is 0.35 per dwelling unit at the AM peak hour on a weekday and 0.44 per dwelling unit at the PM peak hour on a weekday; (3) the average daily vehicle trip generation rate for "223 Mid-Rise Apartment" therefore equals $6.65 \times (0.35 + 0.44) / (0.55 + 0.67)$, which is 4.31 per dwelling unit.

For the trip generation rate of the office at the Redmond TOD, we used "715 Single Tenant Office Building" in the ITE Trip Generation Manual. The average daily vehicle trip generation rate for this type of land use is 11.65 per 1000 sq. ft. gross area (GFA) on a weekday.

For the trip generation rate of the restaurant at the Redmond TOD, we used "932 High-Turnover (Sit-Down Restaurant)" in the ITE Trip Generation Manual. The average daily vehicle trip generation rate for this type of land use is 127.15 per 1000 sq. ft. GFA on a weekday.

For the trip generation rate of the animal hospital at Redmond TOD, the ITE manual has a category "640 Animal Hospital/Veterinary Clinic" but only reports the average vehicle trip generation rate for the peak hour on a weekday, which is 4.08 per 1000 sq. ft. GFA.

Table 4 The comparison of daily vehicle trip generation between ITE guideline and Redmond TOD

	Trip generation rate	Total units	Total daily trips
ITE guideline	–	–	1773
223 Mid-rise apartment	4.31	312	1344.72
715 Single tenant office building	11.65	1905	22.19
932 High-turnover (sit-down) restaurant	127.15	2682	341.02
640 Animal hospital/veterinary clinic	31.45	2081	65.45
Redmond TOD	–	–	661

Instead, we used the daily average vehicle trip generation rate on a weekday for “630 Clinic”, which is 31.45 per 1000 sq. ft. GFA.

Based on the ITE’s trip generation rates, the Redmond TOD would be expected to generate 1793 daily vehicle trips (Table 4). The actual vehicle trips we observed on the survey day was 661, which is only 37.3 % of the ITE’s expected value. This is consistent with the findings from District Department of Transportation (DDOT) recent pilot at 16 locations in Washington, D.C. (Weinberger et al. 2015).

Parking generation

Parking supply and demand recorded for the Redmond TOD project were compared to the number of parking stalls as well as occupancy rates from the 2010 ITE Parking Generation manual.

Residential

For the residential component in the ITE Parking Generation manual, “222 High-Rise Apartment” (rental dwelling units) are defined as units located in rental buildings that have five or more levels (floors) and most likely have one or more elevators. This is the best match for the 5-story multifamily residential uses at the Redmond TOD. The average parking supply ratio reported by ITE is 2.0 parking spaces per dwelling unit at central city, not downtown, sites.

As shown in Table 5, the actual parking supply for the residential units at the Redmond TOD is 1.19 parking spaces per unit or 379 total, which is much lower than ITE’s guideline (2.0 spaces per unit or 644 total).

The ITE average peak period parking demand from seven study sites is 1.37 vehicles per dwelling unit with standard deviation of 0.15, a range of 1.15–1.52, an 85th percentile value of 1.52, and a 33rd percentile value of 1.38. Besides the average rate, the ITE manual also provides the best-fitting regression line for estimating total parked vehicles as a function of the total number of dwelling units:

$$P = 1.04x + 130$$

where P is the parked vehicles and x is the dwelling units

On the surveyed day, the actual peak parking demand of the residential units at the Redmond TOD was 278 at 1:00 am. That is much lower than both the ITE average of 427 (1.37*322*0.969, occupied units only) and the ITE regression estimate of 454

Table 5 The comparison of parking supply and demand between Redmond TOD residential and ITE guideline

Residential				
	Supply		Peak period demand	
	Parking spaces per unit	Total parking spaces	Vehicle per unit	Total parked vehicles
ITE guideline: 222 high-rise apartment	2.0	644	1.37	441
Redmond TOD residential	1.19	379	0.86	278
Commercial (occupied space only)				
	Supply		Peak period demand	
	Parking spaces per 1000 sq. ft. GFA	Total parking spaces	Vehicle per 1000 sq. ft. GFA	Total parked vehicles
ITE guideline	–	51	–	37
932 high-turnover (sit-down) restaurant	14.3	–	10.6	–
701 office building	4	–	2.84	–
640 animal hospital/veterinary clinic	2.3	–	1.6	–
Redmond TOD commercial	3.14	14	1.8	12

($1.04 \times 322 \times 0.969 + 130$, occupied units only). The actual residential peak period parking demand at Redmond TOD is only 65 % ($100 \times 278 / 427$) of the ITE’s average demand using the average parking generation rate and only 61 % ($100 \times 278 / 454$) of ITE’s average demand using the regression equation.

Commercial

There is a total of 11,470 square feet of leasable space for commercial uses at the Redmond TOD, and 26 parking spaces for all commercial uses (not including up to eight on-street parking spaces and an on-street loading zone with capacity for two vehicles). The leased space is 6668 square feet for a family restaurant, an animal hospital, and a retail financial services establishment. We do not have the parking supply and demand data separately for each of these three uses, so we will treat them as a whole.

In the ITE Parking Generation manual, the “932 family restaurant” is defined as an abbreviated version of “high-turnover (sit-down) restaurant without bar or lounge facilities”. The average parking supply ratio at family restaurants is 14.3 spaces per 1000 sq. ft. GFA. The average peak period parking demand is 10.6 vehicles per 1000 sq. ft. GFA during the weekday at a suburban location with a standard deviation of 5.42, a range of 2.59–21.78, an 85th percentile value of 16.3, and a 33rd percentile value of 7.4.

The ITE’s guideline of average parking supply ratio for office buildings is 4.0 spaces per 1000 sq. ft. GFA. The average peak period parking demand is 2.84 vehicles per 1000 sq. ft. GFA during the weekday at a suburban location with a standard deviation of 0.73, a range of 0.86–5.58, an 85th percentile value of 3.45, and a 33rd percentile value of 2.56.

The average parking supply ratio that ITE estimates for animal hospital/veterinary clinic is 2.3 spaces per 1000 sq. ft. GFA. The peak period parking demand ratio is 1.6 vehicles per 1000 sq. ft. GFA based on a 2-h observation.

According to the ITE guideline, the parking supply for these three leased commercial spaces would be 51 spaces $([14.3 \times 2682 + 4 \times 1905 + 2.3 \times 2081] / 1000)$. The actual parking supply for commercial uses at the Redmond TOD is 26 total spaces for all 11,740 sq. ft. of commercial space. We cannot know precisely the actual parking supply just for the leased commercial space, but it would be about 57 % of the total spaces based on the percentage of total space currently leased. That is to say, based on the current leases, about 14 spaces might be associated with the currently leased commercial space. This is only about 27 % of the ITE guideline (as shown in Table 5).

According to the ITE’s guideline, the average total peak period parking demand for these three commercial uses would be 37 spaces $([10.6 \times 2682 + 2.84 \times 1905 + 1.6 \times 2081] / 1000)$, only for leased spaces). The actual peak period parking demand of the commercial uses at Redmond TOD was 12 in the evening on the survey day, which is less than one-third of the ITE’s guideline.

Parking demands for different land uses

The parking demands for different land uses during the survey day are shown in Fig. 4. The peak period of parking demand is different for the different land uses.

For the transit Park-and-Ride, demand was very high at midday. More than 90 % of parking spaces were occupied from 8 am in the morning to 3 pm in the afternoon. The demands dropped very quickly after that and down to less than 20 % occupancy after 8 pm at night.

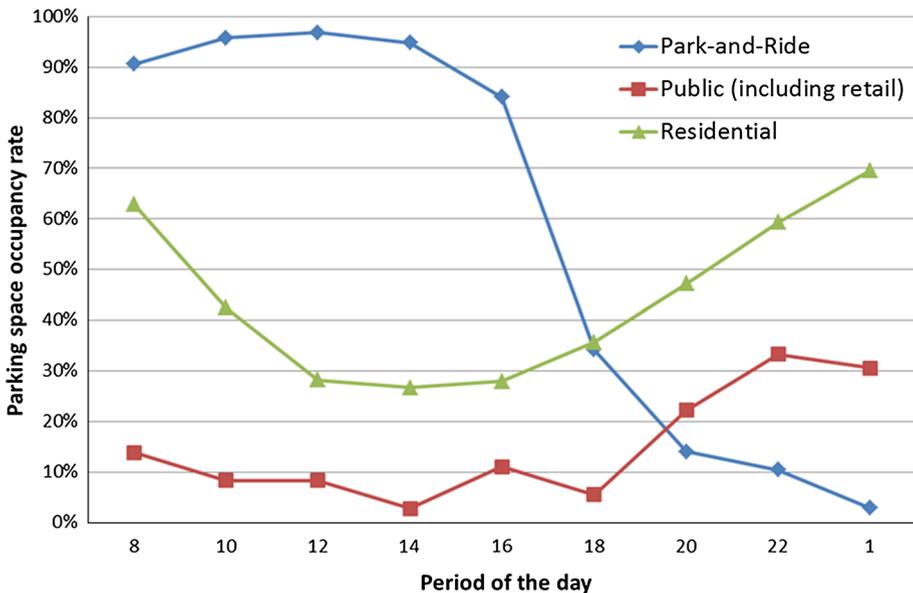


Fig. 4 Parking space occupancy rate for different uses at Redmond TOD

The residential peak parking demands were at night from 10 pm to 8 am. The demands started to decrease during the day and were at their lowest between 12 pm to 4 pm, and then started to increase to after 4 pm.

The commercial parking demands were pretty low during daytime and increased after 6 pm in the evening. The peak commercial parking demand came at 10 pm in the evening.

The peak period of transit parking was daytime, while the peak periods of commercial and residential were evening and night. Given this fact, there is a real opportunity for sharing parking spaces among these different uses, something which is not realized at present.

Conclusion

Redmond TOD case study

Redmond TOD is not large (essentially one large building) and therefore, there probably are not many trips captured internally. It is really the parking supply and pricing as well as the proximity to transit that are producing the travel behavior benefits. Also producing benefits is the placement of this project in an urban/suburban context where neighboring uses can exchange trips with on-site uses.

Based on site visits already conducted, and a review of American Community Survey data, we expect that the vehicle trip and parking reduction may be even greater at some of the other nine sites in Table 1 than at the Redmond TOD. This is the case because some of the sites are more urban/less suburban than the Redmond TOD site, are more exemplary of TOD than the Redmond TOD site (denser, more mixed, and more pedestrian-friendly), and are all rail-served, unlike the Redmond TOD, which is bus served.

Still the vehicle trip and parking reduction at the Redmond TOD site is impressive:

Mode choices Redmond TOD has 1.7 times more trips made by walking and 3 times more trips made by transit than the regional average.

Trip and parking generation Redmond TOD only generates about 37 % of the vehicle trips estimated by ITE Trip Generation Manual. The actual residential parking demand at the Redmond TOD is only 65 % of ITE's average. The actual commercial parking demand at the Redmond TOD is only 27 % of the ITE average. This is due to mode shifts away from the automobile, and maybe to some degree to internal capture of trips within the mixed use site.

Shared parking potential The peak period of transit parking is daytime, while the peak periods of commercial and residential were evening and night. There is a real opportunity for sharing parking spaces among these different uses, something which is not realized at present.

Barriers to TOD

There are many barriers to implement TOD and maximize TOD's benefits. For instance, one of the big barriers for infill TOD is the one-to-one parking replacement policy—one-to-one replacement of any surface parking removed for the purpose of development on transit properties (Cervero et al. 2004; Willson and Menotti 2007). For the parking requirement, TOD has to meet the same minimum parking requirements as the conventional single-use development. For sharing parking between private residential parking and public transit parking, there are issues of ownership, security, etc.

To remove those barriers requires cooperation of cities, transit agencies, and developers. For instance, cooperation may be required to create a special zoning district or change existing zoning provisions for TOD, adopt reduced parking requirements to reflect transit shares and lower automobile ownership in a TOD, encourage or require unbundling of parking spaces for residential and commercial uses.

Other barriers are the ITE Trip and Parking Generation Manuals themselves. There should be stronger statements, in the manuals, warning against the application of their generation rates to TODs. Perhaps, in time, there could be special TOD land use categories for trip and parking generation that reflect the lower rates found in this study. The subsequent case studies of the other nine sites in Table 1 could begin to build a database for such additions to the manuals.

Benefits of TOD

A national survey suggests that the principal aim of TODs for transit agencies is to boost ridership and revenue income (Cervero et al. 2004). This study shows the impact of TOD on residents' mode choices, which confirms the most direct benefit of TOD on ridership. Ridership can increase through economic and population growth around transit stations. Encouraging mixed use developments around transit stations generates internal trips and creates an opportunity for shared parking spaces among different uses. More important for urban planners, TOD provides an opportunity for a transit station being a desirable place instead of just a transportation node.

This study clearly shows some benefits of TOD. For a long term and broad perspective, TOD has economic, environmental, and social benefits. By funding public investments in infrastructure, TOD can attract private investments. By concentrating development and increasing the share of non-automobile trips, TOD can be an effective tool of dealing with urban sprawl, traffic congestion, and air pollution.

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