THE ODDS ON TODS

Transit-Oriented Development as a Congestion-Reduction Strategy in the San Francisco Bay Area

Daniel R. Luscher

Transit-oriented development, which clusters high-density, mixed-use development around transit stations, has been proposed as a way to reduce automobile travel in the San Francisco Bay Area and elsewhere. This paper relates research on neighborhood characteristics and vehicle travel to specific Bay Area characteristics. The analysis shows that, even using optimistic assumptions about travel behavior, redeveloping the area around most of the existing rail transit stations, coordinating similar development around feeder bus routes, and clustering close to one-fifth of the region's population in these areas would reduce vehicle miles traveled in the Bay Area by just 5%. If current trends continue, this would offset only three years of growth in vehicle miles traveled. Thus, transit-oriented development is unlikely to have a significant impact on regional vehicle miles traveled and traffic congestion. Although transit-oriented development may have other worthwhile benefits, it is inappropriate as the cornerstone of the Bay Area's congestion management strategy.

Traffic congestion is a critical problem in the San Francisco Bay Area. In 1990, peak-hour commuters experienced roughly 68 million hours of delay, equivalent to over one-third of total travel hours (MTC 1994a, 37).[1] Using the Metropolitan Transportation Commission's (MTC) estimate of the value of time, $7.28/hour ($1993) (MTC 1994a, 57), this corresponds to a total social cost of approximately $500 million per year. According to annual public opinion polls, transportation was the most important problem in the Bay Area for the nine years from 1983 through 1991 (Bay Area Council 1994), most likely because of concerns about traffic congestion.[2]

Congestion is expected to get worse in coming years as growth in vehicle miles traveled (VMT) outpaces growth in transportation network capacity. Bay Area drivers logged approximately 34 billion VMT in 1990. This figure is projected to increase to 46 billion by 2010 due to a increase in population (of 25%) and per capita VMT (8%) (MTC 1994b).[3] Employment is expected to grow even more rapidly than population (33% from 1990 to 2010) (MTC 1994b).

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Because of these changes, the MTC projects that peak-hour delays will increase by 49% between 1990 and 2010 (MTC 1994a).

The central challenge for Bay Area transportation planners is to accommodate future population while addressing chronic traffic congestion that threatens to get worse. Transit-oriented development has been advanced as one possible answer. Despite assertions that it could impact travel patterns, little quantitative analysis has been done to gauge the magnitude of its potential effects on regional VMT or traffic congestion.

This paper attempts a rigorous assessment of the potential of transit-oriented development to reduce regional VMT in the Bay Area. It uses a three-step process. First, two model transit-oriented developments (TODs) are defined. Second, the impact of each model TOD on per capita VMT is estimated. Finally, these estimates are aggregated over the Bay Area to determine the potential regional impact of TODs. The implications of the analysis are briefly discussed at the end of the article.

It is important to note at the outset that the analysis has significant limitations. First, it uses hypothetical, stylized models of TODs to estimate regional impacts. Because many TODs would be located in infill and redevelopment areas, and because they would need to adapt to specific community characteristics, actual designs may vary substantially. The stylized TODs used here may not adequately approximate the true nature of the TODs that would be built in the Bay Area. Second, the analysis focuses on residential development and does not directly address the role of TODs in altering commercial development patterns. Given that job growth is expected to outpace population growth in the Bay Area, the location of commercial development is crucial. Third, the analysis does not evaluate possible interactions between TODs and other transportation strategies, such as pricing changes. Finally, the analysis only looks at potential VMT impacts. It does not consider other possible benefits of TODs.

What is Transit-Oriented Development?

In recent years, a "new urbanism" has been the subject of increasing interest in urban design circles. Different manifestations of the movement include transit-oriented development, pedestrian pockets, and traditional neighborhood development. Fundamentally, these designs attempt to rethink suburban development by making "communities more diverse and integrated in use and population; more walkable and human-scaled" (Calthorpe 1993). Among the most visible proponents of the new urbanism are architects such as Peter Calthorpe (1993) and Andres Duany and Elizabeth Plater-Zyberk

(1991). Their design ideas have been fully implemented on a large scale in only a few developments, including Calthorpe's Laguna West near Sacramento, California, and Duany's and Plater-Zyberk's Seaside, Florida, and Kentlands, in Gaithersburg, Maryland.

This paper focuses on transit-oriented development, which may differ from conventional suburban development in any or all of the following ways:

- Higher density
- Mixed residential and commercial uses
- Design focused on a transit facility
- Pedestrian-friendly design
- Use of a grid of through-streets (rather than cul-de-sacs and collector streets)
- Provision of significant public space and community facilities
- Traditional architecture

In many ways, TODs mimic early-20th century streetcar suburbs in their density, street layout, and transit focus. From a design perspective, they attempt to bring a human scale and neighborhood character to the suburbs. Possible benefits include their aesthetic appeal, more affordable housing units, and potential to promote a sense of community. Some transit-oriented development is already occurring in the Bay Area, including "transit villages" being planned around several Bay Area Rapid Transit (BART) stations and several developments around Santa Clara County light rail stations and CalTrain commuter rail stations (see, e.g., Knack 1995, Bernick and Hall 1992, and Zinko 1994).

Because transit-oriented development is a general design concept rather than a specific development prototype, I define two model TODs to focus the analysis. The two models do not cover the entire spectrum of possible TODs, but they are meant to be representative of the general kind of suburban TODs that may be built in the Bay Area. They are as follows:

1. *Rail TOD*: A "rail TOD" is a high-density, mixed-use development around a rail transit station. It is modeled after Calthorpe's (1993) "Urban TOD," using densities given in Jeer (1994). It is circular, with a radius of 2,000 ft (the maximum distance people are generally willing to walk to a transit station (Downs 1994, 221; Homburger 1982, 293)) and a total area of 288 acres. A rail transit station is located at its center. It contains 30 dwelling units per acre (du/acre) in the immediate area of the rail station, and 8-16 du/acre farther

out, for an average residential density of 18 du/acre.[4] Thirty dwelling units per acre roughly corresponds to three- and four-story apartment buildings, 16 du/acre to townhouses, and 8 du/acre to small-lot single-family homes. Thirty-five percent of the rail TOD's area is devoted to residential uses, so it contains 1,820 dwelling units housing 4,900 people (neglecting vacancies), or 10,800 people per square mile. For comparison, some BART station areas are already built-up at 30 du/acre; and 12 du/acre is considered to be the minimum density necessary to support rail transit (Jeer 1994).

2. *Bus TOD*: A "bus TOD" is a medium-density, primarily residential development around a bus route feeding into a rail transit station. The bus TOD is modeled after Calthorpe's (1993) "Neighborhood TOD." It is the same size and shape as the rail TOD, but has a lower residential density – 10 du/acre. Fifty-five percent of the bus TOD's land area is devoted to residential uses; and it contains 1,590 dwelling units housing 4,300 people – a population density of 9,400 people per square mile. For comparison, 7 du/acre is typically considered the minimum density necessary to support local bus service (Cervero 1993, 46; Pushkarev and Zupan 1977, 185-186), although Pushkarev and Zupan point out that this threshold can range from 2 to 10 du/acre depending on specific local factors.

The two types of TODs are complementary. Calthorpe (1993) envisions a network of transit routes, with rail TODs centered on rail stations and bus TODs linked to the rail transit system by a feeder bus network. For simplicity, this analysis assumes that each rail station with a rail TOD is served, on average, by a feeder bus serving three bus TODs. Each cluster, consisting of one rail TOD and three bus TODs, would house a total of 17,800 people.

Impact of TODs on per capita VMT

Despite its importance to transportation planning, the effect of land use on travel behavior is poorly understood (Pickrell 1994). Therefore, this paper does not attempt a precise estimate of the impact of TODs on per capita VMT. Instead, it uses the results of previous studies, as well as a re-analysis of the data used by Holtzclaw in his 1994 study of the relationship between residential density and VMT, to construct a range of estimates of the possible effects of TODs.

To frame the discussion, I have identified six TOD characteristics that might affect VMT:

1. *Density.* The model TODs contain, on average, 10 or 18 du/acre – more than the current Bay Area average of 6.3 du/acre (MTC 1994a), and more than the typical residential suburb (4.0 du/acre, based on data in MTC 1994a). Most TODs currently under development are targeted at suburban households, so this analysis assumes that TODs displace typical suburban developments of 4.0 du/acre. Thus, the rail TOD is 4.5 times more dense than the developments it would displace, and the bus TOD is 2.5 times more dense.

2. *Transit Access.* This study uses Holtzclaw's (1994) Transit Accessibility Index (TAI): the number of buses passing within 1/4 mile, plus the number of rail cars passing within 1/2 mile of a residence each hour. For rail TODs, the analysis assumes that trains containing four cars each (more than a light-rail train, less than a BART train, and about the same as CalTrain) pass by at 15-minute headways for 16 hours per day, and that feeder buses pass by at 15-minute headways for 16 hours per day. Assuming that the bus only stops near the rail station, and given the layout of the rail TOD, 62% of the households are within 1/4 mile of the bus stop. All of the households are within 1/2 mile of the rail station. Thus, the TAI for the rail TODs is 27. This is equal to the TAI Holtzclaw calculates for Rockridge, an Oakland, California, neighborhood that is frequently cited as a model for TODs to emulate. For bus TODs, the analysis assumes that buses pass by at 15-minute headways for 16 hours per day. Given the layout of bus TODs, roughly 50% of the households are within 1/4 mile of the bus stop, so the TAI is 2.7.

   For the "typical" suburban developments that would be displaced by TODs, I assume a TAI of 2.0 – approximately the TAI Holtzclaw calculates for Los Altos, California, a Bay Area suburb in Santa Clara County. Suburbs poorly served by transit, such as San Ramon, California, can have TAIs as low as 1.0.

3. *Proximity to Urban Core.* This analysis assumes that TODs are built near the major existing transit systems of the Bay Area – *i.*e., in Alameda, San Mateo, Santa Clara, and western Contra Costa counties, rather than new-growth areas such as Sonoma, Solano, and eastern Contra Costa counties. The model TODs, therefore, are an average of about 15 miles from an urban core (the nearest of downtown San Francisco, Oakland, or San Jose), and they displace developments an average of 30 miles from an urban core. The analysis assumes

that no new TODs are located in San Francisco, downtown Oakland, or downtown Berkeley, because those areas already have higher average densities than the model TODs.

4. *Gridded Street Pattern.* The analysis assumes that TODs have a grid of through-streets, instead of cul-de-sacs and collector streets.

5. *Pedestrian Orientation.* Most conventional suburban developments have wide streets with fairly high traffic speeds and limited sidewalks. The streets often meander, which increases walking distances. Transit-oriented development tries to encourage pedestrian activity by making streets narrower, slowing traffic, widening sidewalks, and providing a range of amenities within a short walking distance.

6. *Mixed Uses.* The analysis assumes that mixed-use TODs displace single-use suburban developments. An important issue tends to be overlooked when TODs are discussed: a large number of mixed-use TODs may provide more commercial floor area than the market can bear. Thus, as TODs become more common, it may be necessary to sacrifice their mixed-use character. All of the model TODs in this analysis, however, are mixed-use developments.

Density

Several studies have examined the extent to which higher density neighborhoods and urban areas exhibit lower rates of automobile ownership and per capita VMT. Holtzclaw (1994) performs a regression analysis, using data from actual neighborhoods in the San Francisco Bay Area and other parts of California. He finds that a doubling of residential density is associated with a 16% decrease in VMT per household.

Holtzclaw's regression model, however, does not include proximity to the urban core as an independent variable. Additional analysis, using Holtzclaw's original data, reveals that when the effect of proximity to the urban core is controlled, a doubling of density is associated with an 11% decrease in per capita VMT. This means that, relative to the typical suburban developments they replace, a rail TOD could reduce per capita VMT by 22%, and a bus TOD could reduce per capita VMT by 14% – simply due to density effects. The data set and regression models are discussed in greater detail in Appendix A.

Harvey (1990) also finds a strong inverse relationship between residential density and VMT. Pushkarev and Zupan (1977) find that transit use increases rapidly above net residential densities of about 7 du/acre, and that transit use is much higher and auto use much lower

in areas with 30 du/acre as compared to areas with 7 du/acre. Smith (1984) finds that transit ridership is significantly higher in areas with a residential density of 16 du/acre than in areas with a density of 7 du/acre. These results suggest that our model TODs, at 18 du/acre and 10 du/acre, may have significantly lower VMT than a typical Bay Area suburb.

Some studies, however, suggest that the effect of density on VMT may be small. Pushkarev and Zupan (1977) point out that density has a greater impact on transit ridership near a central business district. Increasing density may not affect transit ridership at distances of 10 or more miles from downtown (id. 174). Likewise, Kain, Fauth, and Zax (1978) find that residential density affects auto ownership (and, by implication, VMT) only slightly.[5]

Four important issues need to be considered before rushing to claim that the higher residential densities of TODs will result in VMT reductions. First, the studies indicate a correlation between density and VMT, but they do not prove causation. Therefore, altering urban form may not affect travel patterns to the extent suggested by the regression coefficients. Indeed, if the observed relationship between density and VMT is due to resident self-selection rather than behavioral changes produced by higher densities (i.e., people may live in high-density areas because they prefer to drive less, rather than the other way around), increased densities may have no effect on travel behavior.

Second, although some of the studies control for characteristics such as income, other important independent variables may have been omitted. For example, none of the studies takes into account parking availability. Parking availability is often correlated with density, and it is likely to affect travel patterns (Shoup and Pickrell 1979). Thus, any regression analysis that looks at density and VMT, but ignores parking availability, will tend to overestimate the independent effect of density on VMT. This is an important omission, because TODs may increase residential density without changing parking availability, due to developers' preferences and zoning codes.

Third, except for Pushkarev and Zupan (1977), the studies do not explicitly consider the location and concentration of employment, which also affect travel patterns. Finally, the studies cited look at neighborhood units much larger than the model TODs. The model TODs may not have the same impact, because they only increase density locally, with less effect on overall density.

Optimistic models such as Holtzclaw's, then, may provide an upper bound for the possible response of VMT to density. Given the four concerns identified above, it is possible that the higher density of

TODs will have no discernible impact on VMT. Since there is no reason to think that higher densities would increase per capita VMT, zero is a reasonable lower bound for the density effect of TODs. Thus, a possible range for the density-related VMT reduction effect of TODs, relative to a conventional suburban development, is 0% to 22% for the rail TOD and 0% to 14% for the bus TOD.

Transit Access

Several studies have observed high transit ridership among people who live near transit stations. This finding suggests that VMT might be reduced by increasing transit access. It is difficult to estimate the magnitude of that effect from transit ridership studies, however, because they do not distinguish between trips that are diverted from automobiles and trips that would not be made at all if transit were unavailable.

Holtzclaw (1994) studies the relationship between transit accessibility and VMT directly. Using the Transit Accessibility Index defined above, Holtzclaw finds that a doubling of transit access is associated with a 5% decrease in VMT per household, all other things being equal. As with his analysis of density effects, however, Holtzclaw's coefficient for the TAI may be picking up some of the effects of proximity to the urban core. A re-analysis of his data shows that, after controlling for proximity to an urban core, a doubling of transit access is associated with a 3% decrease in per capita VMT (*see* Appendix A for a brief discussion of both models).

Applying this relationship to our model TODs, the rail TOD has 13 times the transit access of a conventional suburban development, corresponding to a 12% reduction in per capita VMT. The bus TOD has 1.3 times the transit access, and a 1% lower per capita VMT. The latter figure may understate the benefits of the bus TOD. Holtzclaw's TAI does not take into account bus route destinations. Since the bus traveling through our model bus TOD would feed into a high-capacity rail transit line, it may have a greater impact on VMT than Holtzclaw's model suggests. Therefore, for this analysis, I assume that the increased transit access of the bus TOD would produce up to a 3% reduction in per capita VMT compared to a conventional suburban development.

The same four caveats raised in the preceding discussion of density effects apply here: the observed relationship between transit access and VMT does not necessarily mean that VMT can be reduced by improving transit access; the model may be under-specified; employment location effects are not addressed; and since TODs are smaller than the neighborhoods studied in Holtzclaw's paper, they may have less effect on VMT. As with the density impacts, the results

of my adjusted model may represent the upper bound of the impacts of transit access on VMT. At the other extreme, it is possible that increased transit access in TODs will have no effect on VMT. Thus, a reasonable range for the estimated transit access effect of TODs on per capita VMT is a 0% to 12% reduction for the rail TOD and a 0% to 3% reduction for the bus TOD.

Proximity to the urban core

There is little research on the independent effect of proximity to the urban core on VMT. Holtzclaw (1994) uses data from neighborhoods at varying distances from the urban core. As discussed previously, however, his regression model does not control for this variation, so the effect of proximity to the urban core probably biases his coefficients for density and transit access. My re-analysis of Holtzclaw's data concludes that a halving of distance from the urban core is associated with a 7% decrease in per capita VMT (see Appendix A). Since the model TODs are half the distance from an urban core relative to conventional suburban developments, my analysis predicts an associated 7% reduction in per capita VMT.

The caveats raised in the discussions of density and transit access also apply here. The Holtzclaw model (as modified in Appendix A) represents an upper bound on the possible VMT effects of proximity to an urban core. It is also possible that the location of TODs would produce no appreciable decrease in VMT. Thus, a reasonable range for the proximity impact of TODs is a 0% to 7% VMT reduction for both the rail TOD and the bus TOD.

Gridded street pattern

Several studies have evaluated the impact of a traditional gridded street pattern on VMT. McNally and Ryan (1993) and Kulash, Anglin, and Marks (1990), for example, use traffic assignment models to study the impact of a hypothetical gridded street pattern compared to a conventional suburban street pattern, and they find that gridded patterns are associated with lower per capita VMT.[6] These models, however, assume that trip generation rates are constant, and thus only compare the length of the routes vehicles follow within the street pattern. Crane (1994) points out that a decrease in trip length represents a decrease in trip cost to the driver, which microeconomics tells us is likely to increase demand for trips, all else being equal. Thus, any VMT savings from decreased trip lengths could be offset by an increase in the total number of trips. The relative size of these two effects would vary from one development to the next (Crane 1994).

A gridded street pattern could therefore slightly increase or decrease per capita VMT in a TOD. For lack of more reliable

information, this analysis assumes that the effect of the gridded street pattern on VMT, whether positive or negative, is negligible.

Pedestrian orientation

Little research has been done on the independent effect of pedestrian-oriented design on VMT. Several studies have linked pedestrian activity and development density, but they have not compared areas with similar densities and different pedestrian environments. It is possible that pedestrian-friendly designs would increase walking trips, but it is unclear whether the added pedestrian trips would be new trips or diverted automobile trips (Handy 1992). A study for Portland, Oregon, indicates that pedestrian-oriented designs could reduce household VMT independent of other factors, although the effect was fairly small (Seskin 1993).[7] Many factors other than the pedestrian character of a neighborhood influence pedestrian activity. This analysis assumes that the independent effect of pedestrian-oriented design on VMT is negligible.

Mixed uses

The impact of mixed-use development on VMT has not been addressed independently from the impacts of other TOD features. Among existing neighborhoods, mixed-use development is probably correlated with density and other factors, so it is hard to isolate its effects. This problem is compounded by the difficulty of defining a meaningful measure of mixed use for the purposes of a model.

A 1974 study of 15 American new towns that juxtaposed complementary land uses showed a decrease in non-work trips compared to conventional developments, but no significant difference in work-related travel (Burby and Weiss 1974). For lack of more rigorous empirical evidence, this analysis assumes that mixing uses has no significant independent effect on VMT.

Total impact on per capita VMT

Combining the effects discussed above can give us a sense of the potential total impact of TODs on per capita VMT. For example, the rail TOD has a maximum VMT reduction effect of 22% due to its higher density, 12% due to its increased transit access, and 7% due to its proximity to the urban core. Together, these effects imply that the per capita VMT of a rail TOD is 64% of the VMT in a conventional development [(1-22%) x (1-12%) x (1-7%)]. Table 1 summarizes this calculation for the model TODs.

As discussed above, the upper end of each range is based on very liberal assumptions about the ability of TODs to reduce VMT. Moreover, the maxima appear to exceed even the expectations of a major proponent of TODs. Calthorpe (1993) states that lowering the

Table 1

Estimated Impact of TODs on per capita VMT.

	Estimated decrease in per capita VMT	
TOD Characteristic	Rail TOD	Bus TOD
Density	0% to 22%	0% to 14%
Transit access	0% to 12%	0% to 3%
Proximity to urban core	0% to 7%	0% to 7%
Gridded street pattern	Negligible impact	Negligible impact
Pedestrian orientation	Negligible impact	Negligible impact
Mixed uses	Negligible impact	Negligible impact
Total	0% to 36%	0% to 22%

fraction of trips taken by automobile to 60% is an "ambitious" goal for TODs. This is roughly equivalent to a 23% reduction in VMT from current levels[8] which falls somewhat above the midpoint of our range for the model rail TOD.

Note that this analysis only addresses the VMT reduction effects on TOD residents, and it assumes that these VMT reductions would not affect the VMT of people who do not live in TODs. In fact, if TODs reduce congestion noticeably, people who live outside of TODs may be encouraged to drive more, which could offset the VMT benefits of TODs.

On the other hand, there may be synergistic effects between TODs if many of them are built. For example, if a person lives in one TOD, and her job and her favorite restaurants are in other TODs, her automobile travel may be reduced by more than if she lived in the only existing TOD.

Given these various concerns, the middle of the estimate ranges appears more plausible than either end. It seems reasonable to expect a 10% to 25% per capita VMT reduction from the model rail TOD and a 5% to 15% reduction from the model bus TOD. Of course, the actual VMT reduction from any particular TOD will be highly dependent upon site-specific factors, design features, and the nature of existing nearby development.

Impact of TODs on regional VMT

How many TODs are needed to effect a 5% reduction in regional VMT? If we use the upper end of our estimate ranges (a 36% per

capita VMT reduction for a rail TOD, 22% for a bus TOD), we can calculate that in 1990, replacing conventional suburban developments with 41 rail TODs and 123 bus TODs would have reduced regional VMT by 5%. If we adopt the midpoint of our estimate ranges (18% for a rail TOD, 11% for a bus TOD), 82 rail TODs and 246 bus TODs would have been necessary. Table 2 shows the number of TODs needed to produce a 5% regional VMT reduction under different estimates of TOD effects. The range of numbers is large; but under all but the most optimistic estimates of per capita VMT reduction, a great many TODs would be necessary to reduce aggregate VMT in the Bay Area significantly.

Table 2

Number of Rail and Bus TODs Required to Reduce Regional VMT by 5%.[9]

Per Capita VMT Reduction from:		Number of TODs required	
Rail TOD	*Bus TOD*	*Rail TOD*	*Bus TOD*
9.0%	5.5%	164	492
18.0%	11.0%	82	246
27.0%	16.5%	55	165
36.0%	22.0%	41	123

To achieve even this modest reduction, a high percentage of the Bay Area's population would need to live in TODs rather than conventional suburban developments. If, for example, 82 rail TODs and 246 bus TODs are developed, they would hold 1.5 million people – almost all of the growth projected for the Bay Area over the next twenty years (equivalent to 24% of the current Bay Area population or 19% of the projected 2010 population). Even under the most optimistic assumptions for VMT reduction from the model TODs, 41 TODs would be needed and would house 0.7 million people (12% of the current Bay Area population).

It seems doubtful that as many station areas could be redeveloped as are indicated in Table 2. The Bay Area currently has 79 suburban rail transit stations: 22 BART stations outside of already high density San Francisco, downtown Oakland, and downtown Berkeley; 30 Santa Clara County light rail stations; and 27 CalTrain commuter rail stations. BART extensions, which include five new stations, are currently under

construction; the new stations are expected to open by the end of 1995 (Margro, et al. 1995).

Most of the region's rail transit stations, however, are in built-up areas (although the stations are often surrounded by large single-level parking lots). In many cases, only portions of the area could be redeveloped. Although Calthorpe (1993) notes that infill development could occur on sites as small as 10 acres, it is not clear that such developments would have any appreciable impact on regional travel patterns. Furthermore, current zoning restrictions preclude TODs around several rail stations. For example, after BART opened in the early 1970s, local governments down-zoned around nine BART stations, reducing the maximum densities allowed (MTC 1979). Many of these zoning restrictions are still in effect.[10] A 1992 survey of transit-based housing in the Bay Area identified 16 projects built between 1987 and 1992 or under development in 1992, totaling 7,837 dwelling units – equivalent to just over four of the model rail TODs (Bernick and Hall 1992).

Even a massive increase in TOD development would have relatively little effect on regional VMT. This analysis indicates that even if most or all of the existing rail transit stations are thoroughly redeveloped around transit-oriented development guidelines, and even if around one-fifth of the Bay Area's population chooses to live in these areas and related developments around feeder bus lines, TODs would reduce Bay Area VMT only by around 5%. Given the MTC's estimate that VMT is growing at the rate of 1.52% per year (based on numbers in MTC 1994b), this would offset only three years of VMT growth.

Implications

This analysis has shown that it is highly unlikely that transit-oriented development could, by itself, have a significant impact on the Bay Area's congestion problems. Therefore, while it may be a useful supplement to other transportation policies (such as public transit improvements and pricing strategies), transit-oriented development is inappropriate as the cornerstone of transportation planning in the Bay Area.

An interesting implication of the analysis is that much of the per capita VMT reduction from TODs can be attributed to the increase in residential density and from closer proximity to the urban core, independent from transit access. Thus, general high-density development close to the urban core may capture much of the VMT reduction benefits of TODs, with more flexibility of location. It is possible that the transit access benefit of TODs has been oversold relative to its other characteristics.

It is important to note that this analysis has only addressed the transportation implications of transit-oriented development. It is clear that transit-oriented development is inappropriate as the foundation of a congestion reduction strategy for the Bay Area. To the extent that TODs are part of a larger scale rethinking of urban design, they are likely to have worthwhile non-transportation benefits, such as an enhanced sense of community and the preservation of open space on the suburban fringe. They may also be a useful mechanism for increasing the supply of affordable housing and revitalizing urban neighborhoods. Transit-oriented development may make a substantial contribution to urban life, despite its limited potential for reducing travel.

NOTES

[1] According to the Metropolitan Transportation Commission (MTC), for a typical 1990 A.M. peak hour, there were 130,600 hours of delay. Assuming similar delays for P.M. peak-hours, and given 260 commute days per year, this represents 68 million hours per year. This figure does not include off-peak congestion, which is considerable in the Bay Area.

[2] Since 1990, transportation has been displaced by the economy and crime as the most important problem in the poll responses – a change that mirrors national public opinion trends.

[3] MTC's population estimate is taken from Association of Bay Area Governments (1992). ABAG's population projections are based on the assumptions that fertility rates stabilize close to the current level, mortality rates continue to decline, and in-migration to the Bay Area slows and is overtaken by out-migration soon after 2000.

[4] Dwelling units per net residential acre. Net residential acreage includes only the area devoted to residential uses, and does not include streets, public areas, and commercial areas. Population density in a TOD thus depends on residential density (du/acre), household size, and the percentage of developed land devoted to residential use. Throughout this analysis, average household size is assumed to be 2.68, which was the Bay Area average in 1990 (ABAG 1992).

[5] For example, the study found that in a county where 53% of the housing units are single-family, a two worker household is 5% more likely to be carless than a household living where 83% of the units are single-family (Kain, Fauth, and Zax 1978, 57). This difference is large in relative terms (it roughly doubles the fraction of carless households) but small in absolute terms.

[6] Kulash, Anglin, and Marks (1990) predict that VMT within the gridded development would be 43% lower than within the conventional

development. McNally and Ryan (1993) predict a 10.6% drop in A.M. peak hour VMT. These studies only look at the part of the trip that occurs within the development, so the percentage reduction in total VMT would be lower.

[7] Seskin (193) defines a "pedestrian environment factor" (PEF) scaled from 4 to 12, and finds that a unit improvement in PEF was associated with a reduction in VMT per household of 0.7 miles per day. The statistical significance of this result is not clear. It is also unclear what the PEF of TODs would be relative to conventional suburban developments. If TODs represent an improvement of 3 in PEF, the Portland model would predict a 3% reduction in per capita VMT, using Bay Area household size and VMT averages.

[8] My calculation assumes that average trip lengths are constant, and that total trips increase by 10% due to decreased transportation costs in a TOD. The 1990 non-auto mode split for commuting in the Bay Area is 13.8% (Rossetti and Eversole 1993).

[9] Calculations assume a conventional suburban neighborhood with average annual per capita VMT of 9,000, which is typical for suburbs in the Bay Area. 1990 Bay Area VMT totaled 34 billion, so a 5% reduction corresponds to 1.7 billion VMT/yr.

[10] In 1994, the California legislature passed the Transit Village Development Act (co-authored by BART chairman Michael Bernick), which allows cities to designate quarter-mile radius redevelopment districts around transit stations and to give developers financial incentives to implement transit village plans (Knack 1995). The act does not give land assembly powers to the redevelopment districts. While the legislation seems likely to increase the ability to build high-density developments around transit stations, it only allows for limited financial incentives for developers, and it does not force localities to accept them.

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Appendix A

Statistical analysis of VMT and community characteristics

The data set on community characteristics and VMT gathered and analyzed by Holtzclaw (1994) includes information on 27 California communities in the San Francisco Bay Area, Metropolitan Los Angeles, San Diego and Sacramento. Data for each community include population, number of households, total developed acreage, net residential acreage, annual income ($ per household), auto ownership (autos per household), VMT (per household), and three constructed indices measuring degree of transit access, neighborhood shopping, and pedestrian accessibility. The transit accessibility index (TAI) measures the number of rail cars or ferries per hour that pass within 1/2 mile, and buses within 1/4 mile, of the average household, normalized to 50 seats per vehicle. The neighborhood shopping index (NSI) is the fraction of the households that have key local shopping establishments within 1/4 mile. The pedestrian accessibility index (PAI) measures factors such as the street grid, sidewalks, and nearness of building entries to the sidewalk. To this data set I added approximate distance from the central business district (CBD) for each of the 27 communities.

Table A-1 shows the correlation between these six variables for the 27 communities.

Holtzclaw performed a least-squares regression of VMT per household on density and TAI using a log-log functional form, and found the following relationship:

$$VMT / HH = 34{,}270\ (density)^{-0.25}\ (TAI)^{-0.076} \qquad R^2 = 0.83$$

This indicates that density and TAI appear to influence VMT.

I reanalyzed the data to look at per capita VMT rather than per household VMT, and to evaluate the independent effect of distance from the CBD. Distance from the CBD is not a perfect measure because the size and characteristics of the CBDs are very different. To mitigate this problem, I excluded communities with small CBDs and focused my analysis on Bay Area and Los Angeles area communities. I regressed per capita VMT on density, TAI, distance from CBD, and income. Table A-2 shows the results.

Table A-1

Correlation between variables (log form)

	Density	TAI	NSI	PAI	Dist CBD
TAI	0.74				
NSI	0.67	0.66			
PAI	0.76	0.64	0.62		
Dist CBD	-0.68	-0.68	-0.52	-0.5	
Income	-0.26	0.14	-0.07	-0.2	-0.0

Table A-2

Regression results: community characteristics and per capita VMT (log-log form).

	Constant	Density	TAI	Dist from CBD	Income
Coefficient	8.661	−0.166	−0.048	0.106	0.047
Standard Error	1.416	0.068	0.040	0.065	0.126
Significance	0.01	0.05			

N	17
Degrees of freedom	12
Std error of regression	0.128
R^2 (corrected)	0.839

This model predicts the following relationship:

$$\text{VMT per capita} = 5{,}773\ (D_1)^{-0.166}\ (T)^{-0.048}\ (D_2)^{0.106}\ (I)^{0.047}$$

D_1 = density
T = TAI
D_2 = Distance from CBD
I = income

This model must be used with caution, because only the constant and the density coefficient are statistically significant. The income, TAI, and distance coefficients are not statistically significant. They are retained in the model because the *a priori* theoretical justification for including the variables is strong.

There are several important limitations to the data set, and to the regression analysis. First, the data set is small, so standard errors of coefficients tend to be large, and regression coefficients are statistically significant only for the strongest variables. The fact that many of the independent variables are strongly correlated makes it even more difficult for regression analysis to isolate the independent effects of different variables with this small data set. There are likely to be many important relationships between community characteristics and VMT, but few can be shown to be statistically significant with this data set.

The hypothesis that residential density affects VMT is clearly supported by the regression analysis. This is the only conclusion that is robust across different specifications of the regression model. While it appears that community characteristics other than density also impact VMT, these effects cannot be precisely characterized with this data set. Thus, any use of these regression results needs to be sensitive to the uncertainties and large standard errors.