Measuring the Air Quality and Transportation Impacts of Infill Development

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The U.S. Environmental Protection Agency (EPA) initiated this project to quantify the air quality emissions impacts from regional brownfield and infill development policies. Industrial Economics, Inc., in association with Cambridge Systematics, Inc., was selected by EPA to perform this work in collaboration with the Metropolitan Area Planning Council (Boston), Denver Regional Council of Governments, and the City of Charlotte. The report was reviewed by a panel of transportation planners: Ken Cervenka, North Central Texas Council of Governments; Gordon Garry, Sacramento Council of Governments; and Scott Lane, The Louis Berger Group.

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Front Cover Photos:
Jefferson North End, Dallas, Texas. This 540 unit residential complex, opened in 1998, was built on a site that had been vacant for 20 years. (Photo Courtesy of US EPA, Office of Brownfields and Land Revitalization)

Back Cover Photos:
Southside Neighborhood, Greensboro, North Carolina. This mixed use redevelopment is within a five to ten minute walk from the central business district. It includes 30 single-family homes, 10 two-family homes, 50 townhouses, 10 restored historic homes, and 20 live/work units. (Photo Courtesy of City of Greensboro, Department of Housing and Community Development)

Measuring the Air Quality and Transportation Impacts of Infill Development

Executive Summary

Infill Development as a Key Transportation Management Strategy

Many regions are struggling to balance transportation needs with community revitalization and environmental protection. The potential for infill development to support all three goals is what sets it apart as a unique strategy. While the positive impact of redevelopment projects may be readily apparent at the community level, their regional transportation and air quality benefits can be harder to quantify.

Fundamentally, well designed neighborhoods in more accessible places make walking, biking and transit more convenient options. Therefore, policies that increase the amount of urban and suburban infill development can help more people meet their everyday needs with less driving. In turn, this can reduce traffic and contribute to better regional air quality.

The complicated nature of redevelopment often requires the public sector to act as a catalyst by providing financial subsidies, assembling land or upgrading infrastructure. The direct economic benefits justify many public investments, but more substantial commitments could be supported if the indirect transportation and air quality benefits could also be quantified.

This study illustrates how regions can calculate these benefits. The basic approach relies upon standard transportation forecasting models currently used by Metropolitan Planning Organizations across the country. The results suggest that strong support for infill development can be one of the most effective transportation and emission reduction investments regions can pursue.

The Report's Purpose: Demonstration of Methods

Although less vehicle travel and fewer emissions are reasonable outcomes to expect from infill development, quantifying such benefits has proved challenging. In most cases, the forecasting models used for regional transportation planning are not set up to capture the effect of innovative land use strategies. Therefore, they typically do not capture the changes in vehicle travel generated by increasing development in walkable communities with convenient access to transit. Quantifying benefits is also complicated by the need to establish baseline development trends. In other words, measuring the net benefit of a set of infill projects requires establishing where development would have otherwise gone.

This report summarizes three case studies, each testing slightly different approaches to these analytical problems within traditional four-step travel-demand models. The analysis shows how standard forecasting tools can be modified to capture at least some of the transportation and air quality benefits of brownfield and infill development.

Some of the key modifications include:

- Indices to reflect how mixed use development changes travel patterns
- Adjustments to account for shifts to non-motorized travel
- Smaller analysis zones in the models to capture the impact of neighborhood land use patterns
- Emissions estimates based on the number of car trips as well as by distance traveled

Key Findings

Across the three case studies, redirecting jobs and households to brownfield and other infill sites reduces overall travel, congestion and emissions from cars. For example, if just 8 percent of Denver's jobs and households were shifted over time toward 10 regional centers, congestion would be reduced by over 6 percent and emissions would be reduced by about 4 percent. This would be equivalent to removing nearly half a million trips per day from the region's roads, a significant share of the daily average (12.7 million miles). If the same amount of development was concentrated in 31 locations, the reduction in emissions would be somewhat smaller (3 percent).

The Charlotte case study evaluated the impact of increased infill development in a single corridor. Although, a much smaller number of jobs and homes were relocated to infill sites, the analysis demonstrates the benefits of focused development around transit. While the new rail service alone did reduce congestion in the corridor, it had a minimal impact on the region's emissions. However, when 16,000 households and 10,000 jobs are relocated near the South Corridor stations, the reduction in emissions was 10 times greater and transit ridership increased by more than 6,000 trips each day.

In Boston, the analysis considered redevelopment in just 13 suburban towns along the I-495 Corridor. Redirecting new development to brownfield sites in these towns reduced vehicle travel by 154,000 miles during the evening rush hour. Given the corridor's average car trip of 15 miles, this reduction is equivalent to eliminating more than 10,000 trips. In road capacity terms, this close to the additional trips accommodated by specific road-widening projects proposed for these towns. These projects are expected to cost $5 to $17 million each. (Boston Metropolitan Planning Organization 2006)

Compared with other policies adopted to meet regional air quality goals, these reductions are both significant and cost effective. For example, the reductions generated by projects funded under the Congestion Mitigation and Air Quality (CMAQ) program typically cost around $20,000 per year for each ton of pollution they eliminate. (FHWA 2006, Appendix 4) With such a benchmark, Denver could spend roughly $17 million to facilitate the kind of infill development evaluated in this study and still be more cost effective.[1]

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[1] Based on the assumption that land use related reductions are maintained over a 30-year period, the rough lifetime of many commercial properties. Residential development tends to have a much longer lifespan and would likely produce VMT reduction benefits over a much longer period. However, a more conservative assumption was made for a basic cost-effectiveness illustration.

Intended Audience and Structure of the Report

The report is intended for both land use and transportation planners, to act as a bridge between innovative redevelopment policy and transportation modeling. The first part of the report outlines the issues, methods, and findings of each case study in general terms. The goal is to help non-technical readers understand how the benefits of infill development might be measured using traditional transportation planning tools. Technical appendices cover the details of each regional analysis at the level of detail needed to design and launch a comparable study. However, as noted by the peer reviewers, the complexity of travel demand models and their unique evolution in each region mean that even the technical appendices are not exact instructions for replicating the analysis. Rather, they illustrate methodologies that must be customized to fit each region. On the other hand, they do describe specific concepts and techniques that can serve as a starting point for modifying most regional travel demand models.

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1.0 Introduction

Local governments across the country are paying more attention to infill development. Former industrial sites, declining suburban malls, vacant properties and other underutilized land all provide opportunities for redevelopment. Projects developed on such sites are often pursued for their economic development benefits. However, redeveloping underutilized land in cities and suburbs also has the potential to reduce vehicle travel and contribute to better air quality.

In fact, the studies summarized in this report suggest that actively supporting infill development can be a highly effective regional transportation policy. If done well, redevelopment creates neighborhoods where residents can accomplish their daily activities with less driving. Previous site level studies suggest that shifting development to more accessible locations reduces vehicle travel per person by 30 to 60%[2].

At a regional level, a significant number of well designed infill projects can go a long way toward helping meet air quality goals. Specifically, such changes can make important contributions to the emission reduction targets contained in State Implementation Plans. These SIP plans are critical because they determine if future transportation investments conflict with regional air quality goals defined under the Clean Air Act.

This study quantifies the air quality benefits of regional growth scenarios that increase development on brownfield and other infill sites. To achieve this objective, three Metropolitan Planning Organizations (MPOs) incorporated new analytical components into their existing travel demand forecasting tools. Their models were enhanced to reflect techniques described in EPA's *Comparing Methodologies to Assess Transportation and Air Quality Impacts of Brownfield and Infill Development* report. Various publications from the U.S. Department of Transportation's Travel Model Improvement Program (TMIP) also served as a key resource in the process. The goal was to develop techniques for estimating emission reductions that would be both transferable and acceptable within a State Implementation Plan (SIP), conformity determination, or ozone flex plan.

However, achieving this objective required overcoming a few major obstacles. First and foremost, the analytical framework[3] at the heart of nearly all regional transportation planning models has difficulty capturing interactions between land use and transportation systems. Even when MPOs have incorporated land use feedbacks into their travel demand models, they tend to be regional in nature and fail to capture the key neighborhood level characteristics. It is these smaller scale land use patterns that often contribute most to the reduced driving expected from well designed infill projects. Other common limitations include: only examining work-related travel, not considering walking as a mode of travel, and including very little detail on land use characteristics between "travel analysis zones."

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[2] Ewing, R. and R. Cervero. 2001. Travel and the Built Environment: A Synthesis. Transportation Research Record 1780, 87-114.

U.S. EPA, 1999, The Transportation and Environmental Impacts of Infill Versus Greenfield Development: A Comparative Case Study Analysis, EPA publication number 231-R-99-005.

[3] Nearly all regional travel demand models follow the "four step" process. Typically this is a set of connected models that estimate the following- (1) trip generation, (2) trip distribution, (3) mode choice and (4) traffic assignment.

Staff from the three participating transportation agencies performed the comprehensive analyses. They included the metropolitan planning organizations in Boston and Denver and the City of Charlotte. Each worked with EPA to test whether a specific set of infill projects in the region could reduce emissions relative to current development trends. They used their existing travel demand models, along with EPA's MOBILE6 emissions software, to measure the benefits of compact infill development scenarios. The analysis also produced transportation outcome measures such as person trips, average trip lengths, vehicle miles traveled, vehicle hours traveled, transit mode share, average speed, and congestion. In each case, the analysis found that increased brownfield and infill development would result in substantially lower emissions of hydrocarbons (VOCs), nitrogen oxides (NOx), and carbon monoxide (CO).

The case studies examined projects at differing regional scales. In Boston, infill development was examined in a small portion of the metropolitan area. It tested how changing growth patterns in one corridor could improve the air quality outlook of the region as a whole. Denver examined the entire region to see how focusing development in a few large urban and suburban centers would compare to current development trends. Charlotte focused on the impact of infill development concentrated around a new light-rail transit line.

1.1 Brief Overview of the Case Studies

1.1.1 Boston

This regional case study evaluated the impact of reorienting development patterns in 13 towns along the I-495 corridor, roughly 20 miles west of downtown Boston. The Metropolitan Area Planning Council (MAPC) and the Central Transportation Planning Staff (CTPS) ran two scenarios:

1) Current development trends continued
2) Concentrated development in town centers and interchanges along I-495.

Both scenarios assumed the same amount of employment and household growth. However, under the *Concentrated Growth* scenario, about 18,000 households (14 percent of the corridor's total) and 102,000 jobs (22 percent of the total) would be redirected over time into more accessible locations. The specific parcels to be redeveloped in the scenario were Ashland Center and Hopkinton Center, two large brownfield sites, and a number of smaller infill sites near the town centers and freeway interchanges in the other 11 towns.

The MAPCs travel demand model found that more accessible development would produce significant transportation benefits. The analysis forecast less driving and traffic congestion as well as more trips made by transit or walking. Overall, people who live and work in the corridor would drive 239,000 fewer miles each day during the evening rush hour. These changes would result in significant air quality benefits for each town and the region as a whole. Compared to current development patterns, shifting growth to the more accessible sites would result in 5 to 8 percent lower emissions of VOVs, NOx and CO by (see Figure 1.1).

The significance of these reductions is best understood when compared to typical transportation demand management and emission reduction policies. Effective regional strategies are generally comprised of many actions that together add up to a significant reduction of regional emissions. It is unusual for any single action to reduce regional emission by more than 1 percent, but 10 to 20 actions together can achieve the air quality targets established under the Clean Air Act. Similarly, individual demand management policies cannot solve traffic problems, but a comprehensive set of policies do have an impact. The reductions in driving and emissions that would result from putting more homes and businesses in the corridor's town centers exceeds many of the demand management actions outlined in the MAPC's Regional Transportation Plan. This is particularly significant in light of the more than 80 jurisdictions for which no land use changes were considered.

Figure 1.1 –Reductions from Focused Redevelopment in the I-495 Corridor

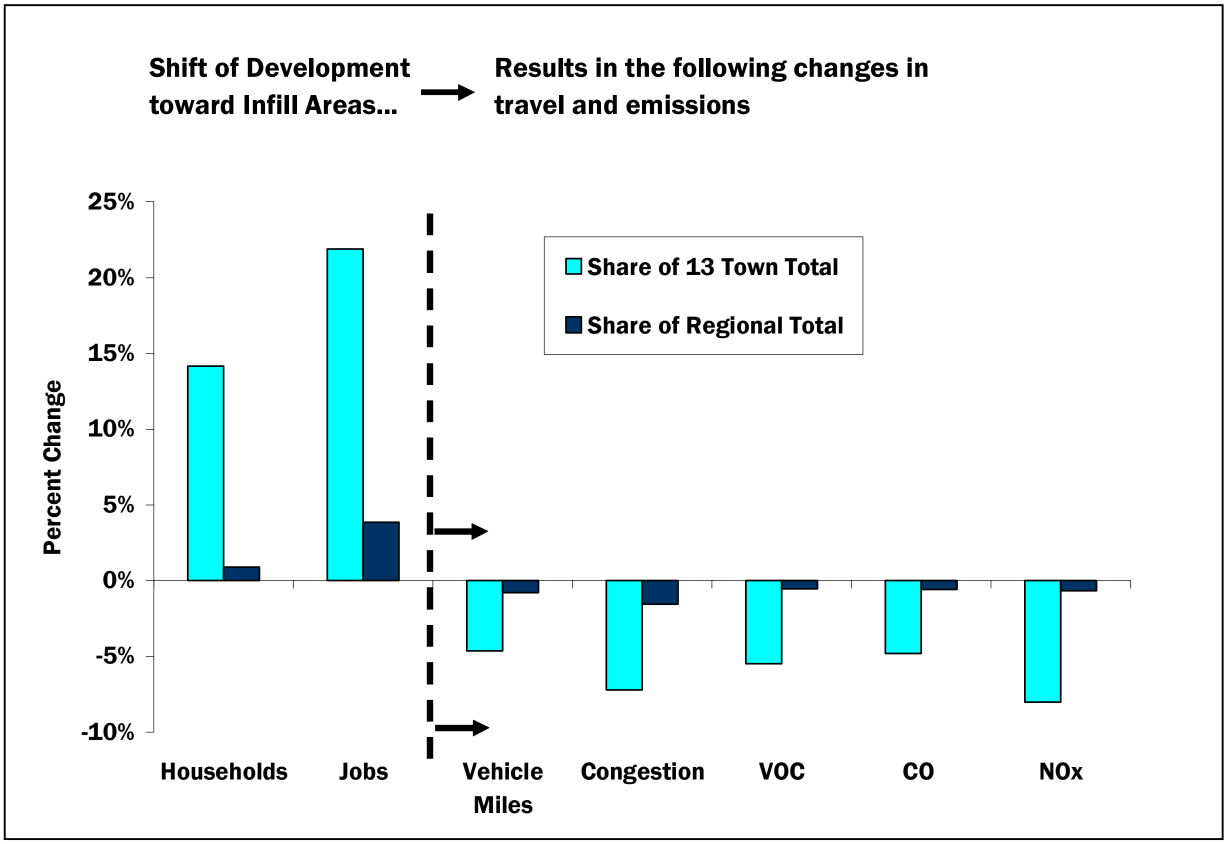
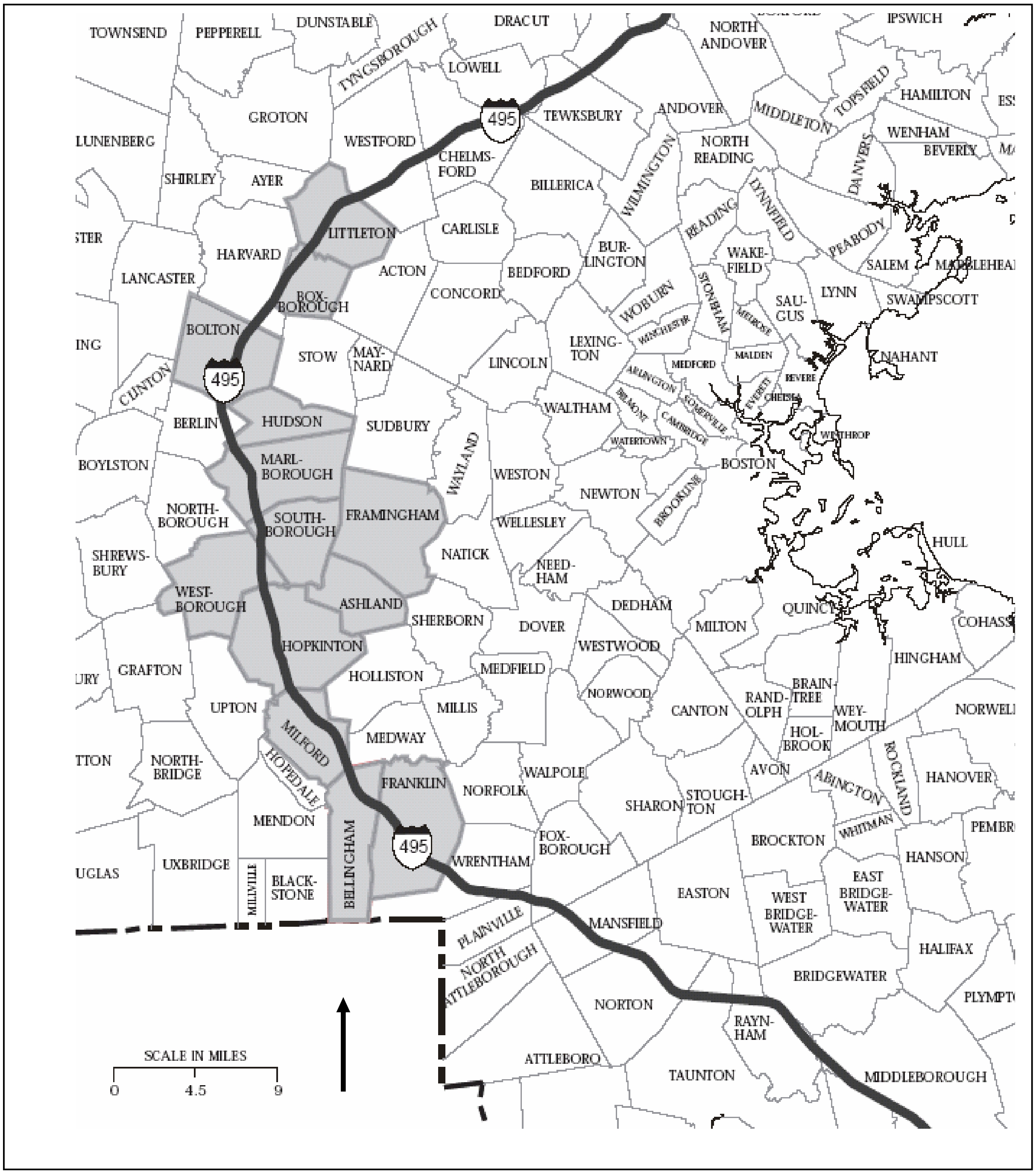


Figure 1.2 Towns in the Boston Case Study



Specific modifications to the region's travel demand model were required to examine the potential benefits. First, the model's traffic analysis zones were redrawn to significantly increase the level of detail (from 54 zones to 137 zones). This change was critical to capturing the effect of moving development to town center locations. The previous zones often grouped these suburban centers and their surrounding town areas into the same zone. The staff also developed a *mixed-use index* indicator to better capture the travel demand impact of co-locating houses, jobs, shopping, and entertainment. This variable was intended to reflect how modest changes in the convenience of daily activities can substantially increase the share of trips made on foot or transit rather than by car. However, the changes in vehicle travel primarily reflect a shift toward shorter car trips rather than substantial increases in walking or transit use. This is not surprising given that the infill projects in the corridor were still surrounded by predominantly low density communities with limited transit services.

1.1.2 Denver

Analysts at the Denver Regional Council of Governments (DRCOG) examined three land use scenarios. The scenarios evaluated differences in driving, congestion, and emissions over a 30 year timeframe. The first extended current development trends, with a majority of new homes and employment widely dispersed across suburban locations. The second focused development into 31 mixed-use centers. The third focused development into 10 higher-density mixed-use centers (Figure 1.3). It is important to note that both alternative development scenarios assumed substantial infill in suburban locations. Together these two alternative scenarios would shift about 7 percent of all households and 9 percent of all jobs into more compact areas.

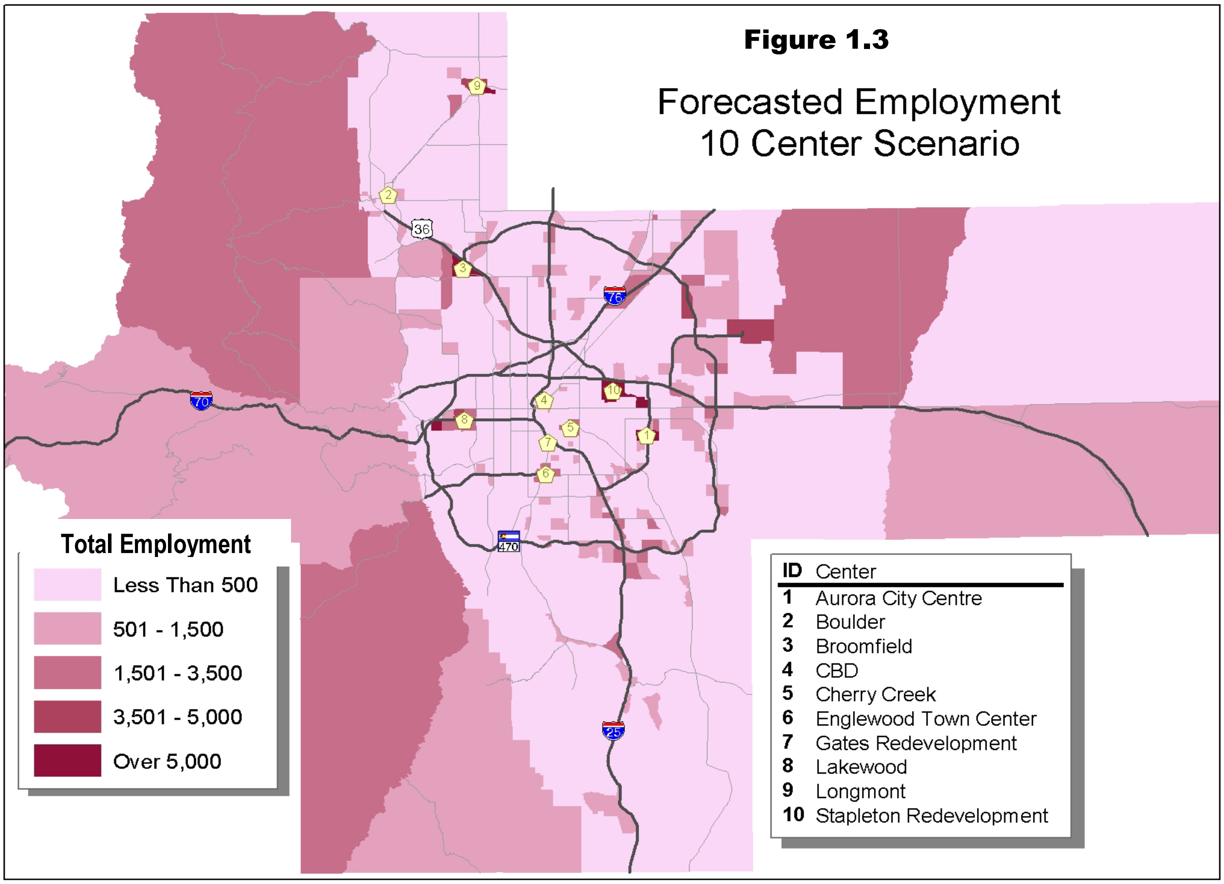
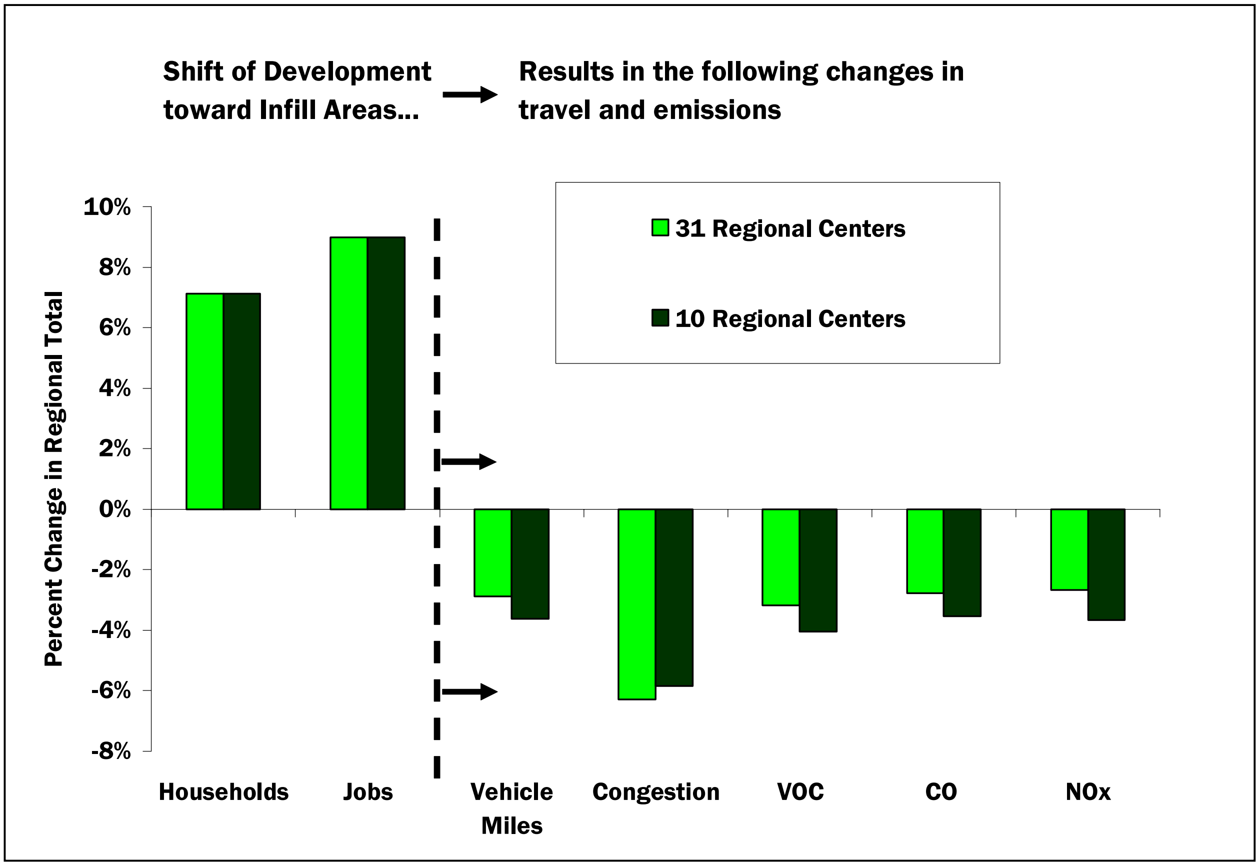


Figure 1.3

Forecasted Employment
10 Center Scenario

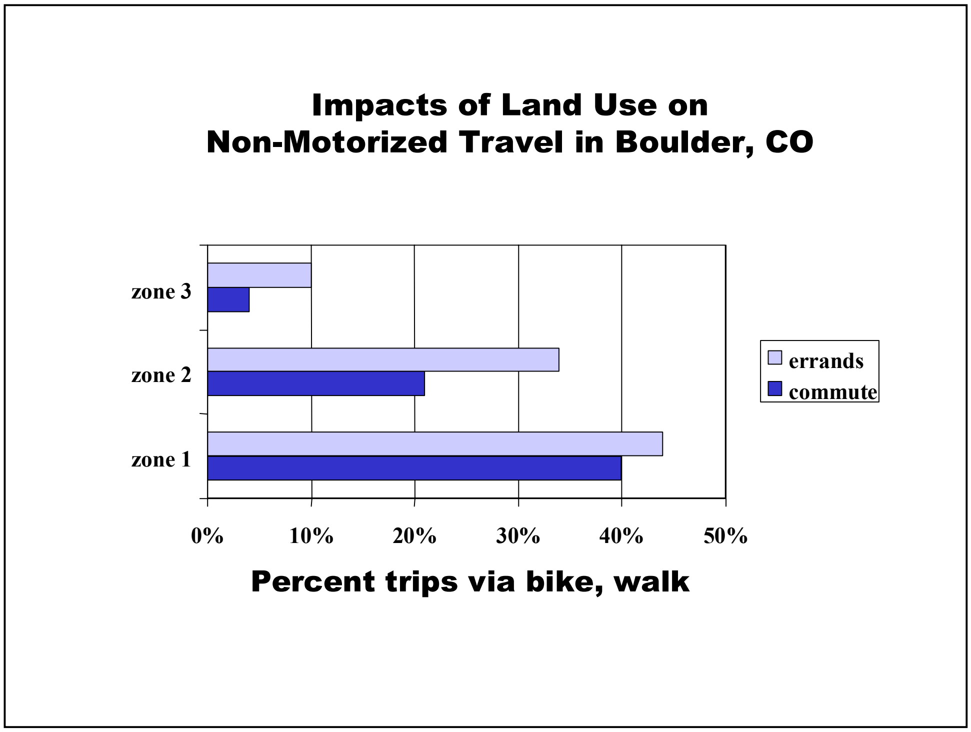
When the travel demand model was run, they showed focusing development could substantially reduce travel at a regional scale. The *31-Center* approach could reduce driving by more than 2.7 million miles per day, about 3 percent of the regional total. Focusing new growth into a smaller number of high-density centers – the *10-Center* scenario - would reduce the daily vehicle travel in the region by 3.6 percent. In both cases, more focused development lowered congestion and raised average travel speeds compared to the trend scenario. Both scenarios would also increase the share of transit trips – by more than 11 percent in the *10-Center* scenario. The changes in vehicle travel from the scenarios were also applied to a regional emissions model that estimated reductions in VOC, NOx, and CO emissions by 3 percent to 4 percent (Figure 1.4).

Figure 1.4 –Reductions from Focused Redevelopment in Regional Mixed Use Centers



The Denver analysis also relied upon modifications to the existing regional travel demand model. First, better estimation of non-work trips was achieved by more accurately representing the attractors of such travel, such as retail centers and major institutions. Second, the original model limited mode choice to car or transit and did not incorporate walking to bike trips. Since a greater share of trips made on foot or by bike is a primary way that infill development reduces driving, this modification of the model was critical. Adjustments to the mode choice component of the travel demand model were tested in a portion of the DRCOG modeling area - Boulder County. Staff divided the county into three zones – from least to most friendly for bicycling or walking. Travel records for these areas were examined in detail. In Zone 1, people walked or bicycled for 40 percent of commuting trips and about 44 percent of errands run from home. At the other end of the spectrum, in Zone 3, just 4 percent of commuting trips and 10 percent of errand trips were via foot or bicycle (see Figure 1.5). Based on the relationship between key land use characteristics in these three zones and rates of walking and biking, the team calculated adjustment factors for the rest of the region's zones.

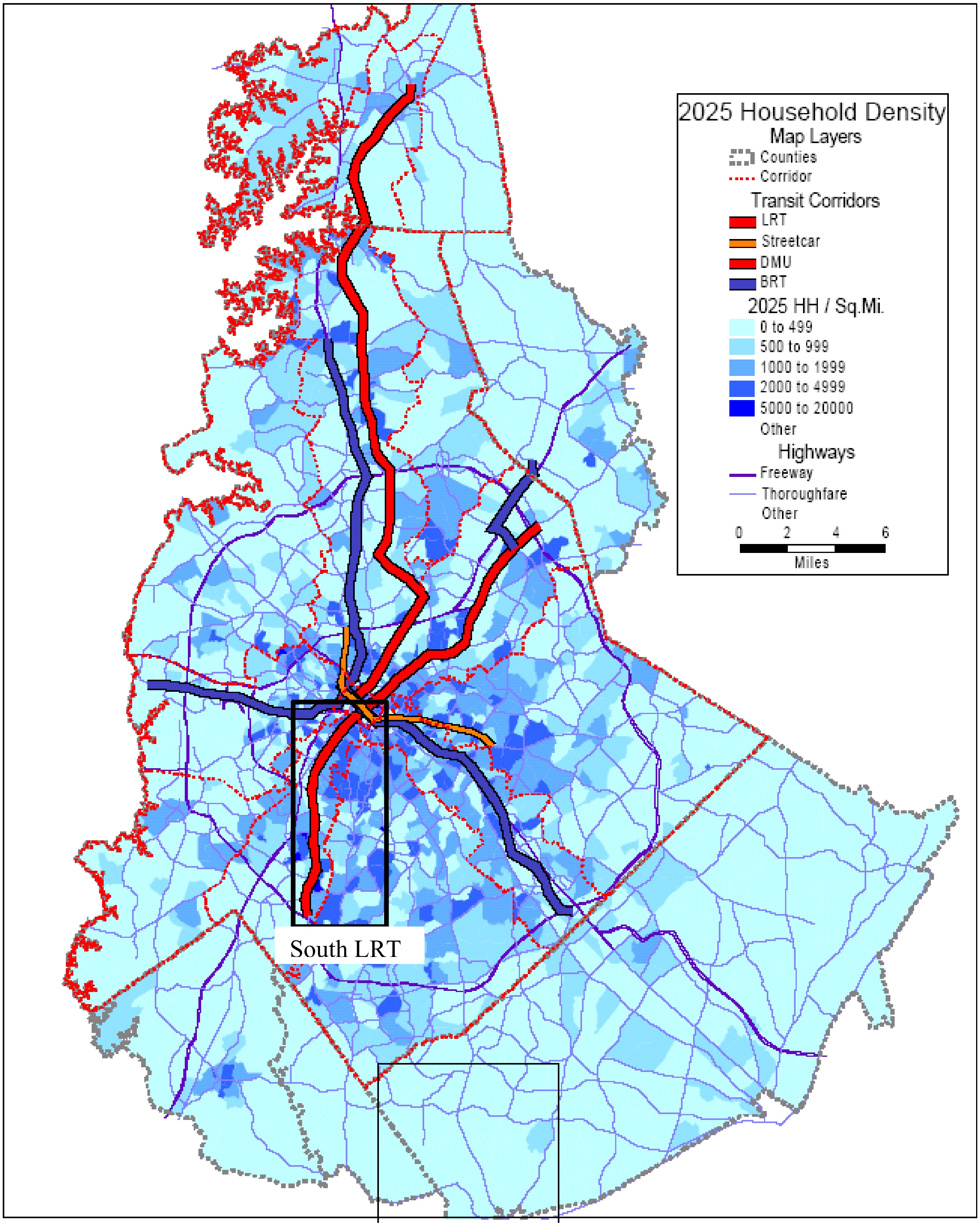
Figure 1.5 - Impact of Land Use on Non-Motorized Travel in Boulder, CO



1.1.3 Charlotte

A third case study was conducted by the city of Charlotte, which also maintains a regional travel demand model. While Denver and Boston each assumed the transportation infrastructure would essentially stay the same, Charlotte wanted to examine the transportation impacts of infill development in relation to their proposed light-rail system. The city conducted its analysis while the South Corridor was still in the planning stages. The project has since moved forward and the rail line is scheduled to open in the Fall of 2007.

Figure 1.6 - Charlotte Transit Corridors with Study Area



Charlotte looked at four scenarios. The *Baseline* assumed no rail line and a continuation of current development trends. The *Transit* scenario assumed the light-rail line would be built, but with no change in current development patterns. The *Transit-Station Infill* scenario projected building light rail and concentrating more development around the 12 station areas in the South Corridor. Finally, the *Transit-Station Infill-Road Improvement* scenario also added improvements to the street network around the station areas. The two infill scenarios assumed that about 4 percent of households in the region would eventually be shifted into the South Corridor, tripling the number of households in the areas surrounding the new light-rail stations. Under these scenarios, a much smaller share of regional employment would be redirected to station areas, but amount of business activity near the stations would still increase by about 50 percent.

Evaluating four scenarios provided an opportunity to isolate the impact of each on vehicle travel, congestion and emissions in the region. The analysis separately measured the impact of: 1) simply adding transit, 2) adding transit and changing land use patterns, and 3) making street improvements near the station areas to accommodate the new development. The model also measured the impact at three different geographic scales: the immediate vicinity of the stations, the entire South Corridor, and throughout Mecklenburg County.

Organizing the scenarios in this manner highlighted important results. For example, adding the rail line without making land use changes would increase transit use in the corridor (1,000 trips per day), but only have modest impact on vehicle travel at the county level. However, when combined with infill development, transit ridership jumped by more than 7,000 trips per day and reduced overall travel in the county by 2 percent (Figure 1.7). On the other hand, moving a significant number of homes and jobs to the station areas did increase vehicle travel and congestion at the neighborhood level (10 to 15 percent). Therefore, the fourth scenario examined whether making road improvements in the station areas mitigated these impacts. In short, the road improvements further increased vehicle travel, but mitigated the localized congestion that accompanied the infill development. This produced slightly lower emissions relative to station area development without local road improvements.

The changes in emissions followed a similar pattern. The biggest emission reductions came from supporting infill development around the rail stations. While the two infill scenarios slightly increased emissions within the corridor, they significantly reduced emissions at the regional level (See Figure 1.8). Since the precursor emissions responsible for ozone pollution (VOC and NOx) are generally not harmful until they combine in the atmosphere, the county emissions total is outcome measure with the most direct implications for public health. Further, making road improvements along with the station area development substantially offsets the local increase in congestion and emissions.

Figure 1.7 Emission Reductions in Charlotte

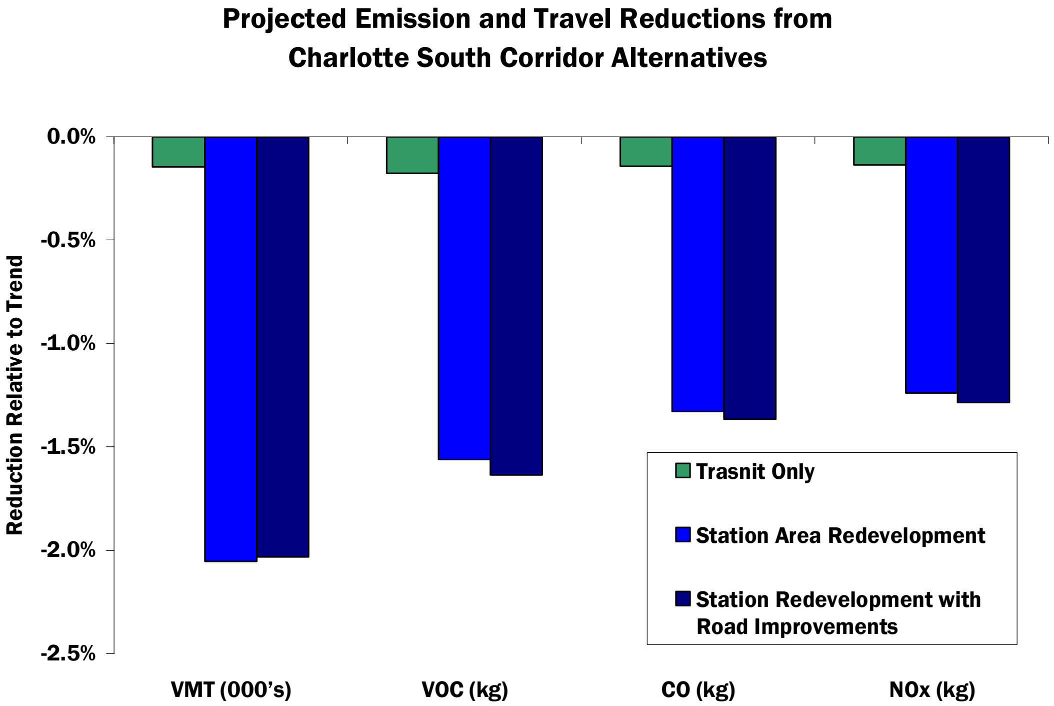
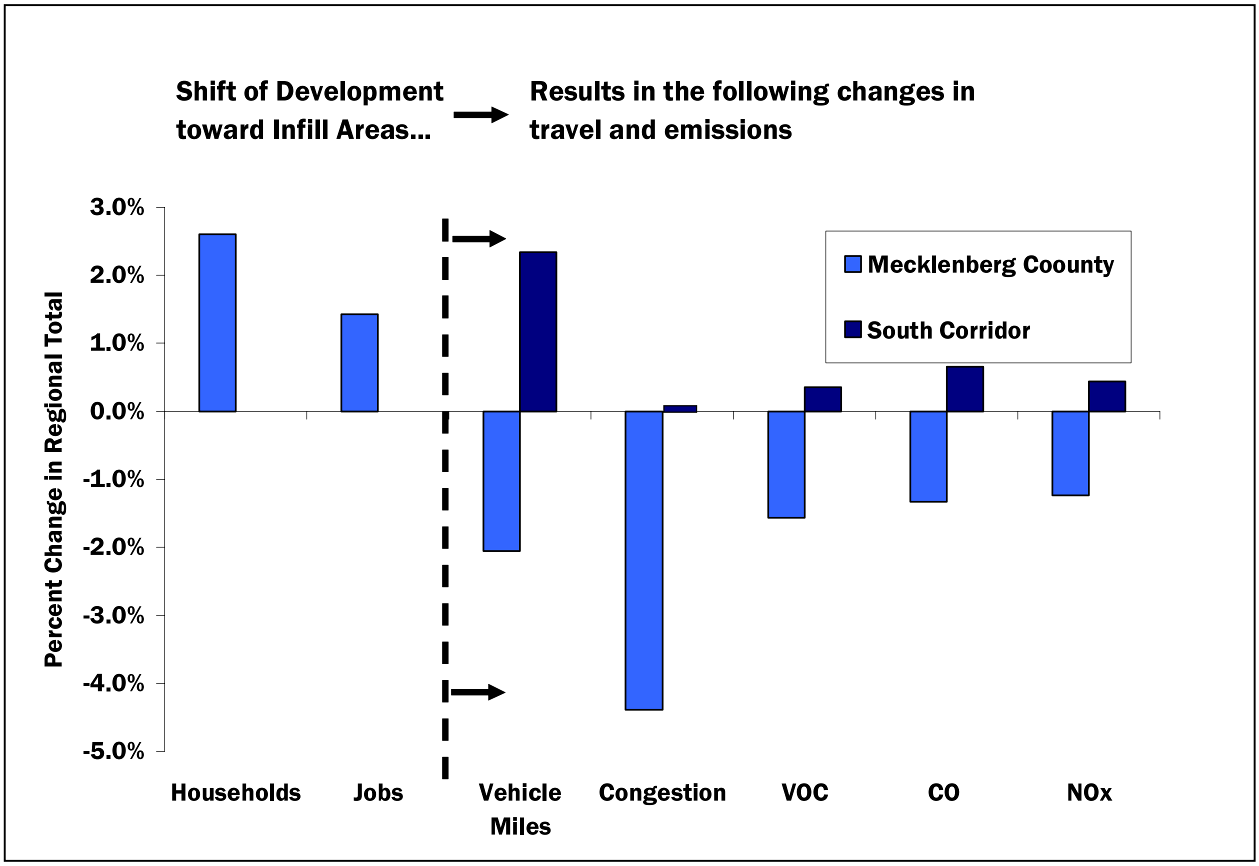


Figure 1.8 – More Travel and Emissions in Corridor Offset by Regional Benefits



Previous Studies and Guidance - *The Atlantic Station Project (Atlanta, GA)*

EPA first examined the potential air quality benefits of infill development for the proposed 135-acre Atlantic Station project in downtown Atlanta. A bridge was needed to connect the development with a nearby MARTA rail station. However, due to air quality constraints, the regional transportation agency could not add the bridge to its capital construction plan. Before the project could move forward, the transportation agency had to demonstrate the net gains in air quality it would produce.

EPA's analysis compared the emissions impacts of the new development to the same number of homes and jobs located on typical sites in suburban jurisdictions. The analysis found that developing the abandoned Atlantic Steel site would substantially reduce driving relative to alternative sites on previously undeveloped land. Shorter car trips alone were estimated to reduce overall vehicle travel by 14 to 50 percent. Additionally, if the new community were designed to encourage bicycling, walking, and transit, driving would be reduced another 5 percent. These changes were then coupled with a regional emissions model to quantify the reductions in key pollutants. As a result of this analysis, the development was designated a Transportation Control Measure in the region's air quality plan. EPA has since issued the following guidance on methodologies communities can use to document the air quality benefits of infill development:

Comparing Methodologies to Assess Transportation and Air Quality Impacts of Brownfield and Infill Development, EPA-231-R-01-001

Granting Air Quality Credit for Land Use Measures:
Policy Options, EPA SR99-09-01

1.2 Key Findings

The three case studies demonstrate - across a range of scenarios and regional contexts - that redirecting development to more walkable, transit accessible areas reduces driving and emissions. Shifting 5 to 10 percent of a region's homes and jobs to infill locations was estimated to produce 2 to 5 percent less vehicle travel and a 3 to 8 percent reduction in emissions (Figure 1.9).

The majority of the reductions were due to shorter vehicle trips. While this is a key finding consistent with previous studies, it also reflects a weakness shared by the three analyses. In spite of modifications, the travel demand models still did not have the ability to examine how good site location and design might increase rates of walking and biking. For example, the Charlotte model was only able to consider personal vehicles and transit as travel modes. Although a mixed-use and mode choice analysis was conducted in Boston, it was not included in the final results. These are important analytical shortcomings since research[4] shows that community design significantly influences the amount of bicycling and walking. Therefore, the

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[4] *Land Use and Site Design: Traveler Response to Transportation System Changes,* TCRP Report 95 Chapter 15

VMT reductions and emissions benefits documented in this project are most likely underestimated.

On the other hand, the project did demonstrate how regions can use existing tools to measure the relationship between redevelopment and air quality. The travel demand models remain limited in their ability to account for small scale changes to the built environment. However, modifications to the models can help mitigate some of these problems. Communities interested in using existing models should consider:

- Smaller zone sizes for analysis in order to capture intrazonal trips at a finer land use scale
- Adjusting mode choice models to capture for increased walking and cycling
- Using indices to represent the degree of mixed use and its impact on travel patterns
- Estimating emissions by number of trips as well as by distance traveled

This report shows that directing new growth into reclaimed brownfield and infill sites can help meet their need for growth while addressing regional air quality issues. While still limited, existing transportation planning tools can help quantify the potential impact of these changes. This is an important step in allowing decision makers to choose the best course for the future of their region.

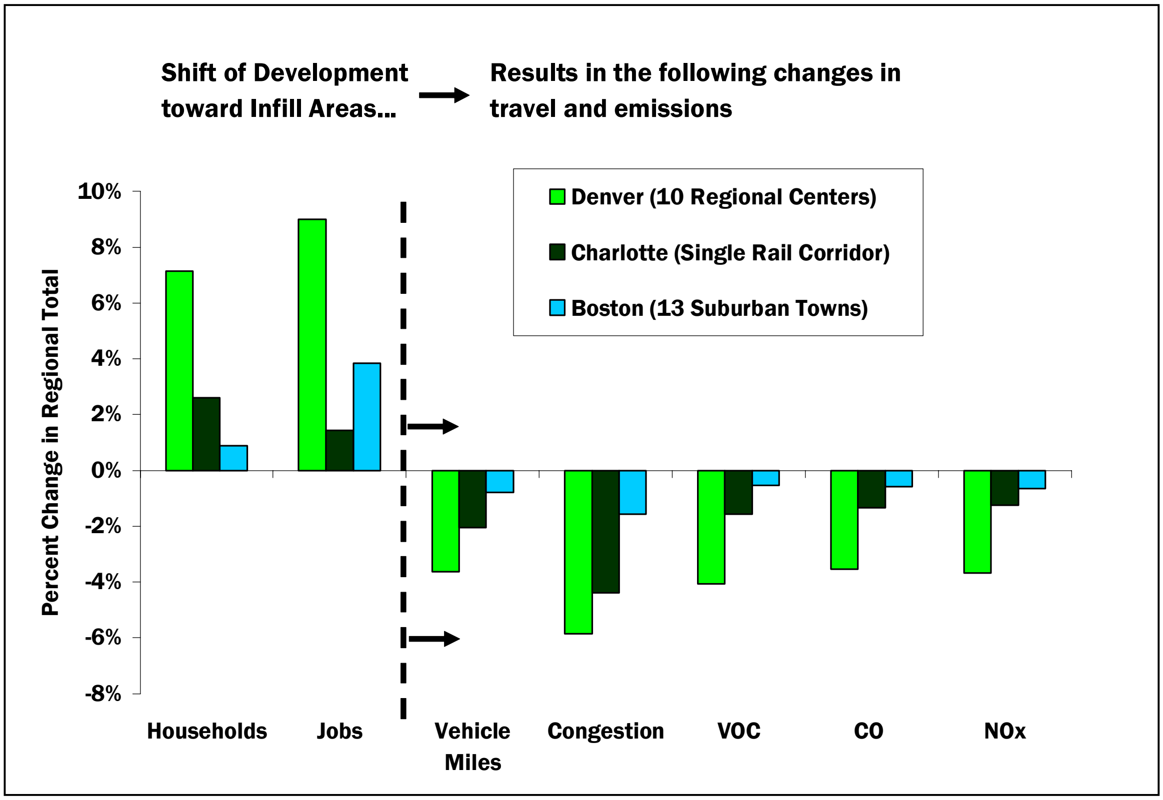

Figure 1.9 – The Effect on Travel and Emissions from Shifting Development to Infill Sites

2.0 Study Design: Lessons Learned

While the MPOs in this study had a variety of objectives, they shared a common purpose - to better capture the benefits of brownfield and infill development. Each had sketched out plans for quantifying the impacts of alternative land use patterns. However, they differed in the scale and context for their analysis.

- Boston - Examined a small part of the metropolitan area to test the impact of local redevelopment on the region as a whole
- Denver – Modeled region-wide shifts in development to see how redirecting growth toward key regional mixed use centers compared with the current pattern of unfocused growth
- Charlotte - Examined the impact of infill development around the station areas of a proposed light rail corridor

They also made different assumptions about their regional transportation systems. Boston and Denver assumed no changes to the system, even though shifting land use patterns often create pressure for road capacity expansion. Based on these simplified assumptions, neither study was able to estimate the secondary effect of changes in transportation supply associated with alternative development patterns. In contrast, the Charlotte analyses examined the effects of changes in both the transit and street networks associated with the proposed land use scenarios.

2.1 Limitations of Traditional Travel Demand Models

All three of the partner communities use traditional four-step models, but have incorporated some features not typically found in other regions. For example, each considers the feedbacks between the transportation network and regional land use patterns. They also take some steps to consider the impact of land use patterns on travel behavior. Even with such modifications, the four-step approach still has some important limitations when evaluating the travel demand impacts of infill development.

The follow sections discuss these specific limitations. However, before discussing the critiques in detail, it is important to first describe the basic components that make up a traditional travel demand forecasting models:

1. **Trip generation** – The number of person trips by purpose generated in each traffic analysis zone. Estimated based on the amount of activity in each zone, defined by population, households, and employment.

2. **Trip distribution** – The trips generated from each zone in step 1 are distributed to create person trips from origins to destinations. They are often segmented by travel purpose (e.g. work vs. non-work trips).

3. **Mode choice** – The trip tables estimated in step 2 are split into different travel modes based on the characteristics of the trip (purpose, distance, etc.).

4. **Trip assignment** – The vehicle and transit trips resulting from the mode choice model are loaded onto the highway and transit networks to produce volumes on roadways and transit ridership estimates. Walking and bicycle trips are seldom modeled directly.

2.1.1 Aggregate nature of models

Because the four-step process was conceived at a time when computers were much less powerful, it was necessary to simplify the way in which urban areas were modeled. One simplification was the aggregation of regions into traffic analysis zones (TAZ). With a few exceptions, all estimated travel is based on the average characteristics for each TAZ. Trips may begin or end at different points within a zone, but are tied to the same average land use and household characteristics. This introduces an aggregation error into the model. Over the years, as computing capabilities increased, models were able to have a much greater number of zones, diminishing—although not eliminating—the effect of aggregation error. Currently, a typical modeling region may consist of several hundred zones or several thousand zones in a larger metro area.

The treatment of trips that stay within a single zone is one key issue where using TAZs as the basis for analysis becomes a critical limitation. Since intra-zonal trips cannot be assigned to a traditional model's transportation network, the system is calibrated so travel within a TAZ matches observations in the baseline year. In scenarios where land use patterns become significantly more concentrated, this calibration will probably underestimate intrazonal travel.

The necessary aggregation of trip end locations into zones also has implications for the type of analysis required for this project. Any concentrated development scenario must be represented by the same zone system as in the baseline scenario. Therefore, if new development were concentrated in zone near a transit station, the model results would still be based on the assumption that growth was spread evenly throughout the zone. However, in the Boston analysis, MAPC and CTPS recognized the constraints of the zone system used in their model and developed a more fine grain set of zones for the 13 towns. This reduced the aggregation error associated with the analysis.

2.1.2 Non-motorized travel

Most travel models in the U.S. do not consider travel by non-motorized modes such as walking and bicycling. The major outputs of models typically include traffic volume and speeds along major roads. Many also include ridership on transit systems. Non-motorized travel historically has played a much smaller role if considered at all. This is due in large part to the difficulty of obtaining empirical information on the amount of non-motorized travel.

Recently there has been more interest in modeling non-motorized travel. This is particularly important for this analysis since concentrated infill development is likely to produce more frequent and shorter trips were walking or bicycling is more feasible. However, among the three models in this analysis, only Boston's currently considers non-motorized trips.

2.1.3 Trip chaining and tour based modeling

One major criticism of the trip-based model is that many trips are actually part of a larger journey. Essentially, stops are treated as independent decisions rather than linked to the overall purpose of the tour. Additionally, while non-home based trips are generated by four step models, their frequency is based on household characteristics. Overall these structural features make it difficult to examine how more accessible land use patterns might reduce vehicle travel. Such changes may lead to more efficient trip-chaining by car or greater use of transit because of the ability to accomplish tasks on the way to or from the station.

In recent years a few urban areas have developed tour based models, which explicitly model the formation of tours and can be responsive to the effects of land use patterns on trip chaining. However, none of three partner communities has a tour based model.

2.2 Emissions Analysis Issues

Two issues are particularly important to appropriately estimating emission impacts. As discussed above, the degree to which travel demand analysis is sensitive to the characteristics that define good infill development is critical for emissions analysis. Additionally, how the emissions analysis takes advantage of the additional capabilities incorporated into MOBILE6 model is important. While MOBILE6[5] was used in all three of the analyses, there were differences in its application. The details are described under each case in the technical appendix. A section specifically addressing the benefits of using MOBILE6 rather than MOBILE5 is also included. Staff from Cambridge Systematics and Industrial Economics worked with the participating organizations to describe potential approaches. In particular, they discussed how current standard procedures use in the region could be enhanced. The approaches described in the following subsections reflect the results of this technical assistance and coordination.

2.3 Evaluation Measures

The scenarios analyzed and the analytical procedures used by the three partner communities all involve the use of regional travel demand models and EPA's MOBILE6 emissions estimation software. A variety of measures can be obtained from these procedures that are relevant to the estimation of the effects of brownfield development. These include measures of the *amount of travel*, the quality of *transportation level of service*, and the *environmental impacts* related to emissions.

This section describes the evaluation measures used in each partner community. The general measures are the same for all three communities, but in some cases the agency was unable to provide some details. In all three cases the measures were computed for the whole region. Where the scenarios target specific subregions (in Boston and Charlotte), the measures are also presented for these subareas.

2.3.1 Measures of the Amount of Travel

Person trips – All of the scenarios examined in the three partner communities preserved the amount of development regionally; any growth moved to a specific area of concentration was "moved" or reallocated from somewhere else in the future trend scenario. However, under different development patterns, the total number of person trips could change. In addition, the amount of development and, therefore, the number of person trips in sub-areas may change. This occurred in Scenarios 3 and 4 in Charlotte, where some development was assumed to occur in station areas rather than outlying areas.

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[5] The initially released version of MOBILE6, now referred to as MOBILE6.0, incorporated capabilities only for CO, VOC, and NO_X emissions. EPA subsequently released draft MOBILE version 6.2 that incorporates particulate matter and air toxic emissions, and also a draft approach for estimating carbon dioxide, CO_2, emissions. The original MOBILE6.0 CO, VOC, and NOX capabilities remain unchanged in draft MOBILE6.2, and so these results are identical with both versions.

Average trip lengths – By definition, brownfields are located in areas that are already developed, and therefore developments in such areas will more likely be closer to potential travelers. Such locations include residences of employees, customers, and visitors to the developments. Comparing the average person trip lengths among alternative scenarios provides a means of quantifying the reduction in travel distance associated with developments that are located in such areas.

Vehicle-miles traveled – The total number of vehicle-miles traveled (VMT) is a standard measure of the amount of automobile and commercial vehicle travel consumed. Previous work has shown that infill redevelopment could result in lower VMT on aggregate and per capita than for a similar amount of development located away from current populations. This is due not only to the shorter average trip lengths associated with such scenarios, but also to the fact that brownfield sites are also more likely to be located near public transportation, which means that travelers to the development are more likely to have choices for travel. It should be noted that even with regionally lower trip lengths and automobile mode shares, there still may be increases in VMT in subareas where there is a greater amount of development under brownfields development scenarios.

Vehicle-hours traveled – The total number of vehicle-hours traveled (VHT) is another standard measure of the amount of vehicle travel. Brownfield/ infill redevelopment could result in lower VHT than for a similar amount of greenfields development. This is due not only to the lower VMT associated with such scenarios, as described above, but also potentially to the higher average speeds, which are discussed below. It should be noted that even if VMT declines and speeds increase in the region, there still may be increases in VHT in subareas where there is a greater amount of development under brownfields development scenarios.

Transit mode shares – The percentage of trips made by transit may change due to changes in land use patterns or changes in the transit or highway level of service. Comparing transit mode shares among alternative scenarios provides a way of measuring how well the scenario provides additional opportunities for persons to travel by means other than private auto.

Walk mode shares – The percentage of trips made by walking (and bicycling) may change due to changes in land use patterns or changes in the transit or highway level of service. Comparing walk mode shares among alternative scenarios provides a way of measuring how well the scenario provides additional opportunities for persons to travel by means other than private auto. Travel by walking and bicycling is not considered, and therefore cannot be estimated, by the travel models in Charlotte and Denver.

2.3.2 Measures of Transportation Level of Service

Average speed – If brownfield/infill development reduces VMT, the subsequent reductions in congestion could increase in vehicle speeds. The average speeds for each scenario are compared, where available, by roadway functional classification. It should be noted that in sub-areas where VMT increases under brownfield/infill development scenarios, there could be associated decreases in speeds. For this project, average speeds for a region or sub-area were computed as the VMT divided by the VHT.

Congestion – The amount of congestion is measured as the difference in the vehicle-hours traveled (VHT) under free-flow conditions and the VHT under congested conditions. One of the benefits of decreased VMT could be a reduction in levels of congestion.

2.3.3 Measures of Environmental Impacts

Emissions – The pollutants evaluated in each study are the three major categories computed by EPA's MOBILE6 model. Travel speeds and the vehicle fleet in a particular region both impact the emissions per mile of travel. MOBILE6 takes inputs from travel demand models and produces regional emissions. Outputs are produced for three pollutants:

- Volatile organic compounds (VOC);
- Carbon monoxide (CO); and
- Nitrogen oxides (NOx).

3.0 Comparison of Results

This section compares the results from the three case studies in terms of changes in the amount of travel, congestion and speeds, and emissions. The localized effects of additional development in specific areas and the potential for mitigation are also examined.

3.1 Land Use and Vehicle Miles Traveled

Since all three case studies dealt with the effects of concentrating growth in specific areas, the effects of the land use changes on the amount of travel in the three studies can be compared. Table 3.1 compares the amount of land use change in each case study. The Boston and Charlotte case studies each have one alternative pattern, while the Denver case study has two. The overall amount of development relocated in each Denver scenario is approximately the same, however, the degree of concentration differs (31 versus 10 regional centers) and alters the travel demand outcomes of the two alternate scenarios.

Table 3.1 – Magnitude of Land Use Change Under Each Scenario

	Boston		Charlotte	Denver
	13 Towns	**Entire Region**		
Percentage of Development Moved in Alternative Scenarios				
Households	14%	1%	4%	7%
Employment	22%	4%	1%	9%
Average change	17%	2%	3%	10%

The land use changes in Table 3.1 are expressed as the percentages of total households and employment that are reallocated from the trend scenario under each land use alternative. Because all of the land use changes in the Boston case study occurred within the 13 towns, it makes sense to present the Boston results in the context of the "13 Towns" area only. In Charlotte, development under the South Corridor alternative was shifted from areas growing under the trend scenario, and it makes sense to present the results as percentages of the entire region.

Table 3.1 summarizes the percentage of each region's jobs and homes relocated in the land use scenarios. The row labeled "average change" represents a weighted average of the growth rates for households and employment. The weights represent the relative contributions of households and employment centers to trip making in the trip generation models.

3.2 Congestion and Speed

Table 3.2 shows the estimated changes in the levels of congestion and average speeds for the three case studies. The increases in average speeds are modest for all of the case studies. This is dependent on both the differences among the regions transportation systems and the specific land use alternatives evaluated. The Denver results indicate that, despite large VMT reductions in the 10 regional center scenario, congestion is higher and speeds are a bit lower. Although the 31 center scenario does less to reduce overall travel, spreading development out across more infill locations reduces congestion at the sites. In Charlotte, congestion at the regional level is significantly reduced by concentrating more development around the rail stations. However, in the corridor itself, congestion levels do not change much as the increased share of trips made by transit is offset by a greater share of the region's trips being shifted to the area. In the Boston analysis, overall travel delays are reduced substantially in the 13 towns, but increase somewhat at a regional level.

3.3 Emissions

Table 3.2 shows the average emissions rates from the model runs. It is important to recognize that per mile rate will vary among the communities due to differences in average speeds, climatic conditions, vehicle fleet mixes and other factors that affect emissions. The rates in Table 3.3 represent the average rates per mile for the baseline condition; the rates for the other scenarios are similar to those for the baseline scenario.

Table 3.2 also shows that the emissions rates vary in several ways. The VOC rate in Boston is about 20 percent lower than in Charlotte and Denver, while Boston's NOx rate is about one third lower than those in Charlotte and Denver. Charlotte's rate for CO emissions is about half of the rate in Denver and two thirds of the rate in Boston.

Table 3.3 presents the estimated changes in emissions for the land use scenarios for the three case studies.

Table 3.2 Average Emissions Rates for Each Community (Base Case)

	Boston*	Charlotte	Denver
VMT (000's)	3,313	23,078	92,308
Emissions (kg)			
VOC	783	6,849	28,200
CO	30,615	136,263	1,018,200
NOx	661	6,614	28,200
Average Emissions Rate (g/mile)			
VOC	0.236	0.297	0.370
CO	9.241	5.904	10.922
NOx	0.200	0.287	0.322

* p.m. peak period and "13 Towns" area only

Table 3.3 Estimated Changes in Emissions for Each Community

	Boston*	Charlotte	Denver 31 Centers	Denver 10 Centers
Percentage of Development Moved	17%	3%	10%	10%
Change in VOC emissions	-5.5%	-1.4%	-3.2%	-4.0%
Change in CO emissions	-4.8%	-1.2%	-2.8%	-3.5%
Change in NOx emissions	-8.1%	-1.1%	-2.7%	-3.6%

* "13 Towns" area only

3.4 Effects of Increased Development in Specific Areas

All three of the case studies examined alternative land use patterns where growth would be concentrated in specific areas. These changes were compared to a baseline consistent with most recent trends. In effect, this implies that some parts of each region will have more development in the alternative land use scenarios than in the baseline. The result would be more trips to and from these areas, and possibly more congestion. The extent to which the increased development – and the associated trips – lead to more vehicle travel, congestion and emissions, will depend on the length of car trips and use of alternative modes. It is worthwhile to examine the types of localized impacts that might be introduced by the alternative land use patterns.

Although this type of analysis could be done using the results from any of the three partner communities, Charlotte is the best suited to illustrating the key issues:

- All of areas with more development in the alternative scenarios are located within a single corridor.
- As part of their analysis, Charlotte summarized the results for the corridor and station areas as well as the region.
- One of the scenarios tested included street network improvements designed to mitigate these localized effects. This was not done in the other two case studies.

All of the redirected development was focused on infill sites close to three stations in the South Corridor. (More detailed presentation of the analyses are presented in technical appendix C.) The 16,500 households reallocated in the alternative land use scenario nearly triples the number of people living near the station areas. However, the 10,500 jobs relocated near the rail stations increases total employment in the corridor more modestly, by about 50 percent.

Table 3.4 summarizes the model results for both the South Corridor and the Region. The tables reveal that while travel and emissions do increase in the Corridor, they are substantially less at a regional level. This result does reveal a tension between the local and regional impacts that such scenarios can produce. When substantially more development is focused around station areas there will also be an increase in vehicle travel, congestion and emissions in the local area. While road improvements

Table 3.5 demonstrates that at least some of the impacts of the increased development in the Station Areas can be mitigated to a certain extent. While the street network improvements implemented as part of Scenario 4 would increase VMT in the Station Areas even more than the increases due to the land use changes (probably by diverting additional through traffic), the percentage increases in emissions are lower than the percentage increases in VMT. The level of congestion in the corridor would drop to only six percent higher than the baseline condition, and average speeds would actually be higher than in the baseline scenario.

Table 3.4 Summary of Charlotte Results (Regional Total vs. Station Areas)

Measure	Scenario 1 Baseline	Scenario 2 Transit	Scenario 3 Development Around Transit	Scenario 4 Station Area Road Improvements
VMT (000's)				
Mecklenberg County	23,078	23,044	22,604	22,609
Station Areas	665	658	728	760
VOC (kg)				
Mecklenberg County	6,849	6,837	6,742	6,737
Station Areas	242	240	257	261
CO (kg)				
Mecklenberg County	136,263	136,069	134,451	134,402
Station Areas	4,496	4,452	4,762	4,932
NOx (kg)				
Mecklenberg County	6,614	6,605	6,532	6,529
Station Areas	207	205	217	225
Congestion (000s of VHT)				
Mecklenberg County	114	113	109	109
Station Areas	3.40	3.35	3.93	3.60
Average Speed (mph)				
Mecklenberg County	29.7	29.8	29.8	29.9
Station Areas	25.2	25.2	25.0	26.5
Transit Trips (000's)				
Mecklenberg County	139	145	150	150
Station Areas	2.9	3.9	10.0	10.0
Person Trips (000's)				
Mecklenberg County	4,156	4,156	4,156	4,156
Station Areas	89	89	185	185
Transit Share				
Mecklenberg County	3.4%	3.5%	3.6%	3.6%
Station Areas	3.3%	4.4%	5.4%	5.4%

Table 3.5 Summary of Differences between Baseline and Alternative Scenarios (Mecklenberg County)

Measure	Transit Only	Transit Plus Infill	Infill with Road Improv.
VMT	-0.1%	-2.1%	-2.0%
VOC	-0.2%	-1.6%	-1.6%
CO	-0.1%	-1.3%	-1.4%
NOx	-0.1%	-1.2%	-1.3%
Congestion	-0.9%	-4.4%	-4.4%
Average Speed	0.3%	0.3%	0.7%
Transit Trips	4.3%	7.9%	7.9%
Transit Share	2.9%	5.9%	5.9%

3.5 Conclusions and Implications

The results of this project demonstrate that land use patterns involving infill and the redevelopment of brownfield areas provide regional transportation and environmental benefits, specifically reductions in vehicular distances traveled and congestion as well as emissions from vehicles. This section summarizes the conclusions and discusses the implications of these conclusions in the context of implementation.

3.5.1 Reductions in Vehicle Travel and Emissions

All three case studies indicated that the amount of regional VMT (aggregate and per capita) can be lowered by concentrating future development in infill areas, closer to trip destinations and public transit, as compared to conventional suburban development patterns. Although it is not possible to make general statements about these reductions based on three specific case studies, it is clear that for these three regions, concentration of future development into specific areas results in substantial reductions in regional vehicle-miles traveled (VMT), and that greater amounts of travel reduction occur if more development is concentrated in these areas. In these case studies the reductions in VMT within the areas within which development was moved were in the two to five percent range. Importantly, these reductions in VMT result exclusively from reductions in trip lengths, not from reductions in trip-making. In other words, travelers are satisfying their mobility goals with fewer motorized miles.

The reductions in VMT lead to several related benefits. Both vehicle emissions and congestion are reduced. Emissions reductions in these case studies ranged from three to eight percent regionally (somewhat less in Charlotte where the land use changes were concentrated in a single corridor of the region). Overall, congestion decreased by five to seven percent in these case studies.

The Charlotte case study shows that the amount of vehicle distances traveled (and therefore congestion and emissions) can be decreased further by coordinating the land use concentration with good transit service. Because all of the development relative to the base scenario was moved to light rail station areas in the Charlotte case study, additional opportunities to reduce vehicle travel existed.

It is important to recognize that while the types of policies analyzed in this project show clear benefits regionally, those benefits are not uniformly distributed across the region. Areas where development is concentrated can experience increased total (although lower per capita) vehicular travel, congestion, and/or emissions, presenting a challenge that may require additional transportation improvements to mitigate these local impacts. Based on the results of the Charlotte case study, it was possible to at least partially mitigate these increases through targeted street network improvements in the areas where development would be concentrated.

3.5.2 Use and Limitations of Travel Demand Models

The state-of-the-practice travel demand models used in the three case study analyses demonstrate that conventional models are useful in analyzing the effects of brownfield and infill development on vehicle travel and emissions. This is particularly true when the models are used to examine alternative land use scenarios; for the most part, transportation planning studies in urban areas assume only a single fixed land use scenario. However, there are several limitations with conventional modeling. These include the following:

- The necessity of using aggregate analysis zones, which do not allow the analysis of different land use patterns within a zone, and limit the ability to analyze intrazonal trips.
- The lack of specific variables to examine the effects of higher density mixed use developments.
- The lack of ability to analyze non-motorized travel (except in the Boston analysis), which would likely increase under scenarios with more concentrated land use patterns.
- The lack of ability to model trip chaining, which might increase under scenarios with more concentrated land use patterns.

The effect of these limitations, though, can be minimized through the implementation of one or more enhancements, as demonstrated in each of the three pilot communities. These include the use of smaller zone sizes, consideration of non-motorized travel, use of intrazonal VMT adjustment factors, and calculation of mixed land use indices. In addition, the use of a trip-based emissions estimation procedure, rather than one based simply on VMT changes, captures emission impacts associated with the changes in trip length that occur with brownfield and infill development strategies.

While even enhanced conventional state-of-the-practice model systems may not be inherently as good as newer and more specialized alternatives, they nonetheless represent the capabilities that currently are used by nearly all MPOs and state DOTs. Consequently, they represent a good presently available approach for evaluating the impacts of a mix of land use and transportation strategies. Based on the experience of working with these three pilot communities, the conclusion is that application of these methodologies sufficiently captures the impacts of regional brownfield and infill policies to permit the results to be incorporated into transportation and air quality decision-making.

3.5.3 Relative Contribution of Land Use Strategies

Compared to other air pollution control and transportation strategies, land use policies appear to offer a way to reduce emissions. For example, in Boston the estimated 239,000 mile reduction in vehicle travel associated with the concentrated development scenario is greater than the reductions estimated for most of the transit projects outlined in the Regional Transportation Plan.[6] While this represents less than one percent of the mobile source VOC, NOx, and CO emissions budgets for the entire region, it reflects only land use changes in 13 of the 101 cities and towns in the region.

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[6] *Regional Transportation Plan 2004-2005 of the Boston Region MPO*, Prepared by the Central Transportation Planning Staff for the Boston Metropolitan Planning Organization, September 11, 2003.

3.5.4 Future Research Needs

As discussed throughout this report, the currently available models make several simplifications about changes in travel behavior. Additional research is needed to expand the application of four-step travel models to evaluate urban infill development. Specifically, enhancements are needed to improve methodologies for estimating non-motorized trips and accounting for changes in the number and average trip length as a function of changes in the mix of development and density. Other areas of future research that would be useful in validating the results of these case studies include trip generation rate changes, changes in trip balancing procedures, and trip table factoring. Furthermore, development of a mixed-use index based on empirical research would also be valuable.

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Detailed Technical Appendices

Appendix A - Boston

Background

The Metropolitan Area Planning Council (MAPC) and the staff of the Boston MPO tested the impact of different development patterns in 13 communities in an arc along the I-495 corridor. Some of the questions the community wanted to answer include the following:

- Should development be in community centers or along I-495?
- What is the impact of mixed used development on future transportation infrastructure?

The project ran two scenarios - one based on current development patterns, the other based on concentrating development in town centers or I-495 interchanges. Both scenarios projected the same amount of employment and household growth, with the concentrated growth scenario moving about 14 percent of households and 22 percent of employees into more compact developments.

The traditional four-step model was modified by disaggregating the existing 54 zones into 137 zones, and also used the MOBILE6 model to calculate emissions estimates. It focused on peak travel and assumed the same transportation and highway improvements for each scenario.

The transportation and air quality impacts of current development patterns were compared to those that could result from an alternative land use scenario. The analysis quantified congestion impacts, vehicle miles traveled (VMT), vehicle delays, and commuter rail use.

The 13 communities in the study area were chosen according to three criteria:

- They are in the I-495 corridor, which has the highest growth rate and largest amount of developable land in the region.
- They represent the three subregions in the corridor.
- They include the area considering formation of a new transit authority.

The 13 towns are projected to grow to a total population of 334,681 over the next 25 years. This represents a projected 127,174 households. The forecasted employment for 2025 is 465,792. There was no attempt by MAPC and CTPS to balance the growth in households and employment. It turns out that the *trend* scenario assumed a higher growth rate for employment (about 35 percent) than for households (about 15 percent). This resulted in the population estimate being close to the 2025 MAPC forecast, but the employment being higher than the forecast. The imbalance was not reconciled, and the transportation model had to account for the imbalance by assuming a higher rate of trips produced outside the MAPC region attracted to communities within the region, including the 13 communities in this study.

The concept of *trend* was introduced by MAPC to determine the effects of the maximum amount of development allowable under current regulations. While *trend* is not necessarily associated with any particular forecast year, the analyses performed for this project was generally assumed the towns would develop available parcels by 2025. Buildout analyses have been done for most of the MAPC communities. This pilot study was intended to determine the effects of alternative development patterns on transportation. Although an additional scenario using projections based on historical development patterns would have been useful, resource constraints did not allow for this analysis.

Two scenarios were analyzed. Thee *trend* scenario, representing the maximum allowable development under current zoning. Scenario 2 concentrated development in existing town centers or near I-495 interchanges. MAPC staff developed this scenario manually by selecting available infill sites that could accommodate the redirected growth. Examples of the alternative sites in scenario 2 included the Ashland Center brownfield site, infill development in Hopkinton Center, and additional development in the western section of Hudson. Scenario 2 also included some redevelopment of sites with a current active land use. The amount of employment and households by type was held constant between the two scenarios for each community. Under Scenario 2 about 18,000 (14 percent) of the households and about 102,000 (22 percent) employees in the 13 towns were moved relative to Scenario 1.

Detailed Results

Tables A.1 and A.2 present the results for two geographic areas. The first area is the entire metropolitan Boston region as modeled by the Metropolitan Area Planning Council (MAPC) and the Central Transportation Planning Staff (CTPS). The second area is the "13 Towns" area, which consists of those towns where development was redistributed under Scenario 2. When reviewing these results, it should be noted that while growth is redistributed, the total amount of development within the 13 Towns area is held constant for both scenarios. The analysis was performed only for the p.m. peak period. Information on person, transit, and walk trips and on average trip lengths was provided only for the 13 Towns area.

According to the results shown in Table A.2 for the 13 towns, the land use pattern under Scenario 2 would result in significant reductions in VMT, emissions, and congestion, on the order of five to 10 percent, while speeds would increase. Regionally, the reductions in VMT, emissions, and congestion would be on the order of 0.5 to 1.6 percent. This is quite large, given that the 13 Towns area accounts for only 10 percent of regional travel.

Within the 13 towns, 14 percent of the households and 25 percent of the employment were relocated under Scenario 2. This represented about half of the growth in households and about 15 percent of the growth in employment from the base year to 2025.

Table A.1. Analysis Results for Boston (p.m. peak period)

Measure	Area	Scenario 1 Trend	Scenario 2 Focused Development
VMT (000's)	Entire Model	30,577	30,338
	13 Towns	3,313	3,159
VHT (000's)	Entire Model	1,315	1,300
	13 Towns	154	145
VOC (kg)	Entire Model	6,329	6,295
	13 Towns	783	740
CO(kg)	Entire Model	294,836	293,089
	13 Towns	30,615	29,149
NOx (kg)	Entire Model	5,871	5,832
	13 Towns	661	608
Congestion (000s of VHT)	Entire Model	565.41	556.59
	13 Towns	77.93	72.29
Average Speed (mph)	Entire Model	23.20	23.34
	13 Towns	21.50	21.76
Person Trips (000's)	Entire Model	n/a	n/a
	13 Towns	654	654
Transit Share	Entire Model	n/a	n/a
	13 Towns	0.22%	0.23%
Walk Share	Entire Model	n/a	n/a
	13 Towns	6.21%	7.37%
Avg. Trip Length (miles)	Entire Model	n/a	n/a
	13 Towns	14.95	14.30

Scenario Definitions:

1. Base - trend for all towns
2. Concentrated redevelopment in 13 towns

It can be concluded from the Boston analysis that the redistribution of development in concentrated areas has significant benefits in terms of reduced vehicular travel, decreases in emissions, and improved congestion levels. The reduced vehicular travel is a result of shorter trip lengths and mode shifts from auto to transit and walking. The benefits of having fewer and shorter trips are noticeable not only in the areas where the development is redistributed, but also regionally. Within the 13 Towns area the reductions in VMT, congestion, and emissions and the increase in transit share are all on the order of five to eight percent. Regionally, these effects are on the order of one to two percent although it should be noted that in most cases the benefits extend beyond the boundaries of the 13 towns.

Table A.2. Difference between Boston Scenarios

Measure	Area	Scenario 2 Minus Scenario 1 Change Due to Focused Development Value	Percent
VMT (000's)	Entire Model	-239	-0.8%
	13 Towns	-154	-4.7%
VHT (000's)	Entire Model	-15	-1.2%
	13 Towns	-9	-6.2%
VOC (kg)	Entire Model	-34	-0.5%
	13 Towns	-43	-5.5%
CO (kg)	Entire Model	-1,747	-0.6%
	13 Towns	-1,466	-4.8%
NOx (kg)	Entire Model	-39	-0.7%
	13 Towns	-53	-8.1%
Congestion (000s of VHT)	Entire Model	-8.82	-1.6%
	13 Towns	-5.65	-7.2%
Average Speed (mph)	Entire Model	0.14	0.6%
	13 Towns	0.26	1.2%
Person Trips	Entire Model	n/a	n/a
	13 Towns	-475	-0.1%
Transit Share	Entire Model	n/a	n/a
	13 Towns	0.01%	4.2%
Walk Share	Entire Model	n/a	n/a
	13 Towns	1.16%	18.8%
Avg. Trip Length (miles)	Entire Model	n/a	n/a
	13 Towns	-0.65	-4.3%

Scenario Definitions:

1. Base - trend for all towns
2. Concentrated redevelopment in 13 towns

Transportation Analysis Methods

CTPS performed the transportation and emissions modeling for the two scenarios described below. The transportation modeling was performed using the regional travel model maintained by CTPS. This is a conventional four-step travel model based on person trips—including both motorized and non-motorized trips. Trip generation, trip distribution, mode choice, and highway and transit assignment were performed using the EMME/2 modeling software. Emissions modeling was performed using the most recent version of EPA's MOBILE program.

To explain the differences between the two land use scenarios, a greater level of detail was needed within the 13 communities. The zone structure within these communities was disaggregated from 54 zones to 137 zones. The highway and transit networks were assumed to be the same for both scenarios, and the 2025 regional transportation plan networks were used. No new transit or highway improvements were assumed in the corridor under either scenario.

The model runs were performed for the two peak periods (a.m. and p.m.) only. Neither transportation nor emissions modeling for the entire day was performed. The time of day modeling was performed by factoring the daily trips after trip generation into peak and off-peak trips, and performing trip distribution separately for these two time periods, factoring the peak trips into a.m. and p.m. and the off-peak trips into mid-day and night, and then performing mode choice, and assignment separately for each of the four time periods. The results were prepared only for the p.m. peak period

Intrazonal VMT Adjustment

The mode choice model embedded in the CTPS regional travel model splits the intrazonal trips that are output from the trip distribution model into auto and transit person trips and non-motorized (mostly walk) trips.

One of the inputs required by the model to split the intrazonal trips is the intrazonal impedances by the walk and auto modes. The intrazonal impedance for either the auto or walk mode for any zone is estimated as 50% of the impedance by that mode to the nearest zone. These impedances are usually held constant among different scenarios. Therefore, any reduction in intrazonal impedance resulting from a "Smart Growth" strategy (more mixed use) is not reflected in the CTPS model.

It has been hypothesized that the CTPS model may be underestimating the number of intrazonal trips in Scenario 2. It would make sense that the more "mixed-use" a development is, the higher the percentage of intrazonal trips.[1] One way to measure the mixed-use nature of a zone is to combine the different employment types plus housing. To address the potential under representation of intrazonal trips, CTPS developed a procedure that uses the concept of "mixed use index"[2] and corrects for the presumed underestimation of intrazonal trips. In this procedure, when more intrazonal trips are added to a given zone, an equivalent number of interzonal trips to and from that zone are removed.

The mixed use index for each zone is defined as follows:

$$\mathrm{MUI} = \frac{B_E\, E \times B_H\, H}{B_E\, E + B_H\, H}$$

where:

MUI = mixed use index for the zone
E = employment in the zone
B_E = weight for employment
H = number of households in the zone
B_H = weight for households

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[1] For example, in Seattle, neighborhoods with mixed use development are almost four times as likely to be able to meet trip needs within a mile of the home, compared to surrounding areas. For more information, see http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c15.pdf.

[2] Rossi, Thomas. "Potential Model Enhancements for EPA Project," Memorandum to Erik Sabina, DRCOG, November 15, 2002.

This formula will produce higher values when either the amount of development increases or its mix of residential and commercial uses becomes more even. The weights are used to represent the relative importance of employment or households in trip making.

The calculations embedded in the procedure are illustrated in the following steps. All calculations were performed for each zone in the study area. The procedure was implemented in an Excel spreadsheet.

1. The weight for employment for each zone, B_E, was determined by dividing the total employment into basic, retail and service types, applying different trip generation rates for each employment type (based on the CTPS trip attraction model), and estimating a weighted average trip generation rate.

2. The weight for households for each zone, B_H, was assumed to be 10, which is the typical trip production rate per household.

3. Using the employment and household weight factors and the land use/ demographic data, the value of MUI for each zone was calculated for both scenarios.

4. Next, for each zone, the Intrazonal Trip Adjustment Factor (ITAF) was computed as the ratio of the MUI for the Scenario 1 to the MUI for the Buildout Scenario.

5. For each zone, the number of intrazonal trips obtained from the trip distribution model for Scenario 1 was multiplied by the ITAF for the zone. The resulting number is the adjusted intrazonal trips for Scenario 1.

6. The difference between the model-estimated and adjusted intrazonal trips for each zone represents the change in intrazonal trips resulting from a better mixed-use type of development in the Smart Growth scenario. Since the total number of trips in the study area is largely unaltered (population and employment do not change), the increase in intrazonal trips should be accompanied by an equal decrease in interzonal trips.

7. It was assumed that 20 percent of the new intrazonal trips would divert to the walk mode. The remaining 80 percent would be auto trips. CTPS based this assumption on experience in other parts of the region.[3]

8. The VMT resulting from the additional intrazonal auto trips was estimated by multiplying the number of new intrazonal auto trips by the average intrazonal trips length for the zone.

9. The average trip length for all interzonal trips originating or destined to each zone was estimated from the trip tables.

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[3] Although it is difficult to isolate the effect of mixed use development from density and other confounding factors, several studies have been conducted that support the substitution of walking for motorized transit as mixed uses increase. For example, traveler response studies in Houston and Seattle were within this range. See http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c15.pdf for more information.

10. For each zone, the average interzonal trip length estimated in Step 9 was multiplied by the decrease in interzonal trips to estimate the reduction in VMT from these trips.

11. The net VMT reduction was calculated by adding the VMT increase from Step 8 and VMT decrease from Step 10.

Emissions Analysis Methods

Subsequent to completion of the initial MOBILE5-based analysis for the I-495 corridor, the Massachusetts DEP completed development of 2007 MOBILE6 files for the SIP development and also developed generic files for use by others in conducting build/no-build and other similar emission analyses. The files are set up to produce emission factors by 1.0 mph increments for freeways and arterials, which then can be applied in a spreadsheet to link-level VMT by speed, similar to the MOBILE5 approach.

Based on the availability of these new MOBILE6 results and the successful experience of the Massachusetts Highway Department in using these data, CTPS applied MOBILE6 for purposes of the I-495 corridor EPA brownfield and infill development analysis.

Appendix B - Charlotte

Background

The City of Charlotte modeled transportation impacts from alternative land use scenarios in a corridor proposed to be served by a new light rail line. VMT and emissions estimates for the alternative scenarios were compared to those for the 2025 Regional Transportation Plan, which assumes continuing trends in land use. The scenarios analyzed include land use shifts to proposed transit (including light rail) station locations. The regional transportation model maintained by the City was used to estimate the effects of these land use scenarios. The project also examined alternative transit and network capacity improvements.

Charlotte's analyses focus on the south corridor, where a light rail line has been proposed. A ½ cent sales tax has been passed to fund the development of light rail. The build and baseline scenario for this light rail line have already been defined in support of the city's application to the Federal Transit Administration (FTA) for New Starts funding. To conform to FTA requirements, the land use for both scenarios was assumed to be the same. This land use scenario was based on existing trends. Figure 2.2 shows the locations of the transit corridors in Charlotte's plan, and Figure 2.3 shows the south corridor in greater detail.

The City was interested in examining the effects of different land use patterns associated with transit stations. Station area plans were developed for seven stations. These plans included both a maximum and a minimum estimate of potential development. The latter was assumed for the scenarios due to the fact that it was felt to be more reasonable and was already the basis of previous transportation model runs.

The following alternative scenarios were modeled by the City of Charlotte:

- Scenario 1 – Transit No Build (as defined for FTA New Starts analysis) – with trend-based land use assumptions;
- Scenario 2 – Transit Build Scenario (as defined for FTA New Starts analysis) – with trend-based land use assumptions; and
- Scenario 3 – Transit Build Scenario with Revised Land Use – with land use assumptions reflecting development plans at stations; and
- Scenario 4 – Transit Build Scenario with Revised Land Use and Highway Improvements – with land use assumptions reflecting development plans at stations, with street network improvements to address issues resulting from the revised land use.

Scenario 1 is the baseline. Scenario 2 adds the proposed light rail line to the baseline. Therefore, the differences between Scenarios 1 and 2 can be considered to be due to the introduction of the new transit service. Scenario 3 introduces the alternative land use pattern, including the station area plans, to Scenario 2. This land use plan includes the redevelopment of some brownfield sites. The differences between Scenarios 2 and 3 are due to the land use changes in the presence of the improved transit. Scenario 4 adds the street network improvements to Scenario 3. The differences between Scenarios 3 and 4 can be considered to be due to the highway improvements in the presence of the improved transit and revised land use.

These scenarios comprise two different transit scenarios (scenarios 1 and 2), two different land use scenarios (2 and 3), and two different highway network scenarios (3 and 4), in each case with everything else held constant.

Both land use scenarios assumed the same amount of growth and total development in the county, however the alternative land use scenarios attract growth that would have occurred in parts of the county outside the study area under the trend scenario. By the analysis year of 2025, it is projected that the employment in Mecklenburg County, where Charlotte is located, will reach 764,862. The forecasted 2025 population is 944,649, representing 397,001 households. Under the alternative land use scenarios (3 and 4), a total of 16,500 households (about 4.2 percent of the county total) and 10,500 employees (about 1.4 percent of the county total) are located in the south corridor that under the trend scenario would have been located elsewhere in the county.

Detailed Results

The City of Charlotte has produced a detailed documentation report for the analysis they performed for Charlotte[4]. While it is impossible to incorporate all of the details provided in that report here, the report is referenced where appropriate.

Table B.1 presents the analysis results for Charlotte. The emissions analysis was performed in two ways: 1) VMT-based only, and 2) including the VMT, vehicle trip, and vehicle based emissions. To be consistent with the analysis performed for the other two partner communities, the emissions shown B.1 are the VMT-based emissions.

The results for Charlotte are presented for three geographic areas. The first area is the whole of Mecklenburg County. The second area is the "South Corridor," which is wide enough to include the location of the transit right-of-way and an interstate or freeway also within the corridor. The third area, referred to as the "Station Areas," is the most focused on the station areas. Figure B.1 shows the South Corridor (orange) and Station Areas (red).

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[4] City of Charlotte. "Air Quality Benefits of Brownfields Development: Methodology Report and Summary Results" (Draft). June 21, 2003.

Figure B.1. Location of Charlotte South Corridor and Station Areas

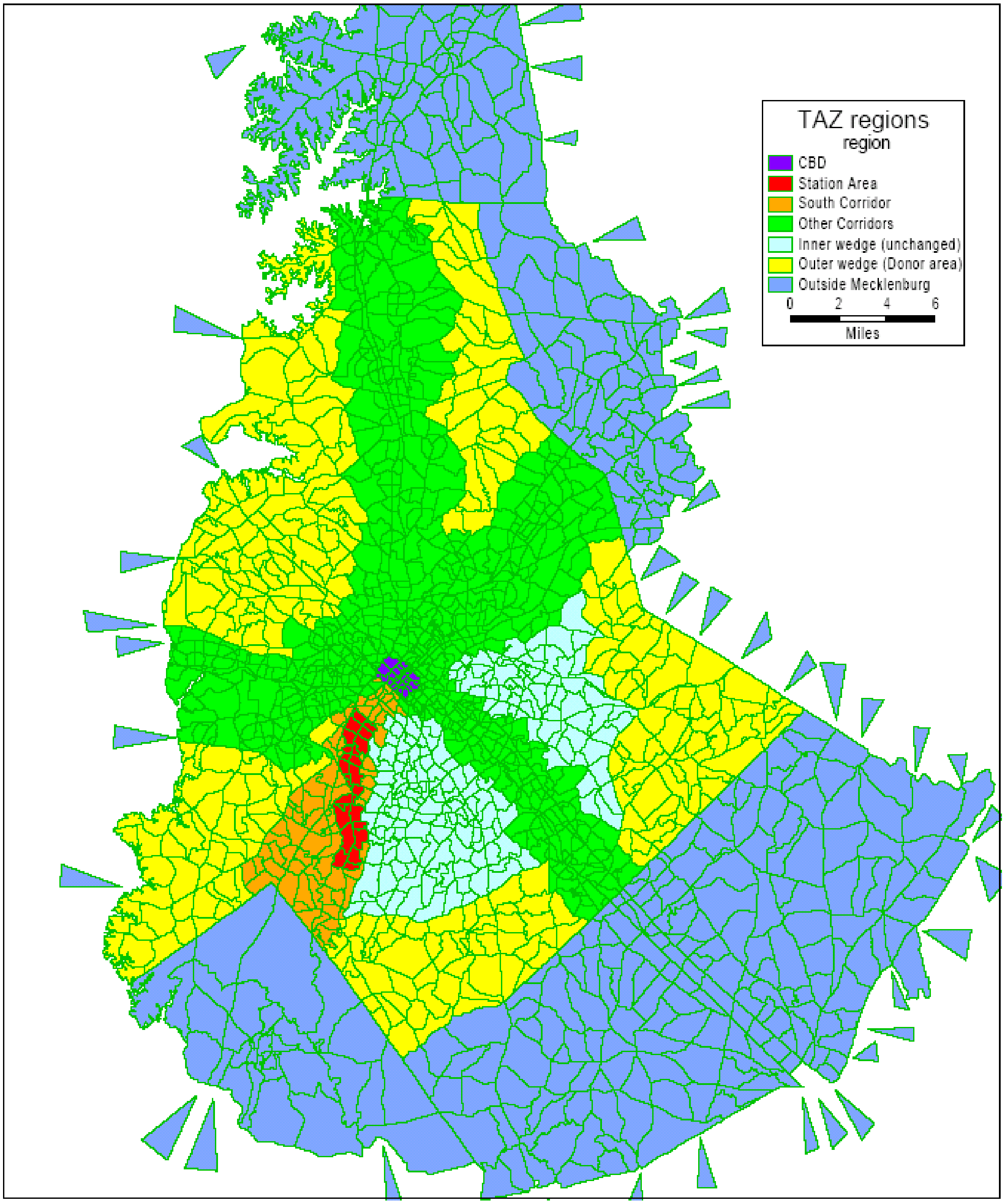

Table B.1. Analysis Results for Charlotte (weekday)

Measure	**Area**	**Scenario 1 Baseline**	**Scenario 2 Transit**	**Scenario 3 Development Around Transit**	**Scenario 4 Station Area Road Improvements**
VMT (000's)	Mecklenburg Co.	23,078	23,044	22,604	22,609
	South Corridor	2,911	2,892	2,968	2,979
	Station Areas	665	658	728	760
VHT (000's)	Mecklenburg Co.	776	774	758	756
	South Corridor	113	112	116	114
	Station Areas	26	26	29	29
VOC (kg)	Mecklenburg Co.	6,849	6,837	6,742	6,737
	South Corridor	1,392	1,384	1,400	1,397
	Station Areas	242	240	257	261
CO (kg)	Mecklenburg Co.	136,263	136,069	134,451	134,402
	South Corridor	27,199	27,050	27,348	27,376
	Station Areas	4,496	4,452	4,762	4,932
NOx (kg)	Mecklenburg Co.	6,614	6,605	6,532	6,529
	South Corridor	1,364	1,357	1,369	1,370
	Station Areas	207	205	217	225
Congestion (000s of VHT)	Mecklenburg Co.	114	113	109	109
	South Corridor	17	17	17	17
	Station Areas	3	3	4	4
Average Speed (mph)	Mecklenburg Co.	29.7	29.8	29.8	29.9
	South Corridor	25.7	25.7	25.6	26.0
	Station Areas	25.2	25.2	25.0	26.5
Transit Trips* (000's)	Mecklenburg Co.	139	145	150	150
	South Corridor	9	12	18	18
	Station Areas	3	4	10	10
Person Trips* (000's)	Mecklenburg Co.	4,156	4,156	4,156	4,156
	South Corridor	327	327	423	423
	Station Areas	89	89	185	185
Transit Share*	Mecklenburg Co.	3.4%	3.5%	3.6%	3.6%
	South Corridor	2.8%	3.6%	4.3%	4.3%
	Station Areas	3.3%	4.4%	5.4%	5.4%
Avg. Trip Length (mi)	Mecklenburg Co.	8.00	8.00	7.93	7.93

* Trips originating in specified area.

Scenario Definitions:

1. Transit no build scenario
2. Transit build scenario with trend-based land use assumptions
3. Transit build scenario with more focused redevelopment around stations
4. Transit build scenario with revised land use assumptions and station area road improvements

In examining the results, it is important to recognize that while the total amount of development is held constant on a regional basis, the amount of development in the South Corridor and Station Areas increases under the revised land use (Scenarios 3 and 4). For comparison purposes, the number of person trips generated in each scenario is presented as a measure of the amount of the increased development in these areas under the revised land use scenario. The number of person trips increases by 29 percent in the South Corridor area and by 108 percent in the Station Areas under the revised land use scenario.

The number of households reallocated in Scenarios 3 and 4 is 16,500, which is about four percent of the regional total households. This household reallocation nearly triples the number of households in the Station Areas and increases the number within the larger South Corridor area by about 60 percent. The total employment reallocated in Scenarios 3 and 4 is 10,500, which is about 1.4 percent of the regional total employment. This reallocation increases the total employment in the Station Areas by about 50 percent and increases the number within the larger South Corridor area by about 10 percent.

Examination of the differences between Scenarios 2 and 1 shows that the introduction of the light rail line would result in decreases of about one percent in VMT, emissions of VOC, CO, and NOx, and congestion in the South Corridor and Station Areas. Speeds would increase slightly while the transit share would increase by approximately 30 percent. Regionally, there would be small reductions in VMT, emissions, and congestion along with a 4.3 percent increase in transit share. Examination of the differences between Scenarios 3 and 2 shows that in the South Corridor, the revised land use would result in increases in VMT (about three percent), emissions (one percent), and congestion (four percent) and decreases in speed (0.3 percent) that more than offset the benefits resulting from the introduction of the improved transit. These changes are due to the significant increase in development in the area. This indicates that although the new development would be concentrated in the areas of the new light rail stations, many of the trips to and from these developments would be made by auto.

However, the percentage increases in VMT, emissions, and congestion are much lower than the increases in the number of person trips. This reflects the fact that the VMT and emissions associated with trips through the corridor, which are included in the summaries, would not change significantly since they would not travel to or from the new development. This also reflects that the new station area development would generate relatively fewer auto trips, as indicated by the increases in transit shares in the area beyond the increases associated with the introduction of the transit improvements alone, as well as shorter trips, due to the more compact nature of the development in the station areas.

Despite the increases in VMT, emissions, and congestion in the South Corridor, it must be noted that regionally there would be decreases in these measures. Regionally, VMT and emissions would decrease by nearly two percent while congestion would decline by nearly four percent.

The highway improvements associated with Scenario 4 would increase VMT in the Station Areas by 4.3 percent. This is presumably due to traffic that might be diverted to the expanded roadways since regional VMT (and emissions) would be essentially unchanged. However, the highway improvements would reduce the level of congestion, even in the Station Areas where the VMT would increase. The level of congestion would improve in the South Corridor area to about the same level as in the baseline scenario (0.2 percent higher) even with 29 percent more development. Regionally, congestion levels would be nearly five percent better than in the baseline scenario.

It can be concluded from the analysis that the combination of increased transit service and corresponding supportive changes in land use patterns can result in significant benefits in terms of reduced vehicular travel, increased transit use, decreased emissions, and improved congestion levels. These benefits are regional in nature as developments occur in the transit corridor rather than in areas where people are more likely to make more and longer vehicle trips. While vehicle travel and emissions are likely to increase in the areas in the transit corridor where development is concentrated, these effects can be at least partially mitigated through selective highway improvements.

Transportation Analysis Methods

The regional land use and travel models maintained by the City of Charlotte were used to perform the analyses. These models are documented by the City in a separate report[5].

The City has a land use allocation model. It assumes regional employment and housing totals are held constant. The model allows specific developments and proposed projects to be added manually. There is a subregional component to this model. This model was used to produce the land use scenario for Scenarios 1 and 2 (the same land use assumptions were used for these two scenarios). The land use scenario used for Scenarios 3 and 4 was based on this land use scenario and manually revised according to the station area plans.

The regional transportation model is a conventional four-step model based on motorized trips (auto and transit). Trip generation, trip distribution, mode choice, and highway and transit assignment were performed using the TransCAD software. There is also an auto ownership model. The highway assignment is done for four time periods, two peak and two off-peak periods.

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[5] "Air Quality Benefits of Brownfields Development – Charlotte, NC: Methodology Report and Summary Results, June 21, 2003.

Figure B.2 Charlotte Transit Corridors

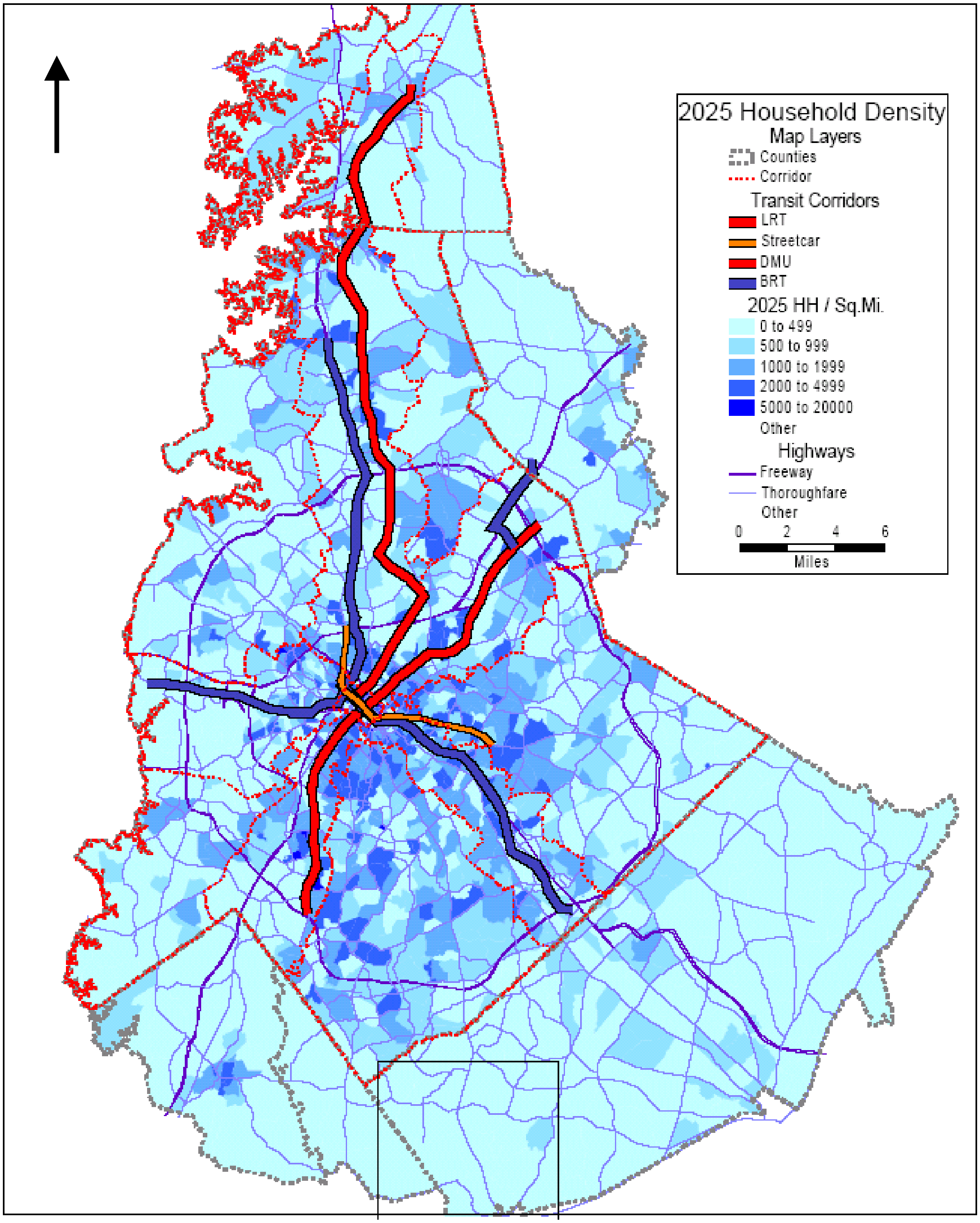
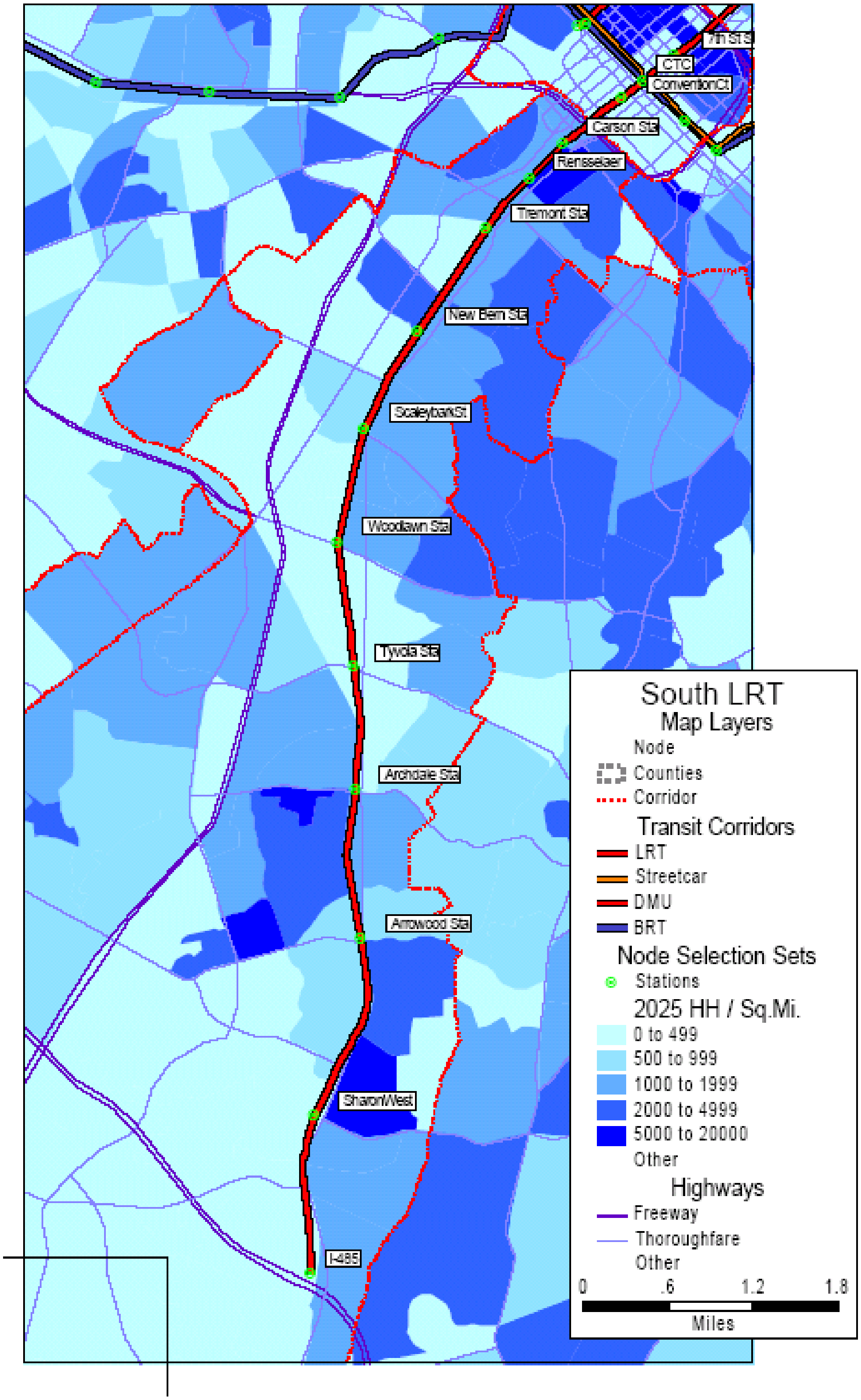


Figure B.3 Charlotte South Corridor



Emissions Analysis Methods

The Charlotte analysis was performed using MOBILE6 input files developed in January 2002 by the North Carolina Department of Transportation. Output emission factors are for calendar year 2025. The input files include the following locality-specific inputs for Mecklenburg County:

- Vehicle age distributions;
- VMT mix (percent of VMT by vehicle type);
- Inspection and maintenance (I/M) program;
- Soak distributions;
- Temperature;
- Fuel RVP; and
- Vehicle speed.

For each land use/transit scenario, 18 MOBILE6 scenarios were run, each with an average speed for six different functional classes and three time periods. Speed was estimated from travel model output as VMT divided by vehicle-hours traveled (VHT). The time periods included a.m. peak and p.m. peak (two hours each) and off-peak (remainder of the 24-hour period). The six different functional classes, along with their corresponding MOBILE6 facility type(s), are shown in Table 3.1.

To account for changes in vehicle trips versus average trip lengths, grams/start emission factors were applied separately to the total number of vehicle trips in the study area under each scenario. (Grams/start were calculated as daily start emissions divided by the default number of daily starts assumed in MOBILE6). Grams/mile emission factors, net of start emissions, were then applied to total VMT under each scenario.

EPA has not published guidance on the proper use of MOBILE6 to model trip-based versus VMT-based emissions. The methodology is straightforward for CO and NOx, for which MOBILE6 reports separate “start” and “running” emission factors. For VOC, however, there are eight different components that must be allocated to trip ends, VMT, or simply the existence of the vehicle. Discussions with EPA staff suggested that the following allocation approach was reasonable:

Table B.1 Functional Classes in the Charlotte Emissions Analysis

Functional Class	MOBILE Facility Type	Other Comments
Urban Interstate	Freeway Ramp (% from assignment)	No Cold Starts
Urban Freeway	Freeway Ramp (3%)	
Urban Principal Arterial	Arterial	
Urban Minor Arterial	Arterial	
Urban Collector	Local	
Urban Local Street	Local	

1. Running -- VMT
2. Start -- Trip-End
3. Hot Soak Loss -- Trip-End
4. Diurnal Loss -- Vehicle
5. Resting Loss -- Vehicle
6. Running Loss – VMT
7. Crankcase Loss – VMT
8. Refueling Loss – VMT

Diurnal and resting emissions depend primarily on whether the vehicle exists, not how much it is used. Although there is evidence that proximity to transit is associated with lower automobile ownership rates, this relationship is complex and is not captured in the model. Some of these eight components could be affected in other ways by the number of starts and/or VMT per day, but some effects will be negative rather than positive. For example, reducing VMT per vehicle may slightly increase diurnal emissions because of the longer time not running and fewer interrupted diurnals.

Because the emissions analysis performed by the other two partner communities included only the VMT-based emissions from MOBILE6, the emissions results for Charlotte were reported in two ways: 1) VMT-based only, and 2) including the VMT, vehicle trip, and vehicle based emissions.

Table 3.2 shows the percentage of emissions allocated to the VMT, vehicle trip, and vehicle for a Charlotte arterial at an average speed of 30 mph in 2025.

Table B.2. Sample Allocation of Emissions to VMT, Trip-Ends, and Vehicles

	VOC		CO		NOx	
	LDGV	**LDGT**	**LDGV**	**LDGT**	**LDGV**	**LDGT**
VMT Portion	58%	55%	61%	61%	87%	82%
Trip-End Portion	34%	37%	39%	39%	13%	17%
Vehicle Portion	8%	7%	0%	0%	0%	0%

Percentages may not add to 100% due to rounding.

Appendix C - Denver

Background

The Denver Regional Council of Governments (DRCOG), which both provides regional planning services and acts as the MPO for the Denver region, is in the process of extending their Metro Vision 2020 Plan to a new horizon year, 2030. One of the core elements of the Metro Vision Plan is the establishment of urban centers around the region, as a means of focusing development, reducing the prevalence of dispersed development, and improving transit accessibility. As part of the evaluation of the effectiveness of such a measure, it is important to forecast how different scenarios of infill and brownfield development affect both transportation and air quality. To identify those impacts, DRCOG carried out the following activities:

- Defined three alternative development scenarios that reflect varying urban densities and rates of infill, and forecast households and employment by traffic analysis zone.
- With the assistance of the City and County of Denver's Department of Health and Hospitals, identified brownfield sites (consistent with EPA's brownfield definition). Highlight and compared the growth predicted in each of the scenarios between 2002 and 2030 for these brownfield sites.
- Used the land development information from the three scenarios as demographic inputs for the transportation model.
- Used this information in the air quality model to predict emissions for major pollutants such as carbon monoxide and nitrogen oxides.

The 2030 population forecast for the DRCOG region is about 3.5 million, which represents about 1.4 million households. The employment forecast is nearly 2 million.

The types of land use scenarios were defined by DRCOG in cooperation with EPA and the consultant team. The following is DRCOG's summary descriptions of the three scenarios:

Scenario 1 – Limited Brownfield Redevelopment (Baseline): Under this scenario, the added growth is spread outside the existing developed urban area. Household growth followed an increased suburbanization pattern, with new employment located in suburban employment centers. These employment centers tend to locate at major interchanges of the freeway system in a metropolitan area. The land use pattern can vary from high density, office towers (as is often seen around airports) to campus-style office clusters. The residential patterns tend to follow the suburban development patterns, with large tracts of residential areas supported by neighborhood retail. This scenario was developed to provide a generalized base case, replicating development patterns of the last twenty to forty years. The development pattern for this scenario is shown in Figure C.1

Scenario 2 – Multiple Brownfield Centers: This scenario focuses growth into 31 specified urban density centers. These centers are spread throughout the metropolitan area, but tend to concentrate in the urban core of the metro area. Both housing and employment development is focused into these areas, allowing for increased multi-modal usage (transit, pedestrian and biking alternatives). Many of the brownfield development projects propose a mixed-use emphasis, relying both on connections within the development along with connections to existing community areas. In many cases, the infrastructure is already in place (water, power, and transportation) allowing for some costs savings for this type of development (to offset land prices and clean-up costs). This scenario provides for many, smaller scale redevelopment projects, which may be a means to overcome costly infrastructure expenses (matching closer to existing scale) and traditional concerns. The development pattern for this scenario is shown in Figure C.2

Scenario 3 – Concentrated Brownfield Centers: The third scenario focuses development into 10 specified redevelopment centers. The scale of the brownfield development is much higher, in part to represent the scale that may be associated with higher land and clean-up costs. While the associated development has much higher densities, the projects may serve as catalyst for further redevelopment in the surrounding community. In the Denver region, examples of this type of project include the Central Platte Valley, Gates Rubber, Stapleton, and Fitzsimons sites. These developments have varied shares of residential and employment components, and still rely on existing infrastructure. However in every case, the development will likely cause some additional infrastructure improvement to adequately serve the scale of development proposed. The development pattern for this scenario is shown in Figure C.3.

The amount of development reallocated into centers was similar under both Scenarios 2 and 3, measured relative to Scenario 1. Under each scenario, about 100,000 households (about seven percent of the total) and about 180,000 to 190,000 employees (about 14 percent of the total) shifted locations.

Table C.1

	Scenario 1: Limited Brownfield	**Scenario 2: Multiple Centers**	**Scenario 3: Concentrated Centers**
Urban Density	Variable	Medium	High
Forecast of Employment	Suburban employment centers focused at major freeway interchanges	Focused on 31 areas in urban core	Focused in 10 redevelopment centers
Forecast of Households	Suburban residential areas near employment centers	Focused on 31 areas in urban core	Focused in 10 redevelopment centers
Infrastructure Requirements	Requires new infrastructure	Generally preexisting	Preexisting, but improvements likely needed

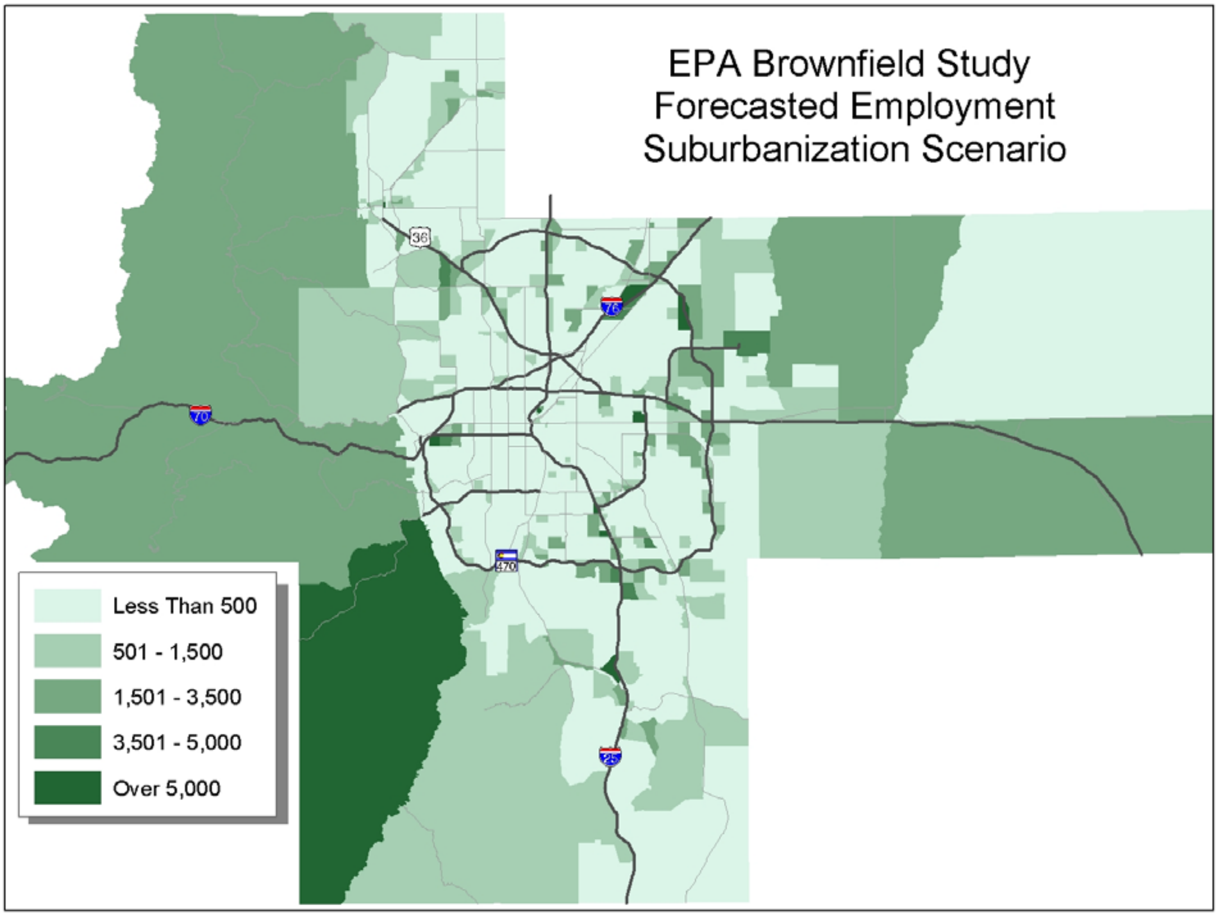


Figure C.1 Denver Baseline Development Scenario

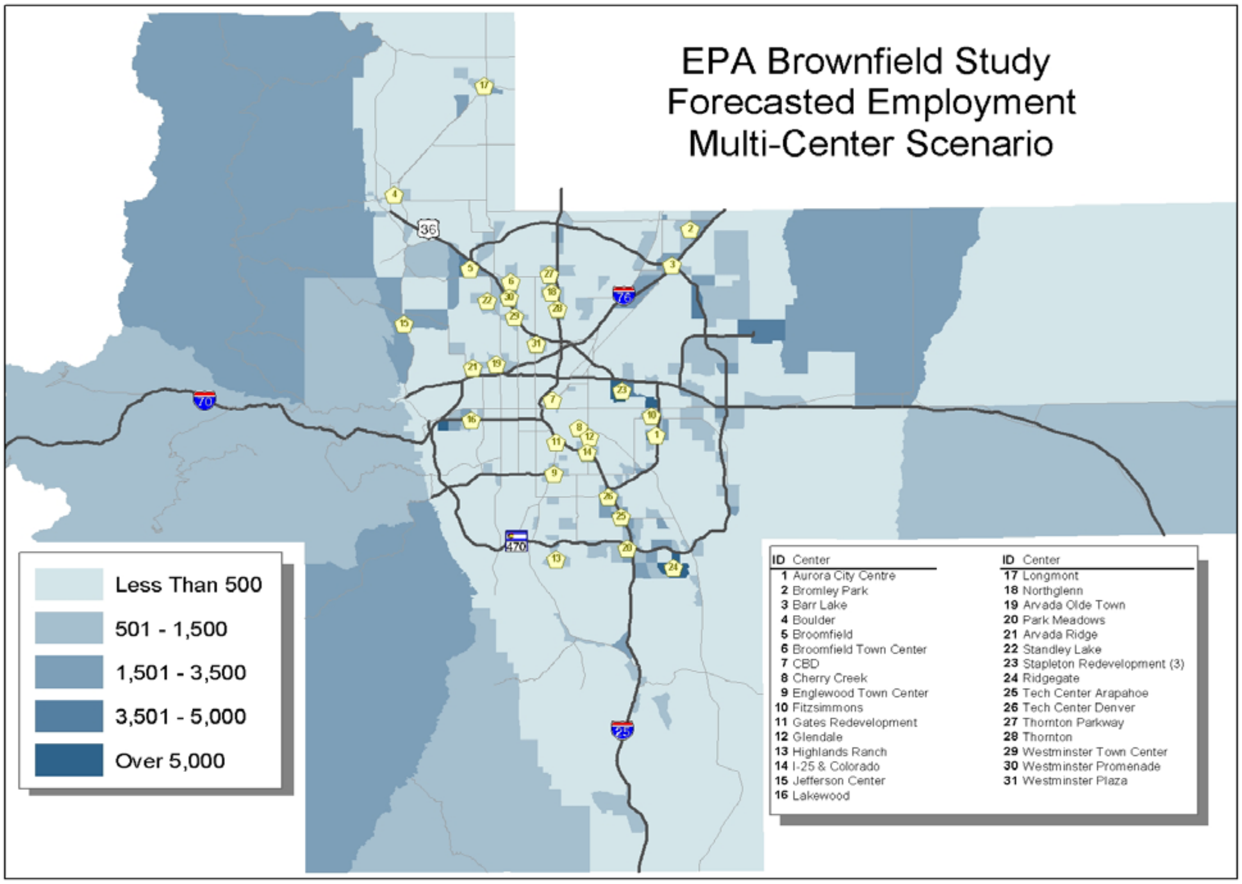


Figure C.2 Denver 31 Regional Center Development Scenario

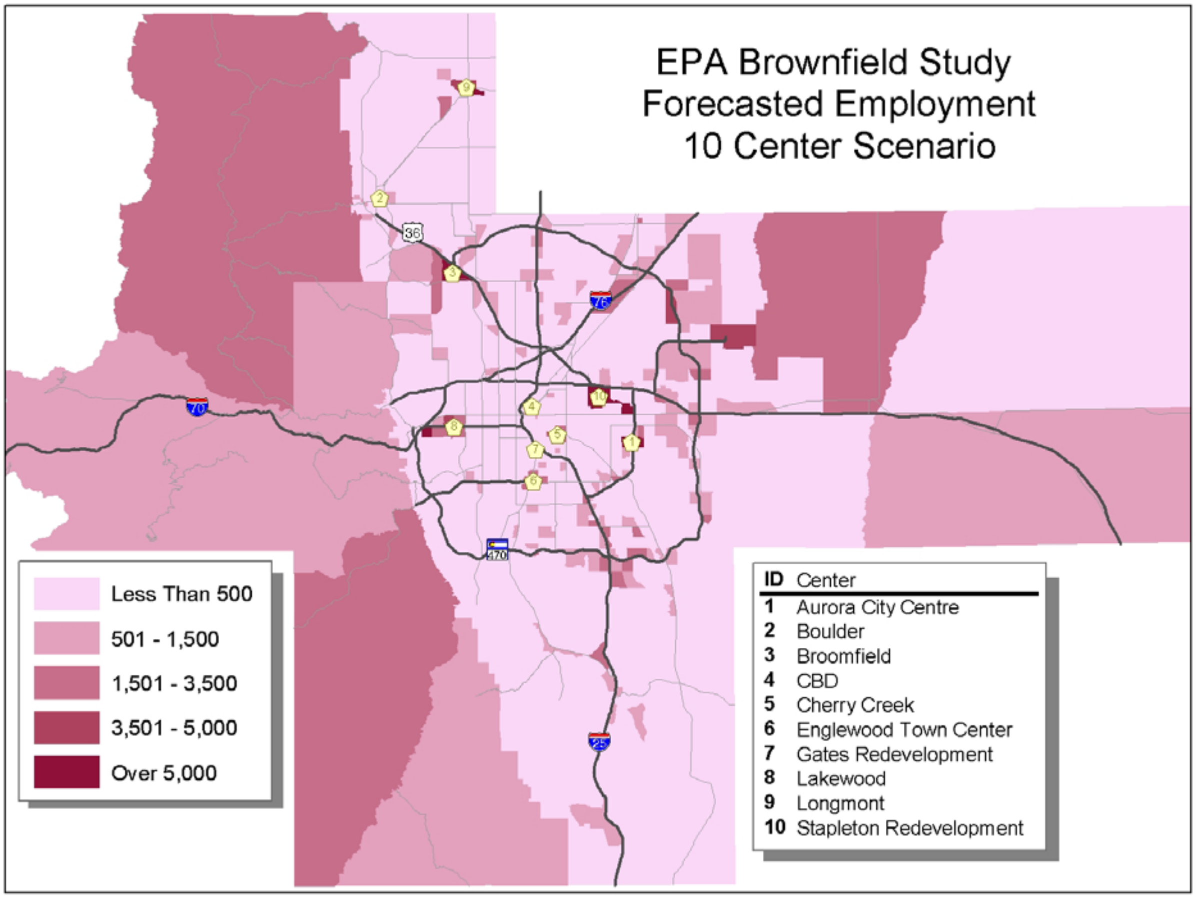


Figure C.3 Denver 10 Regional Center Development Scenario

Detailed Results

Three types of land use scenarios were defined by DRCOG in cooperation with EPA and the consultant team. Scenario 1 represents baseline conditions, where household growth followed an increased suburbanization pattern and employment growth was focused in suburban employment centers. Scenario 2 focuses growth into 31 specified urban density centers spread throughout the metropolitan area. Scenario 3 focuses development into 10 specified redevelopment sites. About seven percent of all households and 14 percent of all employment were relocated in both the second and third scenarios, compared to the baseline scenario.

Tables C.2 and C.3 present the analysis results for Denver. Because the alternative land use patterns were defined for the entire Denver region, it did not make sense to define subareas for presentation of the results. They are therefore presented only for the entire region. The results reflect the trip generation adjustment to the DRCOG travel model described below.

According to the model, concentration of the growth in the 31 centers would result in about a three percent reduction in regional travel, as measured by VMT. Speeds would, on average, increase by 0.7 percent, and congestion would decrease by six percent. Emissions of VOC, CO, and NOx would decline by about three percent.

The results when growth is concentrated around 10 centers are similar to those for the more dispersed 31 center scenario. There would be larger decreases in VMT and emissions, but a smaller decline in congestion and a smaller increase in speed. As with Boston, it can be concluded from the Denver analysis that the redistribution of development in concentrated areas has significant benefits in terms of reduced vehicular travel, decreases in emissions, and improved congestion levels.

Table C.2 Analysis Results for Denver (weekday)

Measure	Baseline Scenario	31 Centers	10 Centers
VMT (000's)	92,308	89,637	88,966
VHT (000's)			
VOC (kg)	34,500	33,400	33,100
CO (kg)	1,018,200	989,900	982,100
NOx (kg)	30,000	29,200	28,900
Congestion (000s of VHT)	667	625	628
Average Speed (mph)	31.85	32.07	31.98
Transit Share	2.4%	2.6%	2.7%
Avg. Trip Length	6.84	6.81	6.78
Person Trips (000's)	12,695	12,316	12,203

Table C.3 Differences between Denver Scenarios

Measure	Change with 31 Centers		Change with 10 Centers	
	Value	Percent	Value	Percent
VMT (000's)	-2,761	-2.9%	-3,342	-3.6%
VHT (000's)				
VOC (kg)	-1,100	-3.2%	-1,400	-4.0%
CO (kg)	-28,300	-2.8%	-36,100	-3.5%
NOx (kg)	-800	-2.7%	-1,100	-3.6%
Congestion (000s of VHT)	-42.27	-6.3%	-39.34	-5.9%
Average Speed (mph)	0.22	0.7%	0.13	0.4%
Transit Share	0.2%	9.0%	0.3%	11.5%
Avg. Trip Length	-0.03	-0.4%	-0.06	-0.8%

Transportation Analysis Methods

The regional transportation model maintained by DRCOG is a conventional four-step model. Trip generation, trip distribution, mode choice, and highway and transit assignment were performed using the MinUTP software. The model does have time of day analysis but does not include non-motorized travel. The model's parameters are currently being updated, but this analysis does not reflect the updates.

The current model is not sensitive to detailed microscale-level land use assumptions, mainly due to its large zone size relative to the scale of typical transit oriented developments. Area type is an important input into several model components, including (motorized) trip generation and estimation of roadway capacity. There are currently five area types in the model: CBD, fringe, urban, suburban, and rural. The same highway and transit networks were used for all three scenarios.

Intrazonal Trip Changes

Mixed land use development could generate a higher percentage of intrazonal trips than typical land use patterns. Closer proximity between households and employment sites would facilitate walking and biking, and reduce dependence on automobile travel, which is more attractive for longer commute trips. It would also help to lower vehicle miles traveled and improve air quality. However, the modeled percentage of intrazonal trips estimated from DRCOG's travel demand model for the Gates-Cherokee development, a mixed use development planned for a brownfield site in Denver, was lower than expected. To improve the model results, Cambridge Systematics developed mixed land use indices to measure land use mix, which could be used to adjust the intrazonal trips estimated from the gravity trip distribution model.

Based on the analyses described below, the available data did not support the use of an adjustment factor to intrazonal trips based on any of the mixed use indices studied. It may be that the lack of correlation between MUI and intrazonal trip rates was due at least in part to the effects of zone size. In addition, the DRCOG model currently considers only motorized trips, and a large portion of intrazonal trips are made by walking or bicycling. This might explain the underestimation of intrazonal trip rates. Therefore, the intrazonal adjustment to the DRCOG model was not used.

However, to improve the model's sensitivity to changes in land use pattern, DRCOG did alter its traditional method of model execution in one important respect, balancing its trip generation model results to attractions rather than to productions. Conventional trip generation models estimate productions based on trip generation rates and households—in Denver's case, the number of households as well as income classification and household size. Such models also estimate trip attractions based on attraction rates and employment—in Denver's case, the model includes different attraction rates for different area types (CBD, urban, suburban, etc.) Balancing to productions is often considered the conservative approach as it is generally believed that household production rates are better known than attraction rates (since typical travel surveys focus on household travel diaries). However, since the Denver production model does not include sensitivity to area type, balancing to productions eliminates an important element of sensitivity to changes in land use pattern. For the model runs conducted for this project for all scenarios, the trip generation model therefore balanced the trip generation results to attractions.

Development and Calculation of Mixed Land Use Indices

Cambridge Systematics developed two mixed land uses indices for this project. Each of these indices requires weights to be computed for each of three land use types: residential, retail, and other. Table C.4 summarizes the average number of trip productions and attractions generated by trip purpose for each of these land use types.

MUI$_1$

A proposed land use mix index was defined by a two-dimensional mixture between industrial and residential land uses. Suppose that there is a three-dimensional land use mixture: residential (X_1), retail (X_2), and other (X_3), where the variables X_i represent the percentages of each land use, weighted by the relative contributions of each land use to trip making. The weights are computed by each land use type using the trip production and attraction rates in the existing DRCOG model, as discussed above.

The mixed use ratio (Y_{ij}) is computed for each pair of land uses in the same way as in the two-dimensional mixture:

If $X_1=X_2=0$, then $Y_{12}=0$; Else $Y_{12} = \frac{X_1 \times X_2}{X_1 + X_2}$

If $X_2=X_3=0$, then $Y_{23}=0$; Else $Y_{23} = \frac{X_2 \times X_3}{X_2 + X_3}$

If $X_1=X_3=0$, then $Y_{13}=0$; Else $Y_{13} = \frac{X_1 \times X_3}{X_1 + X_3}$

Table C.4 Average Productions and Attractions by Land Use Type

	Trips Generated per Household	Retail Employee	Non-Retail Employee (1)
Productions (all purposes)	8.714 (2)	-	-
Home based work attractions	0.035	1.389	1.389
Home based non-work attractions	0.540	6.477	1.685
Non-home based attractions	0.486	4.205	1.114
Total Trips	9.775	12.071	4.188
Weight	0.375	0.464	0.161

Notes:

1. Non-retail employment in the DRCOG model is separated into service and other employment. The figures in Table 3.1 reflect weighted averages of the contributions of these two employment types.
2. Trip production rate per household weighted over the cross-classifications of income level and household size used in the DRCOG model

The combined ratio of mixed household, retail, and other land uses can be calculated using the following equation:

$$MUI_1 = (Y_{12}+Y_{23}+Y_{13}) \times 2$$

where:

X_1 = Ratio of zonal residential land use
X_2 = Ratio of zonal retail land use
X_3 = Ratio of zonal other industrial land use
Y_{12} = Mixed use index between residential use and retail industrial use
Y_{23} = Mixed use index between retail land use and other industrial use
Y_{13} = Mixed use index between residential use and other industrial use
MUI_1 = Mixed land use ratio 1 for residential, retail industrial and all other use

Assuming residential, retail, and other use are the only three types of land use in a zone, the proportion of each land use types X_i $(i=1, 2, 3)$ has to fall within the following constraints:

$$X_1, X_2, X_3 >= 0$$

$$X_1+X_2+X_3 = 1$$

MUI₂

Cambridge Systematics developed an alternative mixed use index. This index is based on the idea of square deviation about the mean, which is defined as the difference between the mean and the ratio of an individual land use type. If residential, retail and other land uses are evenly mixed in a region, the mean ratio of land uses $\bar{X}$ will be 1/3. The square deviation of each land use ratio can be calculated as follows:

$$Z_1 = (X_1 - \bar{X})^2 = (X_1 - \frac{1}{3})^2$$

$$Z_2 = (X_2 - \bar{X})^2 = (X_2 - \frac{1}{3})^2$$

$$Z_3 = (X_3 - \bar{X})^2 = (X_3 - \frac{1}{3})^2$$

The overall mixed land use index is calculated by adjusting the sum of the squared deviation about the mean:

$$MUI_2 = 1 - \frac{3}{2}(Z_1 + Z_2 + Z_3) = 1 - \frac{3}{2}\sum_{i=1}^{3}(Xi - \overline{X})$$

where:

X_1 = Ratio of zonal residential land use
X_2 = Ratio of zonal retail land use
X_3 = Ratio of zonal other land use
Z_1 = Mixed use index between residential use and retail use
Z_2 = Mixed use index between retail land use and other use
Z_3 = Mixed use index between residential use and other use
MUI_2 = Mixed land use ratio 2 for residential, retail, and all other use.

The calculation of MUI_2 also assumes residential, retail, and other use as the only three types of land use in a zone, therefore the proportions land use types X_i *(i=1, 2, 3)* have to fall within the same constraints as in MUI_1:

$X_1, X_2, X_3 >=0$

$X_1+X_2+X_3 = 1$

Range of the MUIs

Both MUI_1 and MUI_2 range between 0 and 1, with 0 meaning the least mixed development and 1 meaning a completely even mixture. Both MUI calculations give a higher number for zones that are more mixed-use, as well as those with more trip making. A lower mixed use index indicates that a dominant land use exists. This can be illustrated through the use of the following three examples, which represent three different levels of land use mixture using both of the MUIs:

Case 1: When all three types of land use are evenly mixed ($X_1=X_2=X_3=1/3$), we will have the maximum MUIs:

$$Y_{12} = Y_{23} = Y_{13} = 1/6 \quad and \quad MUI_1 = 1$$

$$Z_1 = Z_2 = Z_3 = 0 \quad and \quad MUI_2 = 1$$

Case 2: When there is one and only one type of land use in a zone (for example, $X_1 = X_2 = 0 \quad and \quad X_3 = 1$, i.e., a zone with only non-retail land uses), we will have the minimum MUIs:

$$Y_{12} = Y_{23} = Y_{13} = 0 \quad and \quad MUI_1 = 0$$

$$Z_1 = Z_2 = \frac{1}{9} \quad and \quad Z_3 = \frac{4}{9} \quad and \quad MUI_2 = 0$$

Case 3: When residential area accounts for ½ of the land, retail and other industrial land use each takes up ¼ of the area (X_1=½ and X_2=X_3=¼), we will have the following MUIs:

$$Y_{12} = Y_{13} = \frac{1}{6} \quad and \quad Y_{23} = \frac{1}{8} \quad and \quad MUI_1 = \frac{11}{12} = 0.9167$$

$$Z_1 = \frac{1}{36} \quad and \quad Z_2 = Z_3 = \frac{1}{144} \quad and \quad MUI_2 = 0.9375$$

Of these three hypothetical cases, Case 1 is the most mixed land use, Case 2 is the least mixed land uses, and Case 3 is in between. The values of MUI_1 and MUI_2 reflect the degree of mixture.

Calculation of Zonal MUIs for Year 2001 and Year 2025

Each version of the mixed land use index was computed for all zones for the 2000 and 2025 scenarios based on land use data provided by DRCOG. The overall results from both MUIs are very similar. Figures B.1 and B.2 illustrate the aggregated MUIs by county for 2000 and 2025, respectively. These figures indicate that all counties in the region are expected to have a more mixed land use pattern over time. Figures C.6 and C.7, respectively, show maps of MUI_1 at the zonal level for 2000 and 2025. Figures C.8 and C.9, respectively, show maps of MUI_2 at the zonal level for 2000 and 2025.

Figure C.4 MUI$_1$ by County for Year 2000 and Year 2025

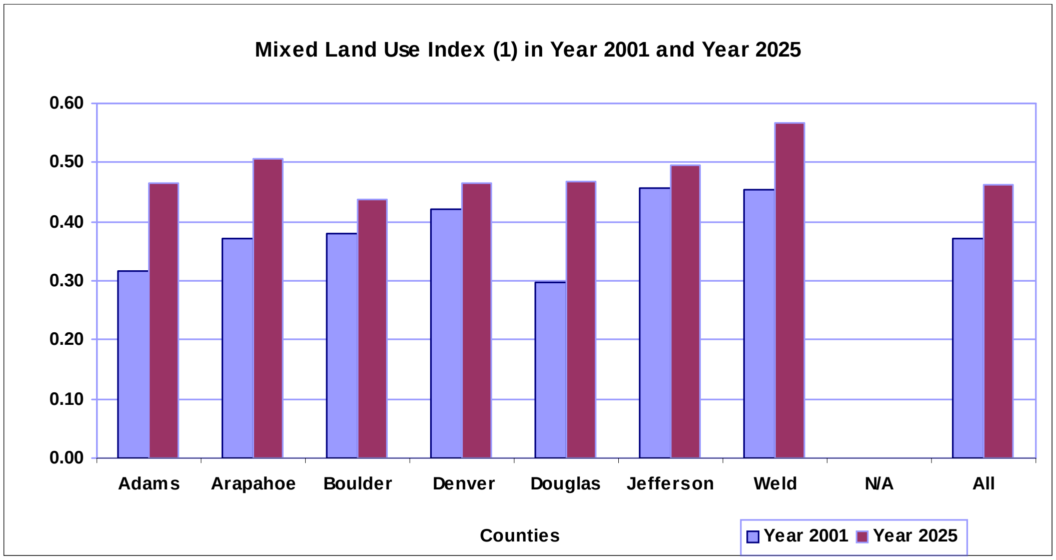


Figure C.5 MUI$_2$ by County for Year 2000 and Year 2025

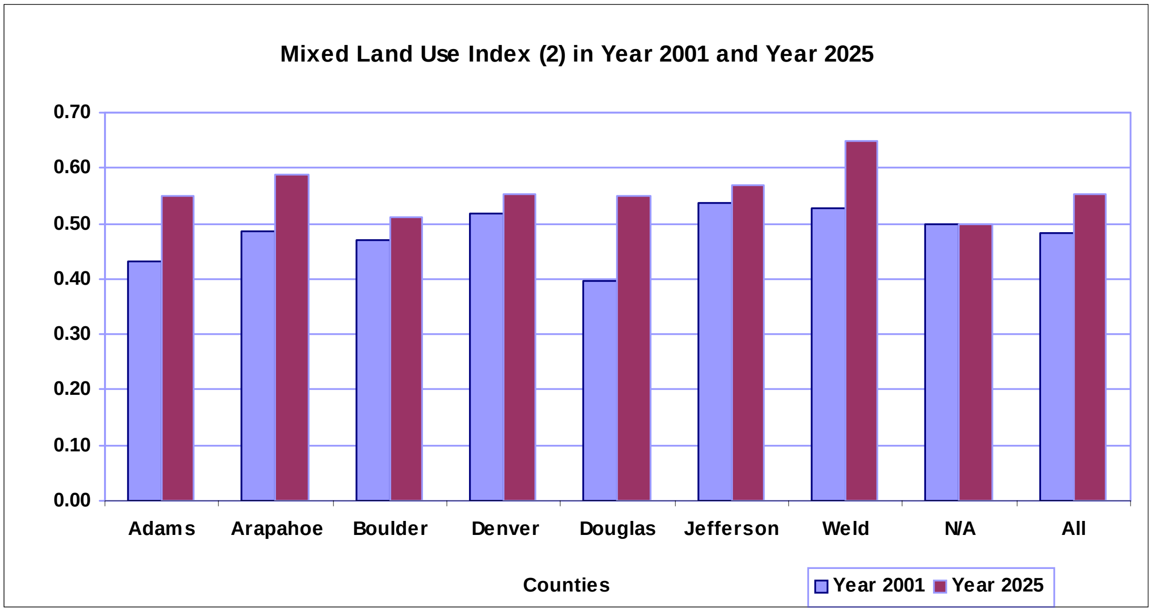


Figure C.6 Distribution of Zonal MUI_1 for Year 2000

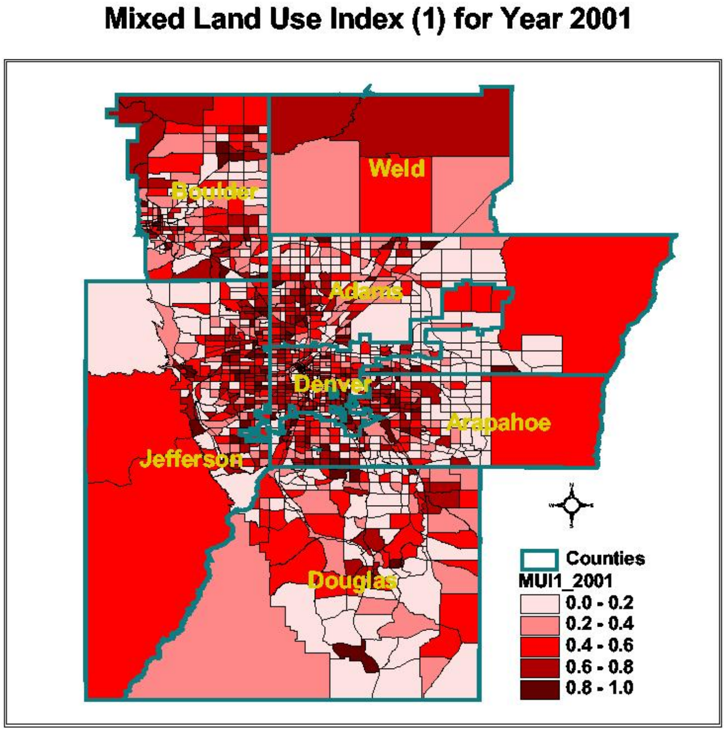


Figure C.7 Distribution of Zonal MUI_1 for Year 2025

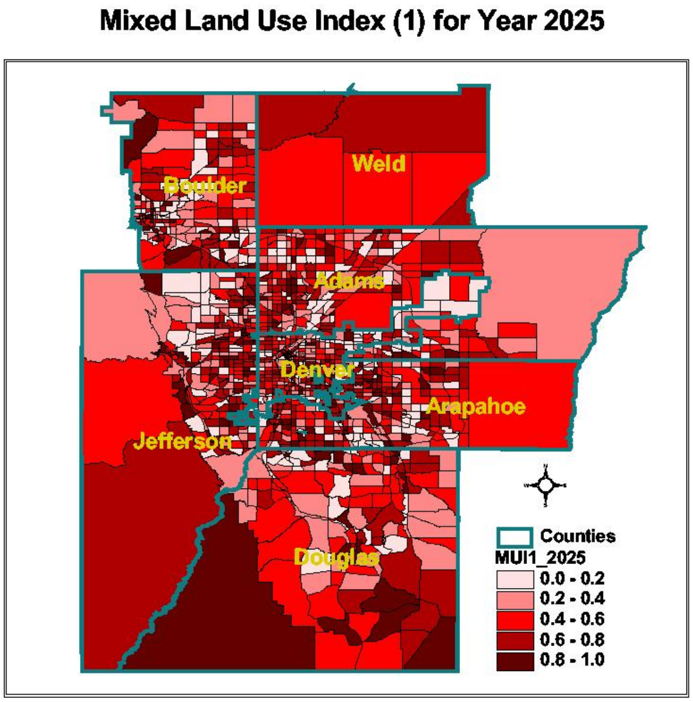


Figure C.8 Distribution of Zonal MUI_2 for Year 2001

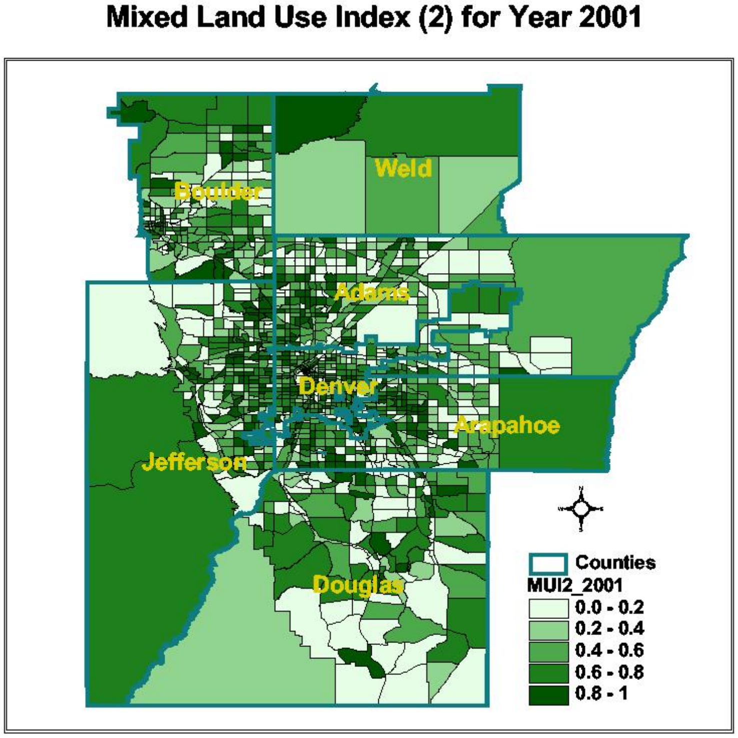
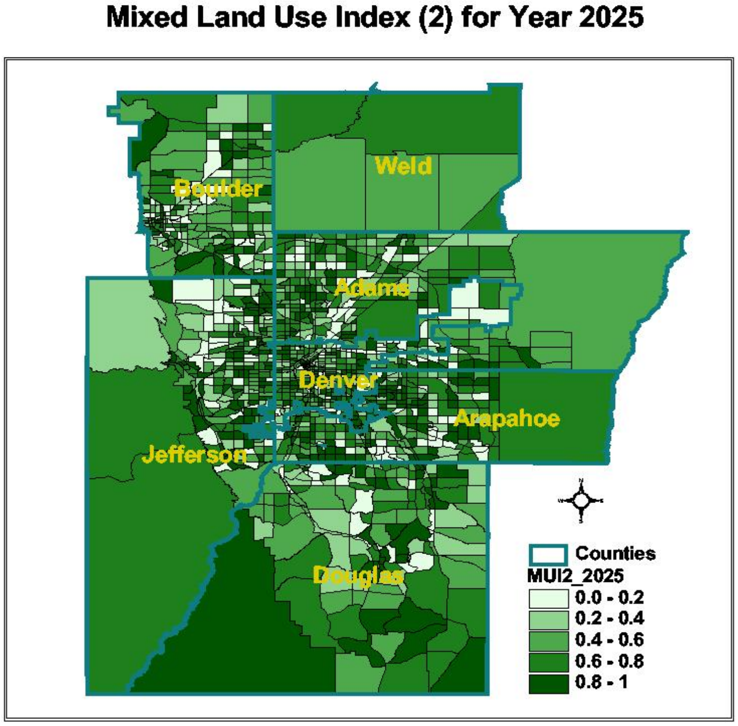


Figure C.9 Distribution of Zonal MUI_2 for Year 2025



Calculation of Intrazonal Trips from Household Travel Survey and Gravity Model

The next step was to calculate the percentage of intrazonal trips from the household travel survey and the DRCOG gravity model.

First, the percentage of intrazonal trips for each zone from the household travel survey was calculated. The household survey is a survey of persons in the households within the region on the characteristics of the household, characteristics of each person residing in the households and any out-of-region visitors staying at the households, and the characteristics of travel made by the person living at the household on the travel survey day. Based on the household travel survey database, the percentages of intrazonal trips for the three trip purposes in the DRCOG model—home based work (HBW), home based non-work (HBNW) and non-home based (NHB)—were calculated. Next, the intrazonal trip percentages based on DRCOG's trip distribution model were calculated.

Figures C.10 through C.13 compare the county-level intrazonal trip percentages calculated from the household travel survey with the intrazonal trip percentages estimated from the gravity model. It is evident from these figures that the gravity models underestimated intrazonal trip rates for all trip purposes.

Intrazonal Trip Adjustment Models

The calculated MUIs can be used to adjust the intrazonal shares coming out of the gravity model, so as to overcome the underestimation of intrazonal trip rates. The hypothesis is that intrazonal trip rates should be higher in areas with higher mixture of land use.

An intrazonal trip adjustment model was estimated for each trip purpose by regressing the natural log transformation of intrazonal trips from the household survey against the natural log transformation of intrazonal trips from the gravity model as well as the mixed land use index. The regression models look like the following:

$$\text{Ln(intrazonal \% from HH survey)} = A*\text{Ln(intrazonal \% from gravity model)} + B*\text{Ln(MUI)} + C$$

where A, B and C are estimated parameters. Adjusting the currently modeled intrazonal percentages, rather than estimating new percentages based only on the MUI, would allow the use of other variables that are currently used in estimating intrazonal travel, such as distance to nearby zones.

The intrazonal trip percentage from the household travel survey was plotted against the calculated MUIs. As seen in Figures C.14 and C.15, no strong correlation was found between the percentage of intrazonal trips and either of the mixed use indices. In Figure C.16, the observed intrazonal trip percentage was plotted against estimated intrazonal trip percentage from the gravity model. These correlations seem to be weak as well.

Figure C.10 Comparison of All Intrazonal Trips

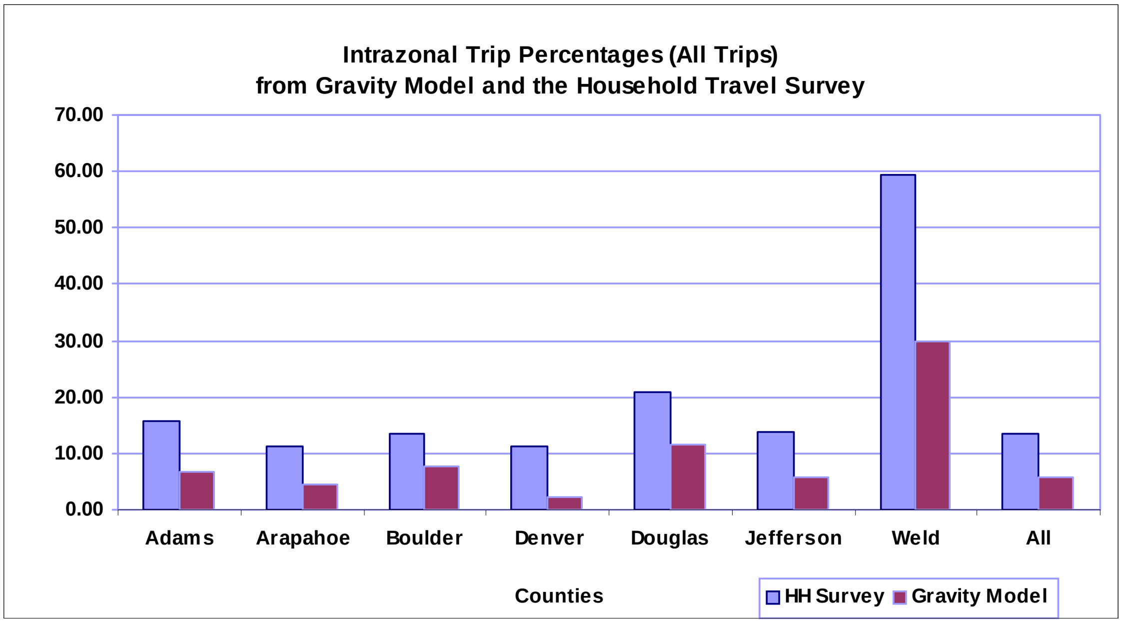


Figure C.11 Comparison of Home-Based Work Intrazonal Trips

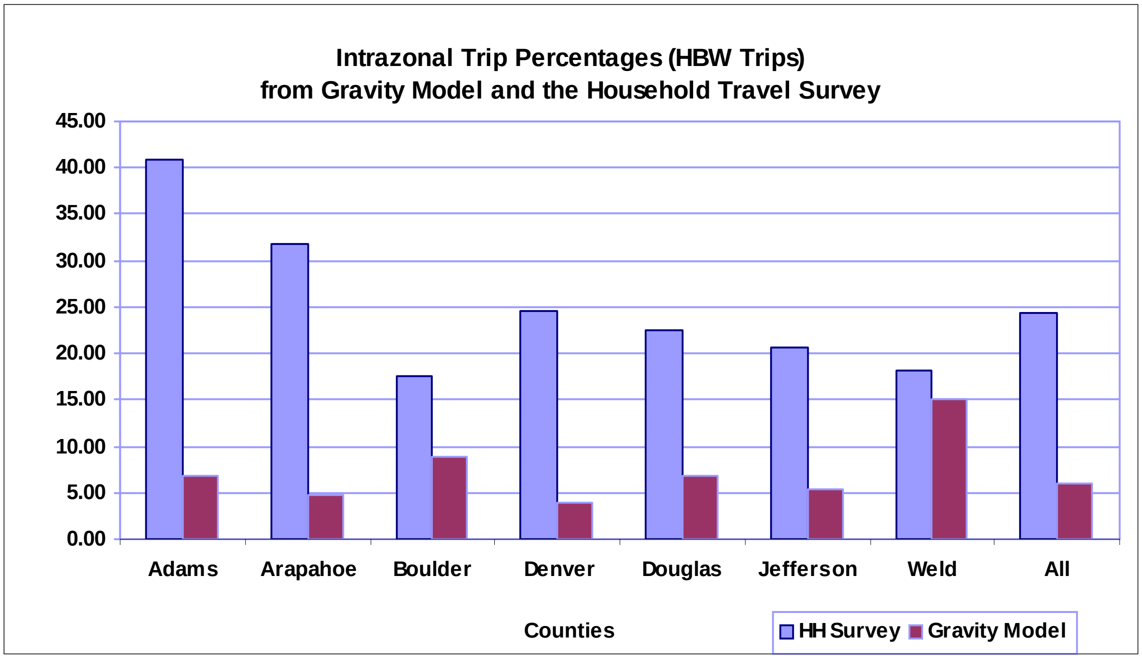


Figure C.12 Comparison of Home-Based Non-Work Intrazonal Trips

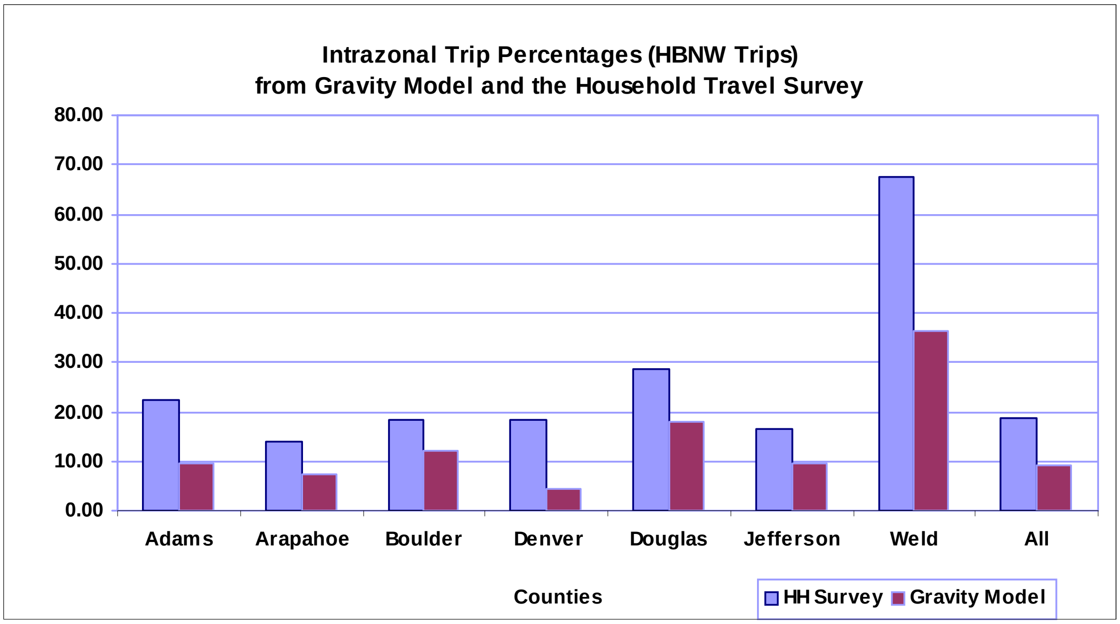


Figure C.13 Comparison of Non Home Based Intrazonal Trips

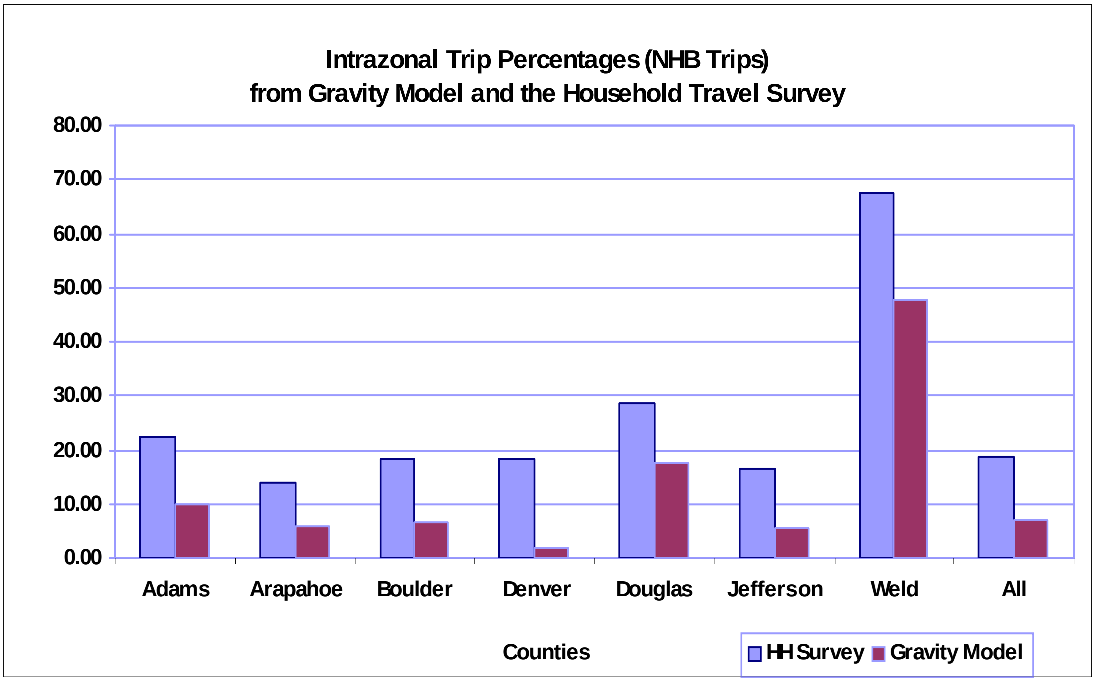


Figure C.14 Plot of Observed Intrazonal Trip Percentage and Calculated MUI$_1$

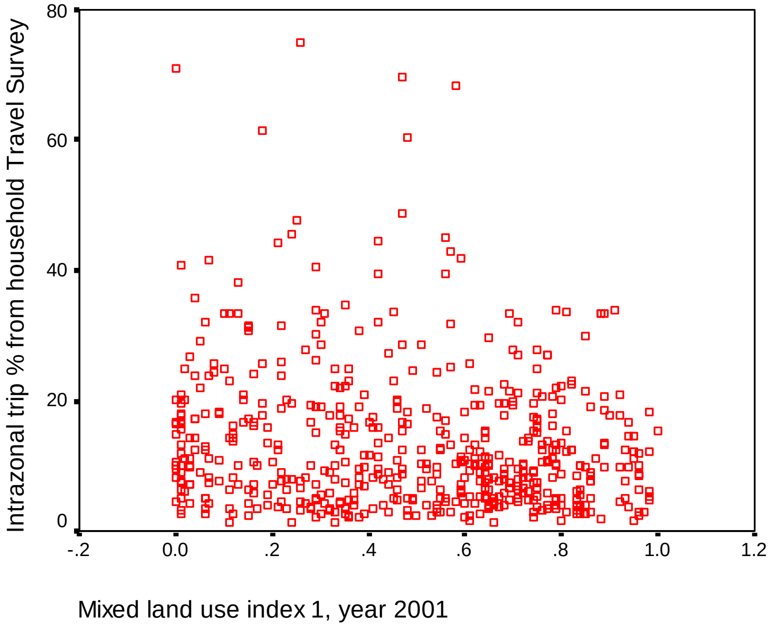


Figure C.15 Plot of Observed Intrazonal Trip Percentage and Calculated MUI$_2$

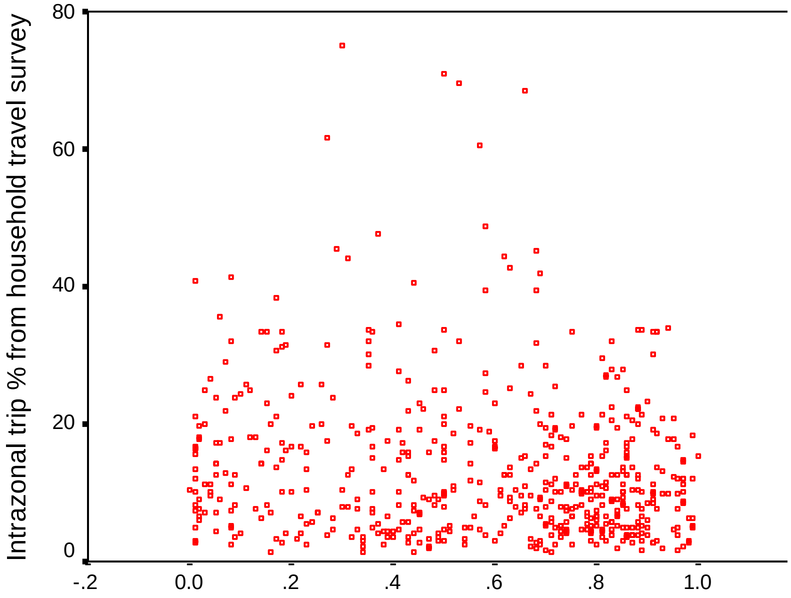
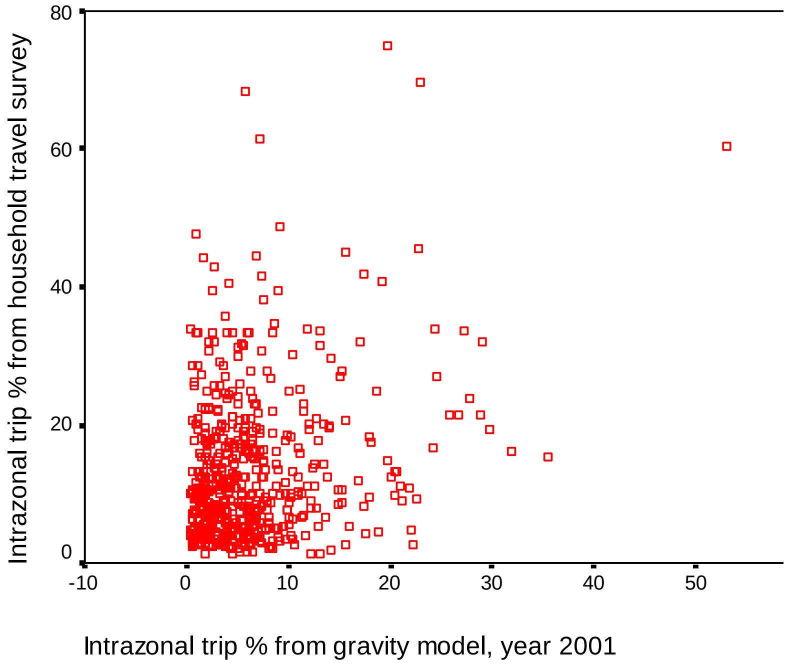


Figure C.16 Plots of Observed and Estimated Intrazonal Trip Percentages



Revision of Mixed Land Use Indices

It was hypothesized that the lack of correlation between MUI and intrazonal trip rates was due at least in part to the effects of zone size. The original calculations of MUI_1 and MUI_2 do not account for zone size. More rural zones are generally large in area and tend to have mixed uses, even when those uses could be miles apart. Therefore, the calculation of mixed land use indices was revised to take zone size into account. The idea was that larger zones provided more opportunities for intrazonal travel. For example, in both of the original measures, a zone with 10 households and 10 retail employees would have the same MUI value as a zone with 100 households and 100 retail employees. But the larger zone could in reality provide more opportunities for intrazonal travel.

To account for zone size, the MUI calculations were revised by using the number of households, retail employment, and other employment instead of percentages of these land use types. The question is, would zones that qualify as mixed use more because of their size than because they represent mixed use development be likely to have higher percentages of intrazonal trips than non-mixed use zones. This may be the case, in part because large zones would be more likely to have intrazonal trips. A trip to the supermarket may be a few miles long but still be intrazonal.

Model Results Discussion and Recommendations

Unlike the CTPS model in Boston, the DRCOG model currently considers only motorized trips, and a large portion of intrazonal trips are made by walking or bicycling. This might explain the underestimation of intrazonal trip rates. Regardless of the reason, it is clear that the available data did not support the use of an adjustment factor to intrazonal trips based on any of the mixed use indices studied. Therefore, the intrazonal adjustment to the DRCOG model was not used.

Trip Generation Revision

The second model enhancement analyzed for Denver is to adjust non-motorized trip rates. The idea behind this enhancement is to consider the hypothesis that pedestrian/bicycle friendly areas should have more non-motorized trips and, therefore, fewer motorized trips. Since the DRCOG model considers only motorized trips, the implication is that (motorized) trip generation rates should be lower in pedestrian or bicycle friendly zones. In model application, these lower rates are applied to zones identified as pedestrian/bicycle friendly.

To implement this model enhancement, Boulder County was used as a test area. The trip rates from the household survey in Boulder County for households in pedestrian/bicycle friendly zones were compared to the rates for Boulder County households in other zones. Because trip rates for attractions and non-home based productions in the DRCOG model already were based on area type, only the home based work and home based non-work production rates were adjusted.

Trip production rates in the DRCOG model are cross-classified by income level and household size. Separate adjustments, however, could not be computed for each cell in the cross-classification due to insufficient data in the household survey data set.

Pedestrian or Bicycle Friendly Zones in Boulder County

DRCOG staff identified zones in Boulder County that are considered pedestrian or bicycle friendly. Three levels of pedestrian or bicycle friendliness were identified as in the following:

- Level 1, the most pedestrian-friendly zones (eight zones)
- Level 2, zones that are somewhat pedestrian-friendly (nine zones)
- Level 3, all other zones in Boulder County

To validate the assumption that these three levels of zones have different levels of pedestrian/bicycle friendliness, the home based work and home based non-work trip records person trip records in the household travel survey that correspond to the Boulder County zones were identified. Households with students at Colorado University were excluded. From these records, the average motorized and non-motorized trip rates by purpose for each zone type were computed.

Table C.5 shows the ratios of non-motorized trips by purpose for zones with different levels of biking/pedestrian friendliness. This table indicates that non-motorized trips in the pedestrian or bicycle friendly zones are higher than average for all trip purposes. For the Level 1 zones, non-motorized trips account for 40 percent of all home-based work trips, 44 percent of home-based non-work trips, and 21 percent of non-home based trips. In contrast, the average regional non-motorized trip ratio is only 6 percent for all home-based work trips, 12 percent for home-based non-work trips, and 13 percent for non-home based trips.

Trip Adjustment Factor Calculation

The formula for calculating the trip rate adjustment factor for each trip purpose is:

$$A_{ij} = \frac{MOTOR_{ij}}{(MOTOR_{ij} + NONMOTOR_{ij})} \div \frac{\sum_i MOTOR_{ij}}{\sum_i (MOTOR_{ij} + NONMOTOR_{ij})}$$

where:

i – Zone types (i = 1, 2, or 3)
j – Trip purposes (j=1 for HBW, j=2 for HBNW and j=3 for NHB)
A_{ij} – Motorized trip adjustment factors for zone type i and trip purpose j
$MOTOR_{ij}$ – Motorized trip number for zone type i and trip purpose j
$NONMOTOR_{ij}$ – Non-Motorized trip number for zone type i and trip purpose j
$\sum_i MOTOR_{ij}$ - Total Motorized trips for all zones with trip purpose j
$\sum_i (MOTOR_{ij} + NONMOTOR_{ij})$ - Total trips (motorized and non-motorized) for all zones with trip purpose j

This formula represents the ratio of the motorized mode share for the zone relative to the motorized mode share for all zones. Table C.6 presents the calculated adjustment factors for all three types of zones by trip purpose.

It is interesting to note the counterintuitive result for home based non-work trips, where the adjustment for Level 2 zones is more significant than for Level 1 zones. To address this concern, factors were computed for a two-tiered zone system, where Levels 1 and 2 were combined. The resultant adjustment factors are presented in Table C.7.

Because of the inconsistent result for home based non-work trips, DRCOG and Cambridge Systematics decided to use the two-tiered zone classification system and the adjustment factors shown in Table C.7. The DRCOG trip generation program was revised to incorporate this revision.

Table C.5 Percentage of Trips in Boulder County That Are Non-Motorized

Zone Type	HBW	HBNW	NHB
Level 1	40%	44%	21%
Level 2	21%	34%	28%
Level 3	4%	10%	12%
All Levels	**6%**	**12%**	**13%**

Table C.6 Calculated Adjustment Factors for the Three-Tiered Zone System

Zone Type	Home Based Work	Home Based Non-Work
Level 1	0.653	0.789
Level 2	0.835	0.726
Level 3	1.016	1.012

Table C.7 Calculated Adjustment Factors for the Two-Tiered Zone System

Zone Type	Home Based Work	Home Based Non-Work
Levels 1/2	0.779	0.739
Level 3	1.016	1.012

Emissions Analysis Methods

The Denver emissions analysis was performed by the Colorado Department of Public Health, which undertakes emissions modeling for the Denver Regional Council of Governments (DRCOG) and other transportation agencies in Colorado. The analysis was performed using MOBILE6, with updated Denver-specific inputs for vehicle registration distribution (based on year 2000 State of Colorado data), VMT mix by road type and time of day, I/M program, and fuel characteristics. Average speeds by facility type were used for the ten time periods modeled by DRCOG. Start-based emissions were not modeled separately from VMT-based emissions.

Appendix D – Benefits of Using MOBILE6

EPA's MOBILE6 emissions factor model incorporates numerous enhancements to the previous MOBILE5 model, many of which are helpful in examining the emission impacts of a regional policy of promoting brownfield and infill development. Table A.1 summarizes the ability of MOBILE6 and MOBILE5 to capture the travel effects typically associated with brownfield and infill development.

MOBILE6 produces different emission factors due to differences in emissions modeling assumptions. A number of states and urban areas have found MOBILE6 to produce higher emission factors in the short term and lower emission factors in the long term compared to MOBILE5. As a result, the absolute emission benefits of a buildout (long-term) analysis could be overstated by the use of MOBILE5. However, it is not likely that percentage differences between scenarios would differ significantly.

In summary, MOBILE6 provides the following specific benefits over MOBILE5 for analyzing the emissions impacts of brownfield and infill developments:

- Allows the use of start-based emission factors as opposed to those based on vehicle-miles traveled (VMT). This is important if infill developments reduce vehicle trips in different proportion to VMT (i.e., if vehicle trip-lengths are shorter but there are just as many vehicle trips or, conversely, if vehicle trip lengths remain the same but there are fewer vehicle trips.) MOBILE5 does not provide separate emission factors for trip ends versus vehicle-miles of travel. As a result, the use of MOBILE5 could potentially underestimate the benefits of strategies that reduce vehicle trips that are shorter than average (shorter trips would have higher per-mile emissions, because of the contribution of start emissions).

- MOBILE6 produces *facility-specific* speed-based emission factors. MOBILE6 also contains updated/improved speed correction factors (SCFs) that vary by facility type. Thus, MOBILE6 provides more reliable estimates of the effects of changes in average vehicle speeds on emissions and also allows shifts in traffic among road types (freeways, arterials, local) to be assessed. These enhancements could lead to different estimates of the benefits of strategies that affect vehicle speeds and also of strategies that shift trips from one facility type to another. The impact of changes in speeds is likely to be smaller when estimated using MOBILE6 than for MOBILE5. Without looking at results in detail, however, it is difficult to say whether the speed and facility type changes alone lead to increases or decreases in emissions between scenarios.

- MOBILE6 allows changes in the *distribution* of trip lengths to be assessed (although this would require additional processing of travel analysis outputs).

Table D.1 Benefits of Using MOBILE6 versus MOBILE5 for Analyzing Infill/ Brownfields Vehicle Emissions Impacts

Effect on Travel Patterns	Do common travel analysis methods give us this information?	Can MOBILE5 Measure?	Can MOBILE6 Measure?
1. Shorter trip lengths due to:		Yes (VMT-based emission factors)	Yes/improved (effects of changes in *distribution* of trip lengths)
a. Regional context/ accessibility	Yes (interzonal trips are modeled)		
b. Local street connectivity	No (unless intrazonal trip lengths are adjusted)		
2. Fewer vehicle trips due to:		No	Yes (Start-based emission factors)
a. Mixed-use development and pedestrian access	Possibly (adjustments such as pedestrian environment factors must be applied)		
b. Transit accessibility (regional)	Yes		
3. Different traffic/driving patterns			
a. Slower average trip speeds due to urban setting	Yes (within limitations of speed output of 4-step models)	Yes (speed correction factors)	Yes/improved (updated speed correction factors)
b. Different mix of travel by roadway type (e.g., more local, less freeway)	Yes (for freeways & arterials – but some limitations for local roads)	No	Yes (speed correction factors by roadway type)
c. Lower acceleration and deceleration rates due to lower speeds, urban setting	No	No (except as embodied in SCF)	No (except as embodied in SCF by roadway type)

The benefits of applying MOBILE6 instead of MOBILE5 depend on having reliable data on travel pattern impacts, including effects of differences in development patterns and urban design on vehicle trip-making, vehicle trip lengths, and vehicle travel speeds by facility. The ability of existing analysis methods to assess these parameters varies.

Brownfield and infill developments also may have travel impacts that are not easily and routinely analyzed by common travel demand analysis methods, such as:

- Changes in vehicle activity patterns (e.g., fewer peak-hour vehicle trips, fewer “cold-start” trips, different soak times.)
- Differences in commercial vehicle trip rates or trip patterns.
- Changing patterns of vehicle ownership and use (e.g., fewer miles per year per car).

If data are available on these travel impacts, MOBILE6 can be used to assess the resulting emissions impacts (generally, more effectively than MOBILE5), but these data are not available in the travel modeling done for any of the three participating partner communities.