Explore the connection between the built-environment characteristics, VMT, and transportation-related CO_2 emissions: Case study of Austin, TX

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Introduction

Identifying effective ways to reduce green-house gas (GHG) emissions has topped the government agenda and attracted growing attention from the academia and the related industries. Transportation sector is at the center of the discussion. To illustrate with statistics the importance of transportation, between 1980 and 2008, total emissions of the six principal GHG pollutants in the U.S. dropped by 54 percent; CO_2 emissions, however, increased by 32 percent along with 91 percent increase of vehicle miles traveled (VMT); Transportation sector accounts for approximately one-third of the CO_2 emissions (USEPA 2009). Three major sources contribute to transportation-related CO_2 emissions: vehicle, fuel, and VMT. The US energy bill of 2007 mandating vehicle and fuel efficiency improvement may help reduce CO_2 emissions close to the targeted level by 2030. Nevertheless, projected VMT growth will likely wipe out the energy bill savings (Ewing, et al 2008).

While it is widely agreed that VMT and the built environmental characteristics are closely related, empirical evidence remains scarce on the extent to which modifying the built environment through land use planning can reduce GHG emissions (Frank et al. 2000, 2007). The commonly suggested land use planning tools for VMT reduction include densification, mixed use development, and transit/pedestrian/cyclist-friendly environmental design. Intuitively, however, denser and more mixed-use developments likely lead to more concentrated and mixed traffic flows, resulting in slower and more frequent stop-and-go movement that on average has a higher emission rate than smooth and fast moving traffic. The net effect of applying the land use tools on GHG emissions is therefore unclear.

To explore the potential of and challenges facing land use planning as an emission reduction tool, this study investigates the connection between the built-environment characteristics, VMT, and transportation-related GHG emissions through a case study of the Austin, TX region. The study first identifies sites, namely mixed-use developments (or MXDs) that display to a certain extent the new urbanist built-environmental features, for instance, relatively high development density, balanced land uses, good local connectivity and regional accessibility. Next, the study geocodes trip origins and destinations of the sampled individuals from the 2005 Austin Activity-

Travel Survey. Based on reported trip and activity times, travel mode choice and trip frequency, daily miles of driving, the number of cold-starts, and GHG emissions are estimated for those living inside verse outside MXDs. Finally, implications are drawn from the study results.

Literature Review

There is a large volume of literature on the land use-travel connection. This review focuses on the relationship between built environmental characteristics and VMT, which in turn links with GHG emissions.

VMT is a function of trip distance, trip frequency, and share of motorized travel. Hence, strategies that modify one or all of these elements will affect the VMT outcome. Transit-oriented development (TOD) is an example of such strateges. Studies have estimated that one transit passenger-mile represents 1.4 to 9.0 miles of reduction in vehicle miles (Holtzcaw et al. 2002). VMT generated from TOD residents is half that of typical suburban communities (Holtzclaw 1999). A recent study by Zhang (2010) for the Austin, TX region estimated a VMT reduction of 21 – 27 percent associated with the region's TOD scenarios. Job and household relocations in the TOD scenarios attribute to the simulated VMT reductions as average trip length shortens. The regional land use-transportation model, namely LUTRAQ developed for the Portland, Oregon area predicts that transit-oriented development likely reduces vehicle trips by 77 percent and VMT by 13.6 percent in the region.

Mixed-use development brings trip destinations (e.g., stores, jobs, schools, et al.) close to trip origins (e.g., homes, work sites). From the transportation service perspective, improved urban design with a more pedestrian- or bicyclist-friendly environment means improved quality for walkers or cyclists (Moudon et. al., 1997). It is thus expected that more mixed-use development and a better pedestrian/biking environment leads to fewer and/or shorter driving and more walking/biking. Empirical evidence reported from the San Francisco Bay Area has confirmed these hypotheses (Kockelman 1997, Cervero and Kockelman 1997). They found that mixed use development pattern also helped reduce VMT; for every one percent increase in land use mix VMT declined by 5~11 percent. A most recently released Transportation Research Board (TRB)

Special Report #298 (TRB, 2009) reviews extensively existing studies and summarizes that: 1) Developing more compactly, that is, at higher residential and employment densities, is likely to reduce VMT; 2) More compact, mixed-use development can produce reductions in energy consumption and CO2 emissions both directly and indirectly; 3) Significant increases in more compact, mixed-use development will result in modest short-term reductions in energy consumption and CO2 emissions), but these reductions will grow over time.

Scholars however have been cautious in generalizing the relationship between land use and VMT. Changes in the built environment (or specific features of it) may influence various aspects of travel in different directions, which suggests unclear net effect on travel outcome. For example, when density increases or land use mix improves (i.e., more balanced job-housing distribution), the average trip distance may decrease, all else being held equal. The decrease in average trip distance, however, suggests a fall in the price of travel, which may induce additional travel, for instance, by way of increased trip frequency (Crane 1996, Crane and Crepeau 1998, and Handy 1996). The final outcome of the combined shorter trip distance and higher trip frequency is thus determined empirically. Rodriguez, et al. (2006) found that at the metropolitan level, urban containment policies were associated with higher population densities but more per capita miles traveled.

More concerns are raised on the net effect of land use densification and mixed development on GHG emissions. Utilizing detailed GPS second-by-second travel recordings, Green and Wang (2009) more per mile vehicle emissions are associated with higher development densities in the Greater Detroit area where travel speeds are lower and there more stop-and-go movements relative to less dense places. The study findings do not offer broad implications though due to a very limited sample size (a group of 85 drivers).

This study aims at contributing to the knowledge base of the relationship among urban form, VMT, GHG emission by offering empirical evidence from the Austin, TX area.

Study Method

The study method includes three parts: MXD identification, geocoding of trip records in GIS, and estimation of travel and emission outcome.

The selection of the research sample of MXD's took a 'bottom up' approach based upon local knowledge of city officials, professional planners, staff of the Capital Area Metropolitan Planning Organization (CAMPO), and academic experts. The sampling process involved three working steps. First, a list of 49 communities in the region was created and the contact information of representative planners or public officials collected. The research team then interviewed by phone the planners or officials, asking them to identify MXD's based on their professional and personal knowledge of their own communities. The interviewee was first given a definition of MXD: "A mixed-use development or district consists of two or more land uses between which trips can be made using local streets, without having to use major streets. The uses may include residential, retail, office, and/or entertainment. There may be walk trips between the uses." If the planner required further clarification, an additional set of characteristics of mixed-use districts, as defined by the ULI (Witherspoon, Abbett, Gladstone 1976) was provided along with known examples, for instance, the Triangle area in Austin.

Mixed-use was a generally recognized concept by the majority of those planners interviewed. However it was sometimes difficult for the planners to unambiguously delineate MXD boundaries. The MXD definition given in this study was relatively expansive and inclusive in order to garner a significant number and variety of samples for statistical analysis. The study did not establish criteria for minimum size, density, or number of land uses for a MXD. A general reference is the area reachable by walking. For example, a circle of ¼~ ½ -mile in radius has an area of approximately 125~502 acres. Downtown districts, with the exception of downtown Austin, and traditional neighborhoods were the primary areas cited by local planners. Some of the candidate MXDs cited were in early stages of development or not fully developed at the time of the CAMPO travel survey in 2005. There were excluded from the sample for this study.

The second step includes two work sessions with experts from CAMPO and from UT Austin. The experts were presented with maps of land use and street network for the study area and asked to draw on the maps the MXD-like developments. CAMPO staff reviewed the preliminary set of MXDs and offered their own identification of MXD samples. UT planning faculty members who have decades of working knowledge on land use and community development in Central Texas were invited to provide their expert knowledge of Central Texas geography and urban planning. The work session led to identification of additional MXD's.

Third, the research team using land use GIS and Google aerial photos refined the MXDs identified from previous steps and finalized the boundaries of the MXD's to complete the sample set. The final sample set contains 42 MXD's. Figure 1 shows the spatial distribution of the MXDs in the Austin region.

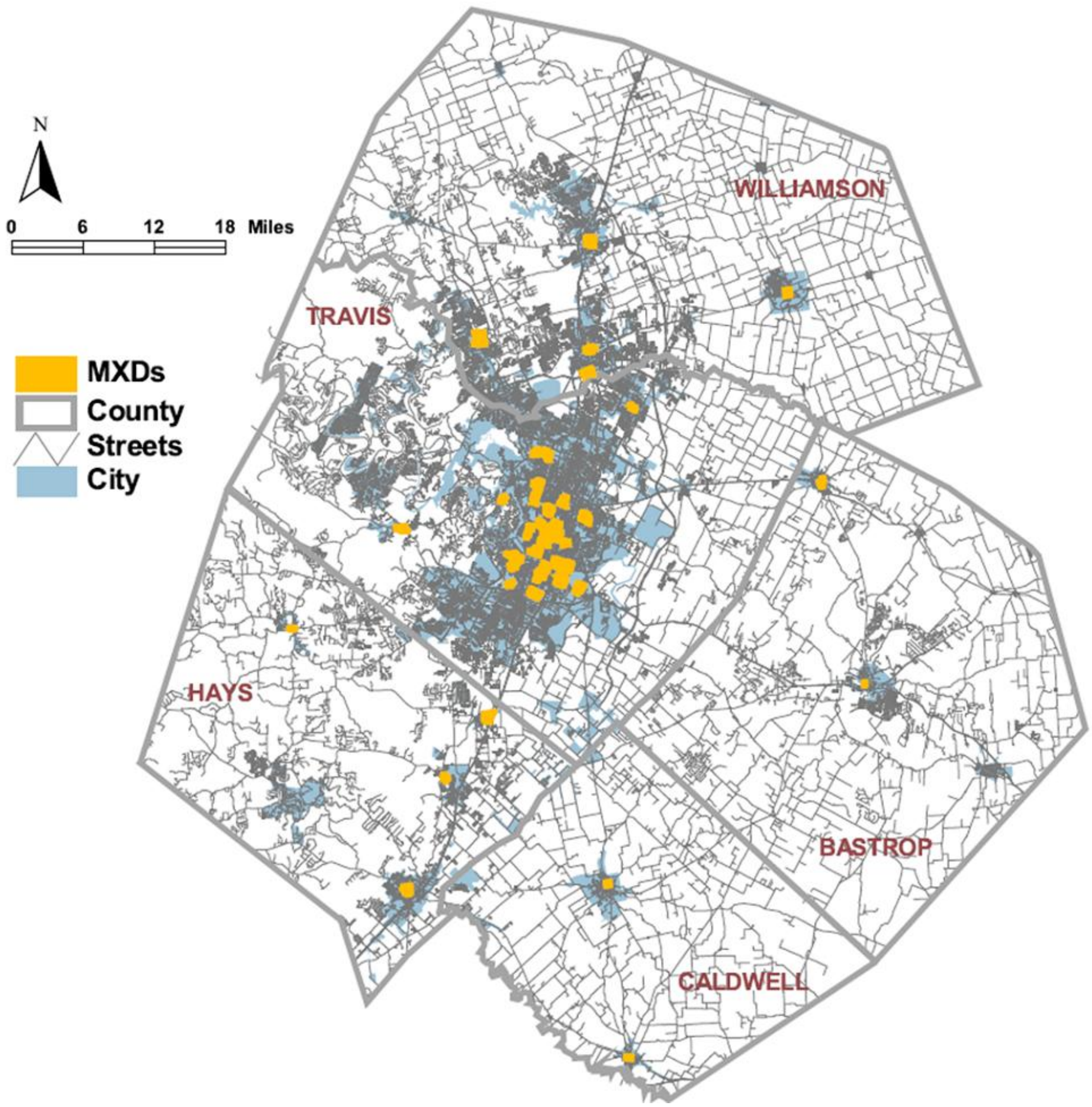

Figure 1 MXD Distribution in the Austin, TX Region

The main travel data for this study comes from the 2005 Austin Activity Travel Survey. The survey records geographic coordinates of activity locations and trip ends (origins and destinations) of the surveyed travelers. For travel analysis, these trip ends are geocoded in TransCAD GIS. Network distance is estimated based on the assumption that the traveler took the shortest path in length between trip origin and destination (Figure 2). Figure 3 illustrates the geocoded trip ends.

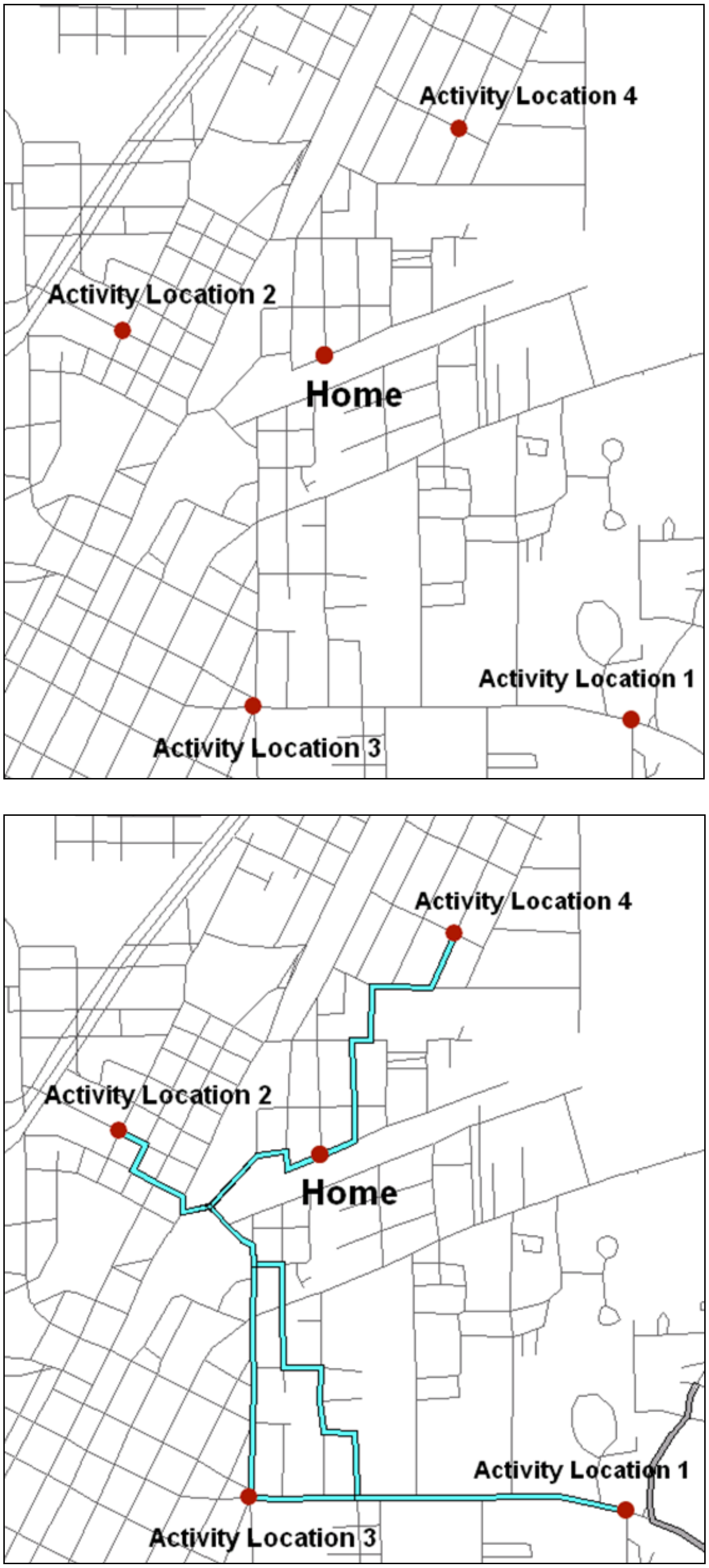

Figure 2 Geocoding of Trip Ends and Trip Distance Estimate

Figure 3 Distribution of Trip Ends in the 2005 Austin Activity Travel Survey

Table 1 reports descriptive statistics of the households located inside and outside MXDs. Notably, households outside MXDs having an average number of 2.82 persons per household are larger than those inside MXDs (2.29 persons per household). The statistical test of difference in sample means suggests that the difference in average household size is significant. This difference exists mainly due to a larger number of non-working dependents in non-MXD households than MXD households because statistically the MXD and non-MXD households appear to have the same average number of workers. On the per capita basis, however, the average MXD household exhibits similar characteristics to the average non-MXD household in terms of income, vehicle ownership, and tenure. The descriptive statistics shown in Table 1 suggest to a certain extent the representativeness of the sampled MXD households for the 2005 surveyed households except for household size.

Table 1 Sample Household Characteristics

	HH Inside MXDs (n=65)				HH Outside MXDs (n=1,354)				
Variable	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max	t-test
# Persons in HH	2.29	1.20	1.00	5.00	2.82	1.54	1.00	13.00	-2.75
# Workers in HH	1.08	0.83	0.00	2.00	1.12	0.80	0.00	2.00	-0.44
HH Income (2005 $1000's)	45.35	36.30	5.00	150.00	54.38	38.33	5.00	150.00	-1.86
Income/Person (2005 $1000s)	22.21	17.19	2.50	87.50	22.92	18.47	0.83	150.00	-0.30
Vehicles in HH	1.80	0.96	0.00	4.00	1.91	0.91	0.00	7.00	-0.93
Vehicles/Person	0.87	0.46	0.00	3.00	0.79	0.41	0.00	5.00	1.59
Vehicles/Worker	1.24	0.46	0.00	2.00	1.41	0.71	0.00	5.00	-1.54
Bikes in HH	0.85	1.39	0.00	7.00	1.67	7.20	0.00	99.00	-0.92
Years in Residence	3.80	1.73	0.00	5.00	3.98	1.58	0.00	5.00	-0.89

The last part of study method concerns emission estimation. Emission rates vary significantly, being affected by vehicle types, vehicle age, operating speed, temperature, along with others. This study relies on published parameters on emission rates. Specifically, it borrows emission information from US Department of Energy (2010) on trip emissions estimated from 1997 national data. Table 2 shows the base emission rates for NOx, CO and VOC used for this study.

Table 2 Emission Rates

	Running Average (gram/mile)	Cold Start (gram/start)	Total (gram/mile)
NOx	1.34	2.1	3.34
CO	6.4	19.7	26.1
VOC	1.3	2.5	3.8
Source: USDOE (2010)			

Analysis and Results

On average, a person living in MXDs travels 17 miles daily, about six miles less than those living outside MXDs. The difference can be attributed mainly to shorter travel for HBNW and NHBO purposes (Table 3).

Table 3 Average Person-Miles of Travel by Households In- and Out-of-MXDs

	Home Inside MXDs (n=123)				Home Outside MXDs (n=3,264)				
Variable	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max	t-test
PMT/Day	17.0	16.5	0.3	84.0	23.2	22.6	0.0	276.0	-3.00
By Purpose									
HBW	5.8	11.5	0.0	71.7	5.9	13.1	0.0	100.7	-0.14
HBNW	8.3	10.2	0.0	61.9	12.2	15.3	0.0	120.7	-2.81
NHBW	1.3	4.9	0.0	33.2	1.9	7.5	0.0	214.9	-0.77
NHBO	1.7	5.1	0.0	36.2	3.2	8.9	0.0	92.4	-1.94
By Travel Mode									
Walk/Bike	0.4	1.8	0.0	16.4	0.7	3.2	0.0	56.3	-1.21
Drive Alone	10.1	14.5	0.0	67.0	11.8	18.4	0.0	143.0	-1.02
Carpool	6.4	10.5	0.0	71.7	10.4	16.8	0.0	123.0	-2.63
Transit	0.1	0.9	0.0	9.7	0.2	5.1	0.0	276.0	-0.17
Other	0.0	0.2	0.0	1.8	0.1	1.2	0.0	50.9	-0.27

To understand factors explaining shorter PMT of MXD travelers, a regression model was estimated (Table 4). Notably, aside from individual and household socioeconomic factors, urban form variables, i.e., regional location (distance to downtown), population and job density, network connectivity, and street density contribute additional explanatory power to distance variance.

Table 4 Regression Analysis of Average Miles of Travel Per Person

	Coef.	Std. Err.	t-Stat.	
Age (years)	-0.0002	0.0230	-0.01	
Gender (1: Female; 0: Male)	-0.6765	0.7108	-0.95	
Employed (1: Yes; 0: No)	6.0265	0.8217	7.33	**
Student (1: Yes; 0: No)	-6.9607	1.1743	-5.93	**
Household Size (Persons)	0.8362	0.5645	1.48	
Income Per Capita (2005 $)	0.0731	0.0256	2.85	**

Vehicles Per Capita	3.3712	1.1585	2.91	**
Years in Residence	-0.1140	0.2274	-0.50	
Distance to Downtown (Miles)	0.1665	0.0395	4.21	**
Population Density (Persons/Acre)	-0.4797	0.1279	-3.75	**
Job Density (Jobs/Acre)	-0.3802	0.1260	-3.02	**
% Cul de sac Intersections	6.9733	3.5944	1.94	*
Street Density (Feet/Acre)	-0.0551	0.0110	-5.02	**
Constant	21.9138	2.7991	7.83	**
Number of obs: 3,369				
R-squared: 0.169				
Adj R-squared: 0.166				
Note: * Significant at 0.01 level; ** Significant at 0.05 level.				

Table 5 reports results of estimated emissions at the individual, daily level. In this table, only those who drove as the driver in the survey day are included. Data records with individuals choosing driving modes as passengers are excluded. Therefore the reported personal miles of traveled equates the vehicle miles traveled of the sample. The top section is for the individuals living in the MXDs, whereas the mid-section for those living in the rest of the region. On average, a driver living in the MXD emitted daily 42.88, 241.13, and 28,87 grams of NOx, CO, and VOC, respectively. Notably, the emitted amount is lower in each of the three items than an average suburban counterpart who emitted daily 68.34, 366.24, and 40.64 grams, respectively. Compared to the suburban residents, the MXD residents tend to own older vehicles (at an average vehicle age of 7.17 or 1999-2000 model vs. 6.98 or 2000-2001 model) and operate at a lower average speed (19.15 mph vs. 24.53 mph). It means that on a per mile basis, the MXD driver likely emits more than the suburban driver. The suburban driver's long daily driving (28.45 miles) wipes out the benefit of driving a newer vehicle at a higher speed; an MXD driver drives 9.52 fewer miles a day and hence emits 162.3 gram less or 34% lower than his/her suburban counterpart.

Table 5 Emission Characteristics of MXD vs. Non-MXD Residents, Austin, TX

MXD (n=97)

Variable	Mean	Std. Dev.	Min	Max
NOx Emission (g/day)	42.88	39.01	1.86	176.10
CO Emission (g/day)	241.13	192.89	16.48	840.31
VOC Emission (g/day)	28.87	25.29	1.38	128.78

Vehicle Speed (mph)	19.15	11.41	2.88	51.14
Vehicle Age (years)	7.17	5.81	0.00	37.00
Cold Start (times)	3.78	2.51	1.00	15.00
Person Driving Miles	18.93	19.32	0.53	97.14

Region Wide (n=2227)

Variable	**Mean**	**Std. Dev.**	**Min**	**Max**
NOx Emission (g/day)	68.34	64.99	0.09	706.02
CO Emission (g/day)	366.24	326.00	0.93	3595.79
VOC Emission (g/day)	40.64	33.85	0.05	447.76
Vehicle Speed (mph)	24.53	12.95	0.05	70.00
Vehicle Age (years)	6.98	4.93	0.00	45.00
Cold Start (times)	3.89	2.51	1.00	31.00
Person Driving Miles	28.45	26.07	0.02	342.51

TAZ comparable with MXD (not including CBD) (n=1,412)

Variable	**Mean**	**Std. Dev.**	**Min**	**Max**
NOx Emission (g/day)	32.47	32.26	0.15	284.55
CO Emission (g/day)	176.11	163.03	1.52	1359.50
VOC Emission (g/day)	19.16	15.94	0.18	130.74
Vehicle Speed (mph)	23.76	14.22	0.70	70.00
Vehicle Age (years)	7.00	4.95	0.00	45.00
Cold Start (times)	2.17	1.58	1.00	14.00
Person Driving Miles	13.26	12.13	0.07	100.57

The bottom section of Table 5 reports emissions by a driver who does not live in MXDs and is neither a typical suburban resident; the person lives in non-MXD TAZs that have comparable geographical dimensions to MXDs. Mostly they are non-MXD urban residents. To eliminate possible distortions caused by downtown residents, the subsample excludes those sampled individuals living in Austin downtown (no MXDs are located in the downtown). It is interesting (and surprising) to see that the MXD resident out-emitted the non-MXD residents in NOx, CO, and VOC. Possible explanations to the results are MXD residents' more frequent trip-making (indicated by more cold-starts) coupling with a slower average driving speed. The higher trip frequency and lower driving speed in the MXDs than in non-MXDs are attributable to the higher development density and mixed uses.

Concluding Remarks

The study of Austin, TX region shows a rather complex picture on the relationship among urban form, VMT, and GHG emissions. While an MXD driver living in dense, mixed use neighborhoods emits less than a suburban driver, a non-MXD urban resident likely emits even lesser! This poses a challenge to the land use-based strategies for GHG reduction—densification and mixed-use development function like a double-edged sword in terms of their effects on VMT and GHG emissions. A question warranting further investigation is: at what density and land-use mix thresholds that their potential adverse effects are minimized.

There exist a number of limitations in this study. First, trip times are based on the self-reported travel durations of the surveyed individuals. Any reporting errors, which are highly likely, will affect speed estimate. Second, the trip distance is estimated based on the assumption that the traveler took the shortest route. This may not be the case in reality and therefore the estimate may introduce inaccuracies in PMT and VMP estimates. Lastly, the study did not consider all categories of GHG emissions. The estimates can be fine-tuned with further consideration of vehicle age, model, and speed as well as other contextual factors such as temperature variations throughout the day.

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