Estimating the Vehicle-Miles-Traveled Implications of Alternative Metropolitan Growth Scenarios – A Boston Example

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Abstract:

This study demonstrates the potential value, and difficulties, in utilizing large-scale, location aware, administrative data together with urban modeling in order to address current policy issues in a timely fashion. We take advantage of a unique dataset of millions of odometer readings from annual safety inspections of all private passenger vehicles in Metropolitan Boston to estimate the vehicle-miles-traveled (VMT) implication of alternative metropolitan growth scenarios: a sprawl-type "let-it-be" scenario and a smart-growth-type "winds-of-change" scenario. The data are georeferenced to 250x250m grid cells developed by MassGIS. We apply a greedy algorithm to assign Transportation Analysis Zone (TAZ) level household growth projections to grid cells and then use spatial interpolation tools to estimate VMT-per-vehicle surfaces for the region. If new growth households have similar VMT behavior as their neighbors, then the let-it-be scenario will generate 12-15% more VMT per household compared to the winds-of-change scenario. However, even the "wind-of-change" scenario, will result in new households averaging higher VMT per household than the metro Boston average observed in 2005. The implication is that urban growth management can significantly reduce GHG but, by itself, will not be sufficient to achieve the GHG emission reduction targets set by the State for the transportation sector.

1. INTRODUCTION

In the last few decades, the growing concentration of greenhouse gas (GHG) in the atmosphere and the associated negative effects of global warming are raising concerns. Governments worldwide are taking increasing steps to reduce GHG emissions and promote sustainable growth. In the Commonwealth of Massachusetts of the US, the Global Warming Solutions Act (GWSA) was signed into law in 2008, making Massachusetts one of the first states in the nation to move forward with a comprehensive regulatory program to address climate change.

The GWSA required the Massachusetts Department of Environmental Protection (MassDEP) to establish 1990 as a baseline assessment of statewide GHG emissions for use in measuring progress towards meeting GWSA emission reduction goals - a 10-25 percent reduction by 2020, and an 80 percent reduction by 2050. The Act also required MassDEP to establish a projection of likely statewide GHG emissions in 2020, under a "business as usual" scenario, which assumes that no new targeted requirements for reducing emissions will be established. This projection has been used to analyze options for emission reduction requirements, and to determine the extent of reductions that will be needed to meet GWSA goals[2].

As an important source of GHG emissions, transportation currently produces about 29 percent of US's carbon emissions. In Massachusetts, its contribution is as high as 36 percent[3]. Moreover, transportation is the most rapidly growing source of these emissions in the US during the last two decades. Between 1990 and 2007, it accounts for almost half of the net increase in the total US emissions (EIA 2007). Previous empirical and theoretical studies identified three major factors that have influenced transportation GHG emissions: vehicle fuel efficiency, the lifecycle GHG emissions of fuels, and vehicle miles traveled (VMT) (Handy, 2005). Modifying the growth trajectories of transportation GHG emissions will likely require a suite of technology and policy approaches, focusing on improving fuel efficiency, promoting clean energy, and reducing VMT. Among the three factors, the impact of how people travel (as measured by VMT) has too often been ignored. In 2009, the US Energy Information Administration (EIA 2009) projected a 15% increase in terms of VMT per capita for light duty vehicles between 2009 and 2030. This trend

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[2] Massachusetts Department of Environmental Protection (http://www.mass.gov/dep/index.html) and the Massachusetts Clean Energy and Climate Plan for 2020 (http://www.mass.gov/eea/docs/eea/energy/2020-clean-energy-plan.pdf), Dec., 2010.

[3] Source: US Energy Information Administration (EIA)

frames a fundamental challenge to global sustainability: How can we effectively reduce household vehicle usage to meet the goals of GHG emission reduction and mitigate the negative effects of improved mobility on us, our ecosystems, and future generations? What kind of role can urban growth management play in reducing VMT? Can we estimate the VMT implications of alternative metropolitan growth scenarios?

In order to project VMT trends under alternative growth scenarios, we would ideally use some form of integrated land use and transportation simulation model to sort through the ripple effects of changes in land use and travel patterns as the metropolitan area grows. Research on large-scale urban simulation models can be traced back to metropolitan transportation studies in the 1950s and has made significant progress over the past decades with growing recognition of the importance of integrating land use, transportation and environmental (LUTE) components. Various integrated LUTE simulation models have been developed, including ILUTE (Salvini and Miller 2005), ILUMASS (Wagner and Wegener 2007), UrbanSim (Waddell and Borning 2004), and MEPLAN (Echnique, et al., 2012). Although large-scale urban simulation models can provide a sound basis for scenario analysis of metropolitan growth, they also demand huge investment in time, technology, and financial resources to produce meaningful results, which most Metropolitan Planning Organizations (MPOs) cannot afford to provide. They also tend to have difficulty gaining the confidence of the public and relevant agencies because of their complex, and debatable, assumptions about the LUTE interactions. Newly available datasets from administrative processes provide alternative methods for estimating the VMT effects of growth that are easier to explain to the public and can complement the more complex urban models.

In modeling the complex LUTE interactions, the majority of empirical studies rely on household surveys, because they provide detailed description of demographic, place of residence, and travel attributes at an individual or household level to support modeling. While such surveys remain the best vehicle to understand household behavior, they often suffer from small sample size, limited spatial scale and low update frequency. Due to budget constraints, household surveys normally contain only a few thousand observations within a metro area. Privacy concerns often limit the geographic specificity with which trip origins and destinations can be revealed. Survey data are usually updated every 5-10 years, which limits the responsiveness of related urban policies in

addressing the rapid metropolitan growth and socioeconomic, demographic, infrastructure and travel behavior changes that may have occurred or are projected to occur in the foreseeable future.

During the last two decades, with the rapid technology innovations, we have seen an explosion in the amount of data with spatial information. These new datasets include urban sensing data from pervasive systems like cellular networks, GPS devices, and WiFi hotspots, and geo-referenced administrative data, such as vehicle inspection records, transit fare card transactions, and assessing records. Compared to survey data, these novel datasets have several advantages:

- They are routinely collected by relevant agencies and are theoretically available to analysts at little or no cost.
- They have exceptionally broad temporal and spatial coverage – usually, the entire population of interest with regular updates that have a much higher frequency than normal surveys.
- They usually have detailed spatial resolution at a street address or parcel level of detail that allows consideration of local attributes relevant to urban planning.

While these novel datasets, accompanied by increasing computational power, enable unprecedented study of millions of people's movements,. they also have drawbacks for urban modeling: for example, socioeconomic and demographic attributes of 'tracked' individuals are generally not available due to privacy concerns, and intensive data processing is needed to mine these data for usable patterns and indicators.

Many recent studies on human mobility and dynamics have employed large-scale urban sensing data such as mobile phone or GPS trace of individual trajectories (Song et al. 2010; Gonzalez et al. 2008; Candia et al. 2008). From the MPO's perspective, geo-referenced administrative data make particular sense as a supplemental data source to traditional household surveys, because they are regularly collected by various government agencies and could have wide-ranging applications in metropolitan planning and urban management.

This study aims to demonstrate the potential value, and difficulties, in utilizing large-scale, geo-referenced administrative data together with urban modeling in order to address current policy issues in a timely fashion. In this study, we use annual vehicle safety inspection records from the Registry of Motor Vehicles (RMV) of the Commonwealth of Massachusetts to develop VMT

measures for every 250x250 meter grid cell in the metro area, and then use them to estimate the VMT implications of alternative growth patterns for Metro Boston. The growth patterns come from the most recent regional plan, called "MetroFuture," prepared by the region's Metropolitan Area Planning Council (MAPC). The MetroFuture plan developed and analyzed several metropolitan growth scenarios out to 2030 but was near completion in 2008 when the GWSA was passed. As a result, it was finished before the state's GIS office (MassGIS) obtained permission to geocode the vehicle safety inspection records so that annual mileage estimates could be associated with the place of residence of each vehicle's owner. Once the geocoded safety inspection data became available, we collaborated with MAPC and MassGIS to overlay the VMT estimates on the MetroFuture growth scenarios and estimate the difference in annual transportation-related GHG emissions that would result if the next two decades of metro Boston growth followed a business-as-usual scenario rather than the proposed MetroFuture plan. Much of the work was done as MIT class projects in 11.524 (Advanced GIS project) during the Spring of 2008-2010.

This paper is structured as follows: the next section introduces the study area, the data, and the spatial unit of analysis. Section 3 describes in detail our empirical analysis. The last section summarizes the research findings and discusses the policy implications of our study.

2. STUDY AREA, DATA AND SPATIAL UNIT OF ANALYSIS

Boston is the State capital of the Commonwealth of Massachusetts in the US. The metropolitan area surrounding Boston[4] consists of 164 municipalities covering an area of about 2,900 square miles (or 7,500 sq. km), 4.4 million people, and 2.5 million registered private passenger motor vehicles. It exhibits a rich set of transportation options and land use characteristics, which makes it a compelling case for our empirical study.

2.1 Vehicle Annual Safety Inspection Data

The annual vehicle safety inspections are required by the RMV beginning within one week of registering a new or used vehicle. The safety inspection utilizes computing equipment that

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[4] Depending on how one draws the outer boundaries, the size and population of greater Boston can vary by a factor of two. In this study we include the 164 municipalities surrounding Boston and within Massachusetts that were included in MAPC's MetroFuture growth planning. Of these municipalities, 101 are members of MAPC.

records a vehicle identification number (VIN) and an odometer reading and transmits this data electronically to the RMV where it can be associated with the residential street address of the vehicle's owner.

We obtained access to this dataset through the research collaboration of the MIT Urban Information Systems Group with MassGIS, the State's GIS Office. MassGIS compared sequential pairs of annual vehicle safety inspection records for all private passenger vehicles, calculated the difference in odometer readings, and pro-rated the difference based upon the time period between inspections to estimate annual miles traveled[5]. MassGIS then geocoded each vehicle to the owner's address using GIS tools. Overall, 2.47 million private passenger vehicles in Metro Boston are included in this dataset. To summarize, the dataset provides the following information for each registered private passenger vehicle: vehicle identification number (VIN), annual miles traveled, home longitude and home latitude.

For privacy reasons, neither the owner name nor owner address was available for our research. The XY locations are street centerline locations that are estimated by MassGIS to be proximate to the home address using MassGIS address matching tools. From the 2.47 million vehicles, 2.10 million (84.9%) have "reliable" odometer readings. For the remaining 0.37 million vehicles, we know their location of garaging but don't have reliable odometer readings, either because the reported reading was determined to be in error or because two readings sufficiently far apart were not available, for example, for a brand new vehicle.

While this dataset lacks individual trip details, it does provide a very high percentage sample of total vehicle miles traveled. Furthermore, this dataset does not depend on the subjects' willingness or ability to remember and report their driving habits, thus providing a more reliable estimate of VMT. The 1994 Residential Transportation Energy Consumption Survey by EIA shows that self-reported VMT values are 13 percent greater than odometer-based VMT in urban areas. EIA suggests that odometer-based VMT should be obtained if possible (Schipper and Moorhead, 2000). Holtzclaw et al. (2002) use a similar dataset in their study, odometer readings from auto emission inspections (smog check), but California exempts new vehicles from smog

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[5] Annual mileage estimates were developed only for vehicles that retained the same license plate registration number for both inspections. These vehicle were unlikely to have changed owners between inspections.

checks for the first two years, therefore their measure systematically biases VMT downwards for zones with large numbers of new vehicles (Brownstone, 2008).

2.2 Spatial Unit of Analysis

The Modifiable Areal Unit Problem (MAUP) is a well-known challenge in studies on spatial phenomena. Data aggregation may lead to inconsistency in measurement results and statistical analyses. To deal with the MAUP, the spatial unit used in this study is a 250x250m grid cell layer developed by MassGIS. Compared with previous research, this study is performed at a much more fine-grained scale. A grid cell contains an area just over 15.4 acres, which is sufficiently small to capture spatial details and neighborhood effects. Table 1 compares the grid cells and some spatial units that are widely used in land use and transportation research for Metro Boston. Meanwhile, using the grid cell as a basic study unit, we can take advantage of powerful raster analysis tools in GIS software. For a more detailed discussion about the grid cell layer, see Diao and Ferreira (2010).

<<< Insert Table 1 approximately here >>>

3. EMPIRICAL ANALYSIS

This study focuses on two urban growth scenarios developed by MAPC as part of the MetroFuture planning process: "Let It Be" and "Wind of Change."

- Let It Be (LIB): This scenario anticipates the future of Metro Boston in 2030 if current growth trends continue. The problems we face today are expected to get worse, with sprawling single family development at the periphery, unaffordable housing, educational inequity, lack of skilled labor, and unsustainable water withdrawals (MAPC 2008).
- Winds of Change (WOC): This alternative would significantly change the regional distribution of growth, while still being modest compared with more ambitious regional intervention alternatives. Instead of being dispersed across the region, growth is focused on locations where infrastructure and services already exist. The WOC scenario requires new land use planning tools and a significant increase in regional cooperation, including some regional decision-making on planning and land use issues (MAPC 2008).

MAPC provided MetroFuture projections of new housing units for both scenarios at the "traffic

analysis zone" (TAZ) level of geographic detail. Since the VMT estimates for each inspected vehicle were address-matched to precise street locations, comparing the VMT implications of the two growth scenarios would appear to be a straightforward task. That is, we can average the VMT estimates across all inspected vehicles that fall within each TAZ, weight these averages by the number of households projected to reside in each TAZ by 2030, and compare the results. However, as is common with spatially-detailed GIS analyses, the devil is in the details and several complications arise. Differences in estimated annual mileage for vehicles residing within a TAZ can be considerable, especially in suburbs with relatively dense town centers surrounded by considerable numbers of detached single-family homes. Many suburban TAZ are projected to contain new housing, but currently have few, if any, houses or vehicles for which we can estimate current VMT behavior reliably. In addition, the number of vehicles per household varies spatially across the region and there are measurement errors both in the timing and accuracy of census-based estimates of households at the block group and TAZ levels, and in the vehicle geo-coding that provides a street centerline location proximate to a parcel's mailing address. Comparing the VMT implications of the two growth scenarios required careful attention to data processing, spatial and temporal correspondence, and interpolation method. As a result, the study provided several educational opportunities as class projects as well as this example of how analysts can use GIS methods and spatially detailed administrative datasets to augment the usefulness of existing urban models and growth scenarios.

3.1 MetroFuture "Alternative Scenario Modeling" for 2030

The MetroFuture planning process implemented by MAPC intended to define a vision for the region's future out to 2030 (MAPC 2008). But MAPC did not have the time, budget, or technology in place to build a comprehensive large-scale land use and transportation model. Rather it used population and employment projections from a macroeconomic model in collaboration with local and regional planning staff across the 164 municipalities to develop the "Let It Be" projection at a municipal level of what Metro Boston would look like in 2030 if current trends continue. Then MAPC made various assumptions about zoning, environmental constraints and local buildout strategies. These assumptions were then built into CommunityViz and ArcGIS to translate the population and employment estimates into TAZ level household and housing assignments and various water, school, traffic, etc. projections for various growth

scenarios with some adjustment of municipal total based on scenario elements and a limited amount of interaction and ripple effects.

The WOC scenario is projected to have slightly higher population growth than the LIB scenario because more immigrants will be attracted by its higher amenity level in terms of housing affordability, transportation network performance, environmental quality, etc. Figure 1 shows the location of the new housing units anticipated at TAZ level in 2030 for the LIB and WOC scenarios. As shown in the maps, the LIB scenario shows more dispersed development emphasizing single-family, detached dwellings on undeveloped land beyond the first ring road, while the WOC scenario shows more compact development along existing transportation corridors and sub-centers as a result of "smart growth" policies. How does this translate into spatial patterns of housing development in Metro Boston at the grid cell level? What impacts will they have on household vehicle usage, transportation energy use and GHG emissions? This study illustrates a way of approximately answer to these questions by using the VMT data to compare growth scenarios.

<<< Insert Figure 1 approximately here >>>

3.2 Locating New Housing Units

In order to get a reasonably accurate estimate of the spatial differences in annual VMT, we carry out our analysis at the fine-grained 250x250 meter grid cell level. In the suburbs, the TAZ are considerably larger than a grid cell and the MetroFuture scenarios estimate only the number of new units of each type of housing that are anticipated to be added to each TAZ[6]. Accordingly, we need to identify those grid cells within a TAZ where the new housing is more likely to be located. Also, the MetroFuture scenarios distinguished 16 different housing types. Each housing type represents a different style with different land requirements. For example, a single family unit might be built on 0.5 acres of land, while multi-unit residences might average 0.1 acres per unit. Hence, some decision must also be made to prioritize the sequence in which types of

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[6] While each grid cell is 15.4 acres (6.25 hectares), the TAZ vary in size. In the denser parts of metro Boston, TAZ are much smaller and they can even be smaller than a grid cell. However, these dense areas are already built out and the anticipated new housing units are generally assigned to TAZ that are much larger than a grid cell.

housing units are assigned to developable land within particular grid cells[7].

One way to allocate the new housing units is to assign them randomly to grid cells within the assigned TAZ that had developable land. Figure 2(a) shows the "random" allocation results under the LIB scenario. Cells without any new housing are unshaded (i.e., white) and cells that were allocated 1-3 new housing units are shaded in yellow. The darker cells are assigned more housing units and the darkest blue quintile of cells were assigned at least 15 housing units.

Alternatively, we could allocate new housing units more purposefully. Instead of assigning them randomly to cells with available land, we could assign them to grid cells that had, say, more accessible locations[8]. This optimization problem can be cast as the canonical discrete optimization problem known as bin packing. Bin packing is the problem of packing objects of different sizes into a finite number of bins, which is known to be NP-Hard, i.e., no efficient algorithm for finding a globally optimal solution. Therefore, as an approximate solution, we apply an iterative greedy optimization algorithm to assign new housing units at the TAZ level to grid cells[9]. The allocation algorithm used in this study is "greedy" because at each step of the algorithm we make the choice that locally improves our allocation the most. At each iteration, the algorithm computes for every housing type and grid cell combination, the maximum number of units of housing type h that can fit into grid cell g, which is the minimum of the total number of units of housing type h requested for the entire TAZ and the number of units of type h that can fit in the available land in grid g. We then find the best grid/housing type combination to allocate at the current step. This choice represents the grid/housing combination that will maximize the average accessibility to non-work destinations the most in the current iteration. The algorithm then updates the number of desired units and the available land to reflect the current allocation step. The algorithm executes iteratively, until all the available land in the TAZ is exhausted or all

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[7] In a few cases, the portions of those grid cells that fell within a TAZ did not have sufficient developable land to accommodate all the new housing that was assigned to the TAZ by a MetroFuture scenario. We attributed this problem to measurement and generalization errors in overlaying TAZ, grid cell, and land use layers that had been generated independently. Since we interpret our end results on a per-new-housing-unit basis, the allocation discrepancies should not be consequential.

[8] When we modeled the TAZ-to-grid allocation of new units (in Spring, 2008), we did not yet have the VMT estimates from the safety inspections. As our proxy for transportation demand in each grid cell, we used the average distance to typical non-work destinations – a measure that MassGIS had developed from business location datasets and US Census surveys about trip frequencies.

[9] The Matlab script for this housing assignment problem was written by Paul Green, one of the students in the 11.521 class during Spring 2008.

of the requested units have been allocated.

We applied the greedy allocation to both the WOC scenario and LIB scenarios[10]. The results are shown in Figures 2(b) and 2(c).Note the marked differences between the WOC scenario and either of the LIB allocations. Whether the LIB allocation is randomized or assigned to the more accessible grid cells in each TAZ, much of the new housing is allocated as scattered, single-family detached housing in the outer suburbs with 3 or fewer units per impacted grid cell. The new housing for WOC scenario is less dispersed and more concentrated than either allocation of the LIB scenario.

<<< Insert Figure 2 approximately here >>>

3.3 VMT Estimation and Interpolation

In order to develop an easily understood forecast of VMT trends for the growth scenarios, we assume that newly added households will behave similarly to their neighbors as a result of living in an area with similar accessibility, land use and demographic characteristics. Hence, we need precise estimates of the current VMT at the grid cell level.

To do so, we first compute the VMT per vehicle for each grid cell based on vehicle-level annual mileage estimates from MassGIS. Some grid cells in the region have very few or no vehicles. We apply spatial interpolation tools of GIS software to overcome issues related to sparse cells and estimate VMT per vehicle values for each grid cell. Two interpolation methods are tested:

- Simple Average: the mean value of annual VMT for the 25 closest "reliable" cars is assigned to all sparse cells.
- Inverse Distance Weighted (IDW) Interpolation: the inverse distance weighted average of the 25 closest "reliable" annual mileages is assigned to all the sparse cells based on the assumption that vehicles that are closer to a grid cell tend to have a larger influence on the estimated value.

Figures 3 plots the interpolated VMT per vehicle at grid cells in Metro Boston using the IDW

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[10] We did not bother with the randomized approach for the WOC scenario, since that option involved increased land use control and would presumably steer new development toward those grid cells that were more accessible.

method. The overall spatial pattern is what analysts would expect: VMTs are lower in grid cells near dense urban centers, but higher in suburban areas. There is also significant variability within suburbs depending on whether the grid cell is near the town center. It is also interesting to note that the interpolation is an important part of the analysis. Many newly allocated housing units are assigned to cells that previously had no population. For example, $119834 - 73714 = 46120$ (or 38%) of the grid cells had no resident population in 2000. For the LIB random allocation, new housing units were assigned to many of these previously unoccupied cells so the interpolated mileages have a significant impact on our estimates of the difference in VMT between the two scenarios.

<<< Insert Figure 3 approximately here >>>

Another estimate required for the analysis is the car ownership rate for households. The VMT estimates are for each VIN and car ownership rates are needed to transform VMT per vehicle into VMT per household at the grid cell level. We combine the vehicle safety inspection data and census data to compute the car ownership level for each grid cell. In the first step, we identify grid cells whose vehicle and household counts are considered "reliable": if the number of vehicles per household in the nearest 9 grid cells (including itself) is within a reasonable range (0-5) and both household and vehicle counts in the 9-grid-cell area are beyond certain threshold values (40 household and 60 vehicles respectively), we consider them to be "reliable" grid cells. We then inflate these estimates of the number of vehicles per household by 5 percent in these "reliable" grid cells to address the fact that only 95% of the vehicles registered in these towns have been geocoded in Metro Boston and the rate of missing values is 5%. For "unreliable" grid cells, the US 2000 Census average of vehicles per household at the block group level is assigned. In the end, the vehicle per household rate that is assigned to each grid cell is the average rate for the 9-grid-cell window centered on that grid cell.

3.4 VMT Implications of Alternative Growth Scenarios

Table 2 presents a set of relevant statistics to compare the current situation (measured in 2005) with the two growth scenarios, including two variations of the LIB scenario depending on how new housing is allocated to grid cells within a TAZ. We label these three scenarios WOC-Optimize, LIB-Optimize, and LIB-Random, and we use the Simple Average and IDW methods

respectively to interpolate VMT values for previously unoccupied grid cells. Both interpolation methods yield similar overall results. We use the IDW numbers (from Table 2a) for this interpretation.

The annual VMT per newly added household does get much worse under the LIB scenarios. For the LIB-Optimize allocation it is 19.6% worse than the current average VMT per existing household. For the randomized LIB allocation, the VMT for new households is 22.6% higher than the current annual VMT per household.

The annual VMT per household under the LIB-Optimize allocation is also 12.3% higher than the WOC-Optimize allocation, and LIB-Random is 15.1% higher than WOC-Optimize. From the sustainability and GHG reduction perspective, the WOC-Optimize allocation outperforms the two LIB allocations with its lower VMT per vehicle and lower car ownership rate. In addition, the LIB-Optimize allocation is notably better than the LIB-Random allocation.

While the WOC-Optimize allocation performs much better than either LIB scenario, the WOC results are still 6.5% higher than the *current* annual VMT per household (as of 2005). New households in the WOC scenario are much less likely than in LIB to occupy single-family detached homes in the outer suburbs. However, new WOC households are nevertheless less likely than the *current* residents to locate in relatively dense, low mileage urban areas. So their VMT expectation is much better than for new LIB residents but still worse than the average current resident. Compared to the "current" households living in Metro Boston in 2005, the projected new households on average tend to both own more cars and use each car more intensively in all three growth scenarios.

The WOC scenario is also projected (by the MetroFuture model) to make greater Boston more attractive so that more new households are added by 2030. Compared to the current mileage, the total VMT increase from added households under the WOC-Optimize, LIB-Optimize and LIB-Random scenarios are 22.5, 22.1, and 22.7% respectively. Hence, the savings in VMT per household anticipated in the WOC-Optimize scenario is offset by the higher population growth (14% higher) projected by MAPC for WOC over LIB[11]. However, if the WOC scenario attracts

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[11] MAPC projects 339k new households under WOC and 297K under LIB. Tables 2 and 3 show small (0.01%) differences between LIB-Optimize and LIB-Random due to measurement and round-off errors in overlaying TAZ, grid and land use boundaries and slight differences in the allocation algorithm's stopping rules.

more in migration to Metro Boston than LIB, then presumably other areas would experience more out migration. So the net GHG emission effects of the growth scenarios are best addressed by expressing changes on a per-new-household basis.

To estimate the GHG effects of the LIB and WOC growth scenarios, we estimate the added emissions due to a 20% growth increase in the number of households living in Metro Boston by 2030. 20% of the current 1.926 million households = 321K new households. We assume an average fuel-efficiency of 22.1 miles per gallon[12], and an emission level of 8.8 kilograms CO_2 per gallon[13]. Under these assumptions, we estimate 751 to 923 million extra miles and 34.0 to 41.8 million extra gallons of gas consumed annually by locating the 321k new households via the optimal or randomized version of LIB versus WOC, which is equivalent to 0.30 to 0.38 million tons of CO_2 emissions. It should be noted that the assumed fuel efficiency level is the average U.S. passenger car fuel efficiency in 2005. Our projection of GHG emissions ignores the trends of improving fuel economy in the US and probably overestimates the 2030 GHG emissions – but not the relative differences across the scenarios.

<<< Insert Table 2 approximately here >>>

3.5 Sensitivity Analysis

To test the sensitivity of our analysis, we carry out the same set of analyses at the TAZ level and compare the results with the grid cell level analyses. As shown in Table 3, the general story is still intact at the TAZ level: those new households added to the region in the next 25 years, under both the WOC and the LIB scenarios, will on average have higher VMT per vehicle, higher car ownership rates, and hence higher VMT per household than current households. Compared to the LIB scenario, the WOC scenario can save 15.4% in VMT per newly added household. Compared to the grid-cell level calculation, the estimates of VMT per household are slightly higher for the TAZ-level calculations – 0.6% higher for 2005 and about 2% higher for WOC and LIB scenarios[13]. .

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[12]According to Research and Innovative Technology Administration, Bureau of Transportation Statistics, the average U.S. passenger car fuel efficiency is 22.1 miles per gallon in 2005.

[13] Slight differences for the baseline 2005 case are possible because the grid-level estimate excludes grid cells with unreliable household counts from the averaging. For the WOC and LIB scenarios, differences can arise because of within-TAZ variation in VMT and because, when allocating new households to grid cells within a TAZ, some TAZ did not have quite enough developable land to accommodate all the allocated units.

<<< Insert Table 3 approximately here >>>

While the general nature of the results are still evident at the more aggregated TAZ level of analysis, some intra-zone variations in vehicle usage cannot be captured at the TAZ level. Figure 4 plots the VMT per vehicle estimates at the TAZ level using the same breakpoints as were used in Figure 3. In the inner city, a TAZ may only contain a few city blocks, whereas in the suburb it is not rare for an entire town to be a single TAZ. Within a suburban town, areas close to the commuter rail station could have significantly lower VMT than other areas (Diao 2010). Our study suggests that analyses of the spatial pattern of VMT should be carried out at the more fine-grained scale in order to reflect the within-TAZ variations in VMT that are evident in some of the suburban areas.

<<< Insert Figure 4 approximately here >>>

4. SUMMARY AND POLICY IMPLICATION

Given the quasi-static nature of our analysis, our study cannot project all the ripple effects of a given policy on long term vehicle usage after various land use changes and population shifts have occurred. Such an effort would require a dynamic model of land use-transportation interaction or a computational general equilibrium approach that includes more interactions than we have considered. None the less, this study takes advantage of newly-available, spatially-detailed administrative data to estimate the VMT implications of growth scenarios using assumptions that are easily explained to the public. The regional planning process had already developed the MetroFuture growth scenarios when the GWSA law was passed. From the safety inspection data, we were able to generate credible VMT estimates at TAZ and grid cell scales for all current vehicles. Combining the two in order to estimate the VMT of new households based on current VMT estimates for their forecasted neighborhoods is easily explained to the public and adds credibility to the conclusions about the VMT differences between the scenarios. There are a growing number of questions and data sources where planners and spatial analysts can capitalize on existing, georeferenced administrative data streams by using them to interpret and amplify ongoing urban modeling efforts and scenario development in order to address topical issues in a timely and affordable fashion.

This study shows the substantial impact on vehicle usage in Metro Boston that is likely to arise

from current metropolitan growth patterns. The average VMT per household of projected new households under the 'let it be' (LIB) scenario is estimated to be 12-15% worse that under the 'winds of change' (WOC) scenario. The WOC scenario allocated much of the new growth to clustered developments along transportation corridors and regional sub-centers compared with the LIB scenario that emphasized single-family detached homes in the outer suburbs. But even the WOC growth scenario still has VMT per household and VMT per vehicle greater than the current regional average. Hence, the direct impact of regional growth will be for the region-wide car ownership rate and car usage to continue to increase. The WOC scenario does a lot better than the LIB scenario, but still does not 'bend the curve' enough for the state's private passenger mileage total to trend downward.

Successful regional development could also entice even more households to come to Boston. For example, MAPC projected that the WOC scenario will attract 41.6 thousand more households to the region due to its higher quality of life compared with the LIB scenario. Therefore from the perspective of individual metros, the saving in VMT per household from "smart" growth could easily be used up if the policies lead to plausibly faster growth. In terms of global effects, the faster growth in Boston might come at the expense of some other region, so any added Boston growth need not necessarily imply higher global emissions. However, the Massachusetts law has targetted a 10-25 percent reduction of statewide GHG emissions by 2020 from the level of 1990 and an 80 percent reduction by 2050. Our findings lead to the sobering conclusion that urban growth management alone will most likely not save enough GHG emissions to assist the state in meeting its emission reduction targets. Hence, a more comprehensive set of technology, economic, and land use policies will be needed together with land use controls in order to adequately reduce GHG emissions and achieve the State's goal in fighting global warming.

This study also demonstrates the potential value as well as difficulties in utilizing georeferenced administrative data, such as the vehicle safety inspection records, for urban modeling. Administrative data enable us to build useful, understandable, fine-grained, and tractable indicators to measure the performance of cities, to stimulate dialogue among the public and local and regional planners on regional sustainability issues, and to accelerate the responsiveness of urban planning. On the other hand, administrative data are not purposely designed for modeling, so some critical information may be lacking, and the datasets are often not in an easy-to-use

format, which restricts the usefulness of the raw data without intensive processing and careful interpretation.

The locational privacy issues associated with analyzing human behavior using detailed individual level location-aware data are another complication associated with the use of many administrative data sources. Analysts need to understand technical options and good practices (such as anonymization) when tapping administrative data to update urban indicators and benchmarks or to estimate the impacts of planning scenarios.

In summary, both administrative data and survey data have their pros and cons. Survey data still dominate current research efforts and remain necessary for ground truthing and calibrating certain behavioral models. Nevertheless, georeferenced administrative data can provide a meaningful alternative, or supplementary, data source that can be timely, voluminous, and cost effective. Careful use of administrative data in urban modeling can reduce the dependence on surveys and complement their usage in metropolitan planning.

Acknowledgements

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List of Figures

Legend
— Major roads
☐ City of Boston
☐ Metro Boston Boundary
☐ Massachusetts Towns

N
W   E
S

├┼┼┼┼┼┼┼┤ Miles
0 2.5 5   10

1(a) Let-It-Be Scenario   1(b) Wind-Of-Change Scenario

Figure 1: New Housing Units at the TAZ Level

2(a) LIB-Random

2(b) LIB-Optimized

2(c) WOC-Optimized

Legend

Metro Boston Boundary

New housing units

- 1 - 3
- 4 - 6
- 7 - 9
- 10 - 14
- 15 - Maximum*

Figure 2: New Housing Unit Allocations for a Transect of Metro Boston

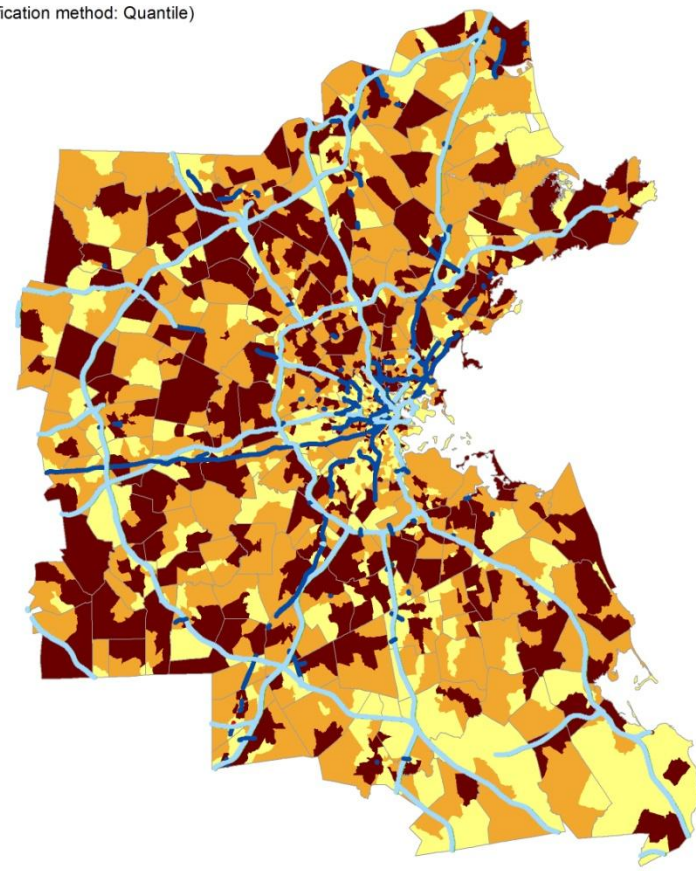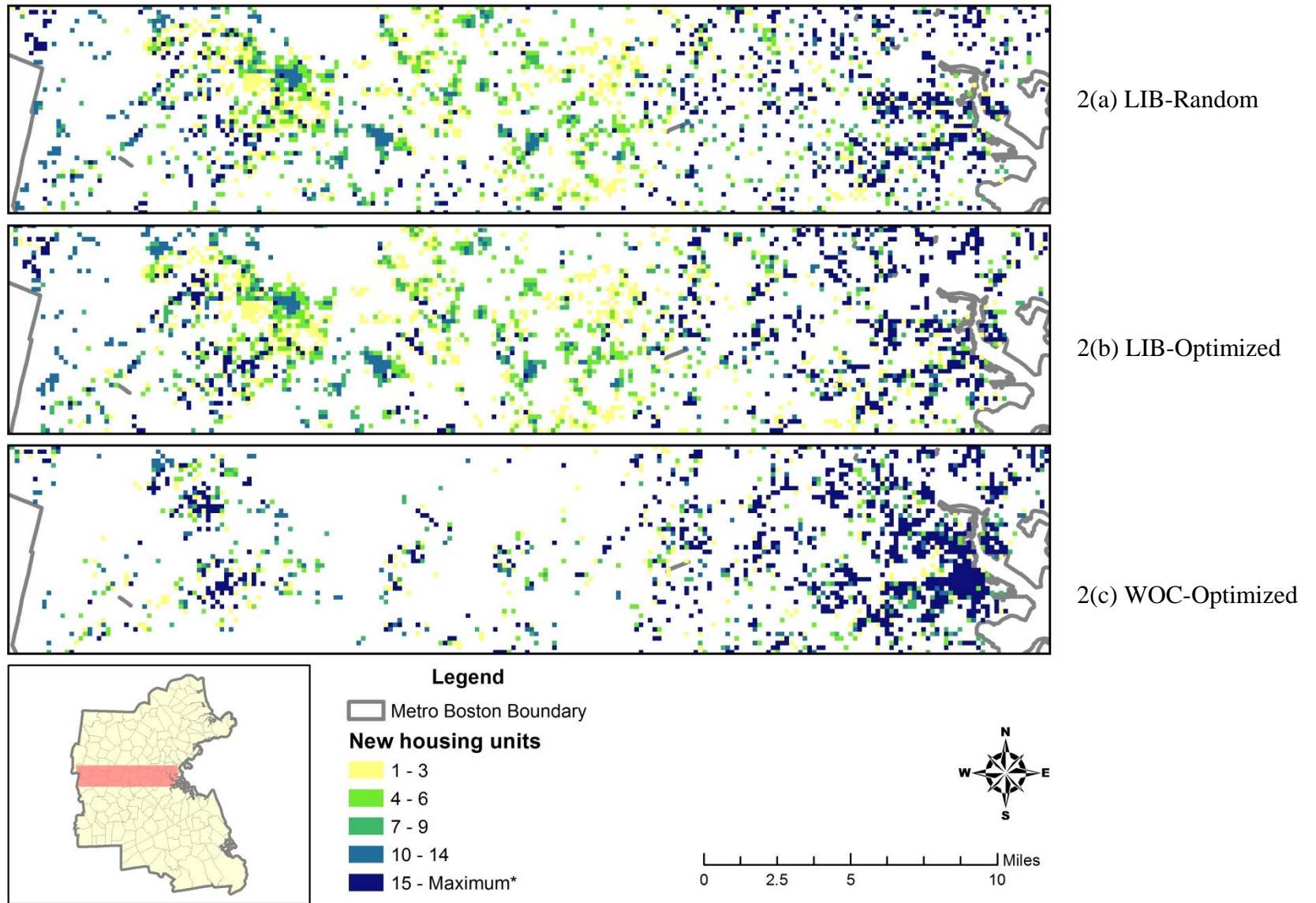*: the maximum value varies in the three scenarios: 875 (LIB-Random) 594 (LIB-Optimized) 1393 (WOC-Optimized)
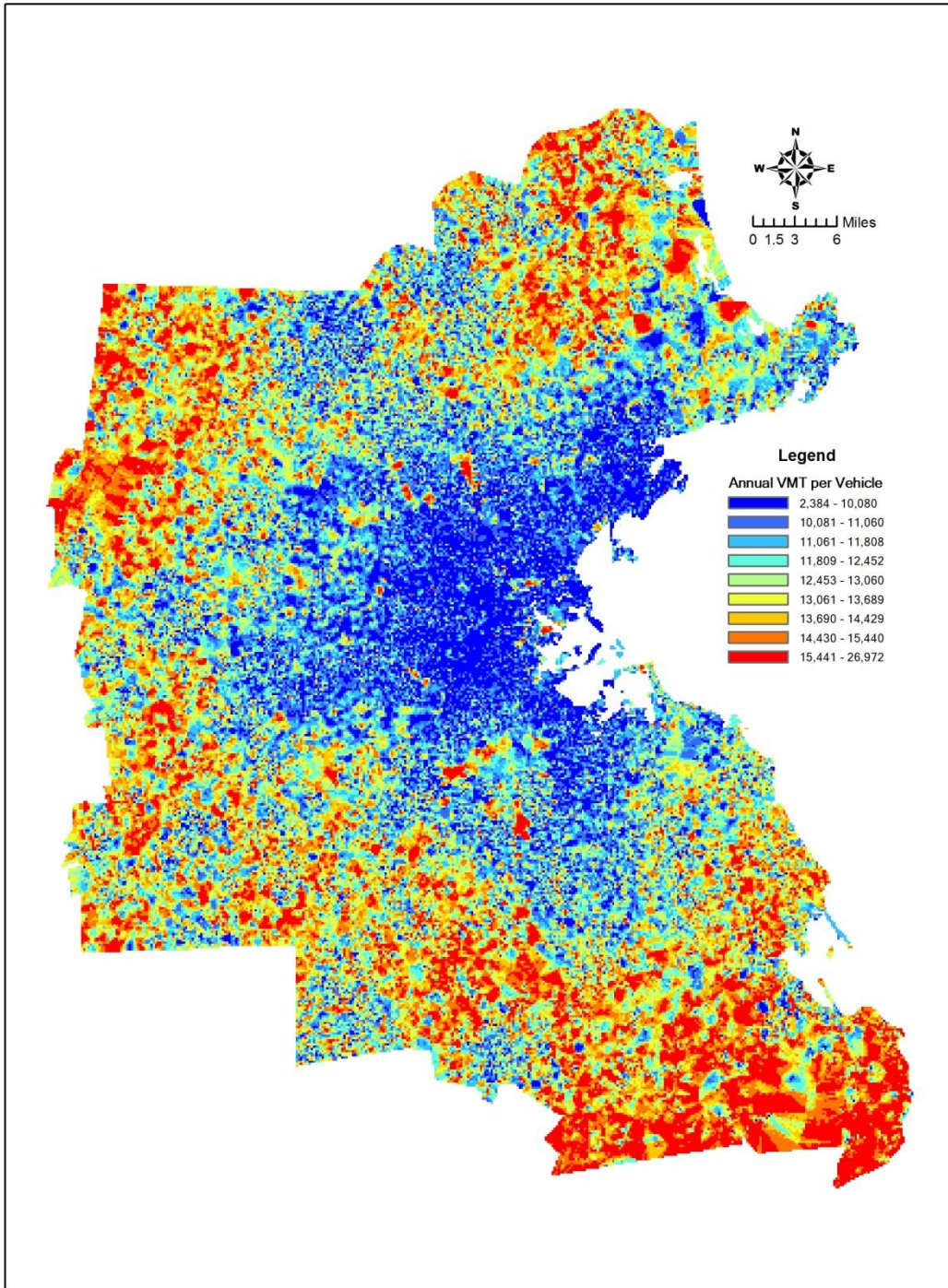
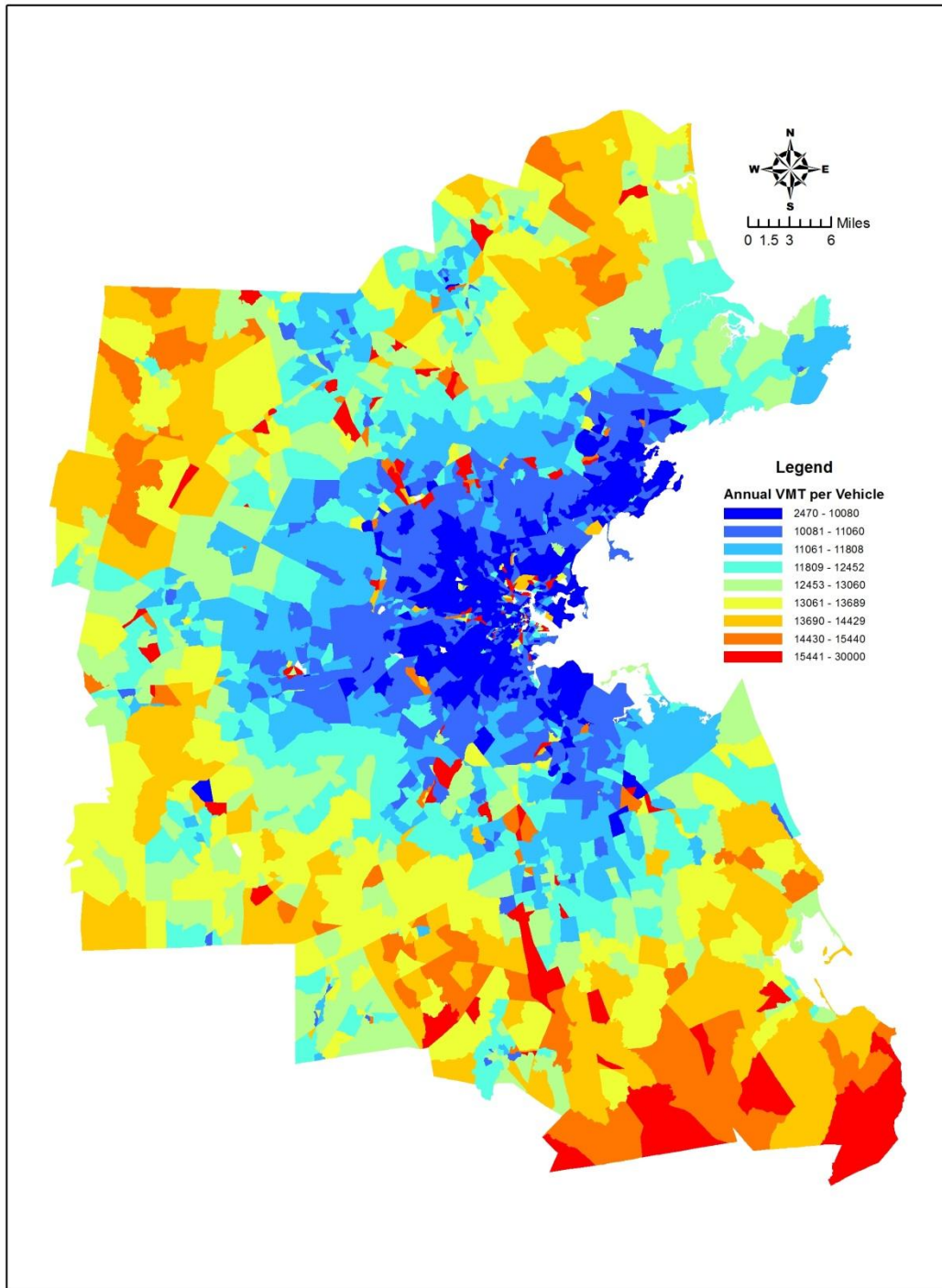Figure 3: Estimated VMT per Vehicle at Grid Cell Level (IDW Interpolation)

Figure 4: VMT per Vehicle at TAZ Level

Table 1: Comparison of Spatial Units for Metro Boston

	Grid Cell	TAZ	Block Group	Census Tract
No. of observations	119,834	2,727	3,323	894
No. of observations with population	73,714	2,606	3,319	894
Vehicle count for populated units				
Min	0	0	1	1
Max	3,117	3,022	11,593	13,631
Mean	32	941	744	2,764
Std. Dev.	49	603	514	1,514
Household count for populated units				
Min	0	0	0	0
Max	1,624	2,318	2,211	4260
Mean	22	631	495	1,839
Std. Dev.	48	391	246	713
Individual count for populated units				
Min	1	1	2	70
Max	3,673	4,969	6,131	12,051
Mean	58	1,654	1,297	4,817
Std. Dev.	112	992	626	1,825

Table 2a: VMT Comparison between Baseline and Three Scenarios/Allocations at Grid Cell Level (IDW)

Scenario/Allocation	VMT/VIN (mi)	VIN/HH	VMT/HH (mi)	Pct above Current	Pct above WOC
Current (2005)	11,591.	1.54	17,847		
WOC-Optimize	11,672	1.63	19,006	6.50%	
LIB-Optimize	12,030	1.77	21,347	19.61%	12.31%
LIB-Random	12,080	1.81	21,881	22.61%	15.13%

* The statistics for the three growth scenarios/allocations are computed for the projected new households only.

Table 2b: VMT Comparison between Baseline and Three Scenarios/Allocations at Grid Cell Level (Simple Average)

Scenario/Allocation	VMT/VIN (mi)	VIN/HH	VMT/HH (mi)	Pct above Current	Pct above WOC
Current (2005)	11,587	1.54	17,840		
WOC-Optimize	11,621	1.63	18,924	6.07%	
LIB-Optimize	12,015	1.77	21,320	19.51%	12.66%
LIB-Random	12,068	1.81	21,859	22.53%	15.51%

* The statistics for the three growth scenarios/allocations are computed for the projected new households only.

Table 3: VMT Comparison between Baseline and Two Scenarios at the TAZ Level of Aggregation

Scenario	VMT/VIN (mi)	VIN/HH	VMT/HH (mi)	Pct above Current	Pct above WOC	Total HHs	Total Vehicles	Total VMT (M mi/yr)
Current (2005)	11623	1.54	17955			1,643,981	2,539,582	29,516.9
WOC	11907	1.63	19359	7.82%		348,837	567,152	6,753.24
LIB	12255	1.82	22334	24.39%	15.37%	307,477	560,356	6,867.30

* The statistics for the two growth scenarios are computed for the projected new households only.