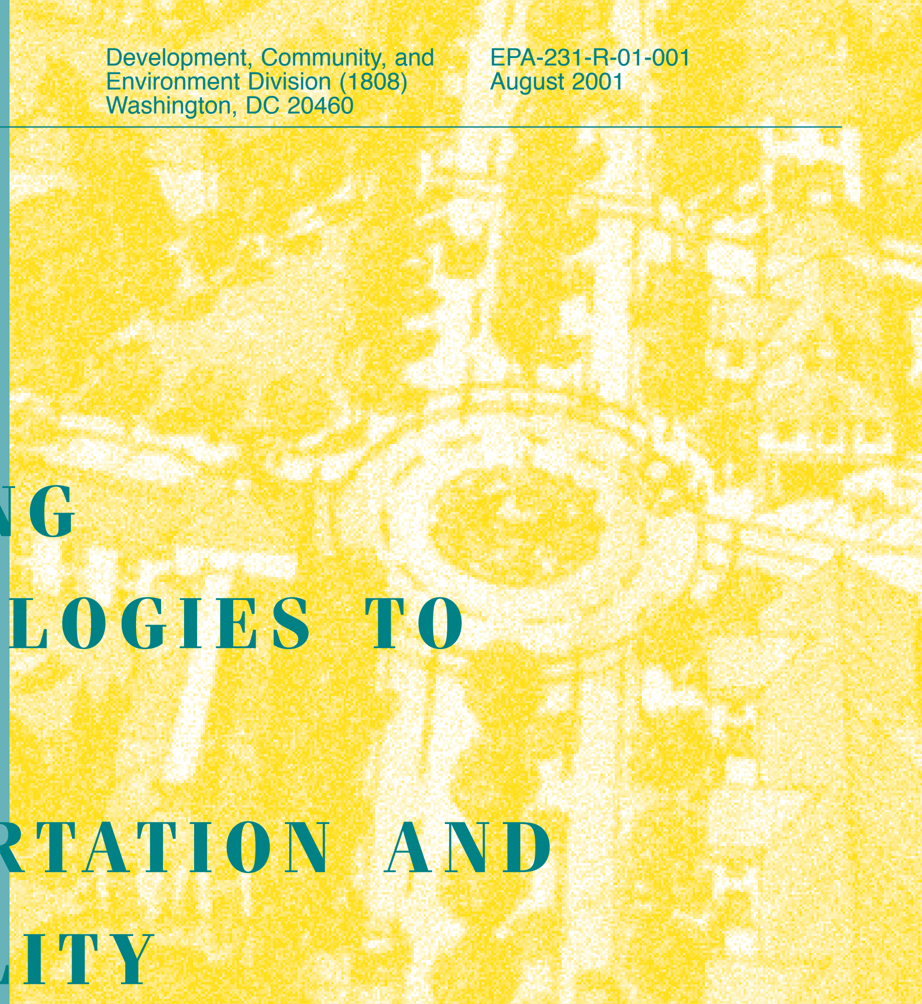
EPA
United States
Environmental Protection
Agency

Development, Community, and
Environment Division (1808)
Washington, DC 20460

EPA-231-R-01-001
August 2001



Comparing Methodologies to Assess Transportation and Air Quality Impacts of Brownfields and Infill Development

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
2565 PLYMOUTH ROAD
ANN ARBOR, MICHIGAN 48105-2498

OFFICE OF
AIR AND RADIATION

JUN 07 2001

MEMORANDUM

FROM: Robert Larson, Acting Director
Transportation and Regional Programs Division

TO: EPA Air Division Directors, Regions I - X
State and local agencies involved in preparing SIPs and conformity determinations

SUBJECT: Guidance on applicable methodologies to account for the benefits of infill in SIPs and conformity determinations

I. Introduction

The attached document, "Comparing Methodologies to Assess Transportation and Air Quality Impacts of Brownfields and Infill Development," EPA 231-R-01-001, was prepared for EPA's Office of Policy, Economics, and Innovation. This document discusses four methodologies to quantify the air quality benefits associated with infill development. "Comparing Methodologies" contains valuable information that will be helpful to areas that want to quantify air quality benefits of infill development and should be used in considering the methodologies available.

The purpose of this memorandum is to provide guidance regarding the use of the methodologies from "Comparing Methodologies" in preparing state implementation plans (SIPs) and transportation conformity determinations.

In addition to the information in this memorandum, areas that would like to calculate the benefits of infill development should rely on the guidance document called "Improving Air Quality through Land Use Activities," EPA 420-R-01-001, published January 2001. This guidance discusses statutory and regulatory requirements that must be followed when including the benefits of land use activities in SIPs and conformity determinations. It is available on our website at http://www.epa.gov/otaq/traq (then click on "Sustainable Development"), and can also be obtained through the National Service Center for Environmental Publications, by calling 1-800-490-9198.

As discussed in EPA's "Improving Air Quality through Land Use Activities," areas that want to quantify the benefits of a land use activity, such as infill development, must consult on the methodologies and assumptions that are used in SIP development and conformity analyses. Emissions benefits from infill projects should be based on the best information available, and areas should ensure that double-counting of infill benefits does not occur. The transportation conformity rule (40 CFR 93.105) requires a consultation process be established for evaluating and choosing models and the latest assumptions used in conformity analyses. For example, in metropolitan areas, the metropolitan planning organization (MPO), the state air quality agency, the Department of Transportation (DOT), and EPA must consult on the models and assumptions before they are used for conformity. Areas should also consult with their EPA Regional office when quantifying the emissions impacts of infill for SIP development.

<u>When would an area use one of these methodologies?</u>
Overall land use patterns are captured in regional transportation modeling that is used in SIP development and conformity determinations, because population and employment forecasts must be made for the amount of travel and emissions to be estimated. Areas may decide to include the impacts of infill development in the regional transportation modeling used in SIPs and conformity, and if so, they would not use any of the methodologies described in the "Comparing Methodologies" document. They would capture the air quality benefits of the infill within the overall results of their transportation modeling. We believe this is a valid way to capture the benefits of an infill development, and a good method to use particularly when the infill development is large. Because the benefits of the infill development would be captured in the overall results, areas would not know the precise amount of benefit that an infill development would have.

Nevertheless, an area may not be able to capture the benefits of infill using the overall modeling process. First, a single infill development is often too small, relative to the size of the geographical units used in the transportation model, for it to affect the overall results of the transportation modeling. Second, an area may need to determine the benefits of an infill development at a time when the transportation modeling has already been done and will not be done again for several years. Third, an area may need to quantify the benefits from infill separately, rather than as part of the overall transportation modeling done for the area, to quantify the specific benefits that result. In these cases, an area could use one of these methodologies in accordance with this guidance.

<u>II. Guidance on the four methodologies</u>

As in "Comparing Methodologies," we use the abbreviations M1, M2, M3, and M4 to refer to the four methodologies. All of these methodologies are a way of answering the question, "if development did not go to the infill site, where would it have gone instead?"[1] These methodologies provide an alternate

---

[1]In quantifying the benefit of infill, the implicit assumption is that when an infill site is developed, the population and employment that would go to the infill site is growth that has already been accounted for in future forecasts. It is not more growth over and above what has been forecast. The population and employment associated with the infill site is growth that is being shifted from somewhere else in the region, rather than being

methodologies and assumptions that are used in SIP development and conformity analyses. Emissions benefits from infill projects should be based on the best information available, and areas should ensure that double-counting of infill benefits does not occur. The transportation conformity rule (40 CFR 93.105) requires a consultation process be established for evaluating and choosing models and the latest assumptions used in conformity analyses. For example, in metropolitan areas, the metropolitan planning organization (MPO), the state air quality agency, the Department of Transportation (DOT), and EPA must consult on the models and assumptions before they are used for conformity. Areas should also consult with their EPA Regional office when quantifying the emissions impacts of infill for SIP development.

When would an area use one of these methodologies?
Overall land use patterns are captured in regional transportation modeling that is used in SIP development and conformity determinations, because population and employment forecasts must be made for the amount of travel and emissions to be estimated. Areas may decide to include the impacts of infill development in the regional transportation modeling used in SIPs and conformity, and if so, they would not use any of the methodologies described in the "Comparing Methodologies" document. They would capture the air quality benefits of the infill within the overall results of their transportation modeling. We believe this is a valid way to capture the benefits of an infill development, and a good method to use particularly when the infill development is large. Because the benefits of the infill development would be captured in the overall results, areas would not know the precise amount of benefit that an infill development would have.

Nevertheless, an area may not be able to capture the benefits of infill using the overall modeling process. First, a single infill development is often too small, relative to the size of the geographical units used in the transportation model, for it to affect the overall results of the transportation modeling. Second, an area may need to determine the benefits of an infill development at a time when the transportation modeling has already been done and will not be done again for several years. Third, an area may need to quantify the benefits from infill separately, rather than as part of the overall transportation modeling done for the area, to quantify the specific benefits that result. In these cases, an area could use one of these methodologies in accordance with this guidance.

II. Guidance on the four methodologies

As in "Comparing Methodologies," we use the abbreviations M1, M2, M3, and M4 to refer to the four methodologies. All of these methodologies are a way of answering the question, "if development did not go to the infill site, where would it have gone instead?"[1] These methodologies provide an alternate

[1] In quantifying the benefit of infill, the implicit assumption is that when an infill site is developed, the population and employment that would go to the infill site is growth that has already been accounted for in future forecasts. It is not more growth over and above what has been forecast. The population and employment associated with the infill site is growth that is being shifted from somewhere else in the region, rather than being

scenario for development, to be compared to the infill development scenario. Through this comparison, the air quality benefits of the infill development can be estimated. The alternate scenarios are:

M1: The population goes to a single "greenfield" site.
M2: The population goes to the fastest growing parts of the region.
M3: The population is distributed throughout the region, in amounts determined by the local land use model.
M4: The population is distributed throughout the region, in amounts proportional to the distribution of other growth.

Please refer to"Comparing Methodologies" for the complete description of the methodologies.

Given the strengths and weaknesses of the four methodologies, we believe:

- M3 is the best approach, and should be used by areas that have land use models.
- M4 and M2 are preferred approaches in areas that don't have land use models.
- M1 is the weakest of the approaches, and should not be used for SIPs and conformity, but is still useful as a sketch planning tool.

If an area chooses to use M2, M3, or M4 (or a variation of it that is described in "Comparing Methodologies,") the area should follow the steps described in "Comparing Methodologies." Deviations from or adaptations of these steps could be acceptable but must be discussed through the interagency consultation process.

A. Areas that have a land use model should use M3

The purpose of land use models is to assess where new population and development will occur, based

---

additional growth to the region. This assumption has been made when areas develop long range planning scenarios; EPA believes it is a valid assumption.

However, these methodologies compare scenarios where growth is added in both the infill and the comparison scenario. This is why the question is stated, "if growth didn't go to the infill development, where would it have gone instead?" In these methodologies, the two scenarios being compared have the same total population, but this total is slightly higher than the area's planned forecast. The total is higher by the population associated with the infill development, a very small portion of the total regional population.

Some might argue that this doesn't accurately represent the "no-build" case. However, adding growth to both scenarios is a convenience for calculation's sake, and does not represent an expected increase in regional population. To compare infill with the no-build case, the infill scenario would have to draw anticipated growth from elsewhere in the region, since the assumption is that population will remain the same, regardless of individual projects that are built.

Comparing two scenarios where growth is added in both cases is very similar to comparing a scenario where infill "pulls" growth from elsewhere in the region to the "no-build" case. Therefore, we believe adding growth to both scenarios is a valid way to examine the benefits of infill.

on the available land area and local conditions. As indicated in "Comparing Methodologies," regional land use models are suited to answer the question, "How will regional land use change in response to increased infill?" In addition, using a land use model is an objective method to determine where population and employment would occur if the infill site is not developed. Land use models are objective in that they are the least influenced by personal opinion. In M3, the land use model chooses where growth would go if the infill site were not developed. Therefore, results should be replicable regardless of who runs the model. Given their purpose and their objectivity, we believe that land use models are the best method of developing an alternate scenario for comparing an infill development, and should be used by areas that have land use models.

EPA encourages areas that currently do not have a land use model to obtain one if they use a travel demand model, given that it can provide an objective basis for transportation modeling and subsequently, emissions modeling. See EPA's "Improving Air Quality through Land Use Activities," for more information regarding land use models.

One limitation of M3 is that land use models may not be able to analyze small developments, if the size of the unit area examined within the model is too big. Land use models must be consistent with the travel demand model used. At best, the size of the geographical unit examined in the land use model can only be as small as the size of a geographical unit examined in the travel demand model, called a travel analysis zone (TAZ). Some land use models use census tracts as the smallest geographical unit examined. We encourage areas, where possible, to refine both travel demand models and land use models to examine smaller geographic areas. Doing so will improve their capability to examine small changes accurately. However, even given this potential limitation, land use models are useful for examining reallocation of population at a broad regional level.

B. Areas that don't have land use models should use M4 or M2

For areas that do not yet use a land use model, we believe M4 and M2 are also acceptable methods.

M4. As discussed in "Comparing Methodologies," M4 is also an objective method, because it is based on travel demand and emissions modeling outputs. M4 provides a way to estimate the effects of growth being "widely dispersed" throughout the region if the infill development were not built. M4 simulates dispersing growth by determining the average VMT and emissions associated with new growth, and multiplying by the population of the infill site. In this way, M4 is essentially a substitute for running a land use model, or adjusting housing and employment characteristics of each TAZ (please see "Comparing Methodologies" for the full description of M4).

One disadvantage of M4 as described in "Comparing Methodologies" is that it attributes all changes in VMT and emissions over time to new population. It does not separate out the effects of additions to the transportation network, or new emission reducing technologies or regulations. However, though average emissions may be overestimated or underestimated, that over- or underestimate is applied to both the infill case and the comparison scenario, so we believe that this drawback is relatively minor.

M2. Another option available to areas that don't use a land use model is M2. As in M3 and M4, M2 is an objective method, in that it relies on the model to distribute new growth. In M2, growth is distributed to the fastest growing travel analysis zones (TAZ). M2 could be applied using different cut-off points for the number of TAZs, e.g., areas could:

a. distribute growth to the 20 fastest growing TAZs, in proportion to the percentage of new growth going to suburban and urban areas;

b. distribute growth to a percentage of the total TAZs, such as the fastest growing 10% of TAZs;

c. calculate the mean growth and standard deviation of TAZs, and distribute growth to the TAZs where growth is greater than or equal to three standard deviations above the mean;

Please rely on"Comparing Methodologies" for a full description of the methodology and its variations.

The disadvantage of options (a) and (b) is that no solid basis exists for either choosing a particular number of TAZs or choosing a particular percentage of areas in which to distribute growth. However, we believe this drawback is minor. Even if as few as the 20 fastest TAZs are chosen, growth is distributed in a way that is replicable, comparable, and conservative. Areas should consider the size of the infill project when determining how many TAZs would be reasonable. The larger the infill project, the greater the number of TAZs should be chosen for the comparison scenario. The number of TAZs chosen when applying M2 must be agreed to through the interagency consultation process, but we believe areas should choose at least 20, as was done in EPA's "Comparing Methodologies" study.

We recommend that areas with a large number of TAZs choose options (b) or (c) rather than (a). For example, in an area with 500 TAZs, assigning the infill growth to just 20 TAZs only spreads the growth into 4 % of the TAZs. Such an area may decide to assign the infill to 10% of their TAZs, which would be 50 of them. Areas should select enough TAZs to reasonably represent how growth is occurring in the area. The percentage selected should be decided on through the interagency consultation process.

C. Circumstances where M1 is appropriate

In M1, the development of an infill site is compared to a scenario in which the infill growth goes to one, two, or three "greenfield" sites in the area (please see "Comparing Methodologies" for the full description of the methodology).

EPA believes that M1 has several disadvantages and the other methods are superior and more appropriate for quantifying the benefit of infill in a SIP or in a conformity determination.

What are M1's disadvantages?

The main disadvantage of this approach is that choosing a site for comparison is done subjectively. With M1, it would always be possible to find some site that is farther away than the chosen infill site. Therefore, regardless of where the infill site is located, it would always be possible to choose a site farther away that would thus generate a greater amount of VMT and emissions if the infill growth were to be allocated there. In this way, M1 is subjective: its results can be influenced by the comparison site that is chosen. For example, suppose an infill development is on the edge of a town; it doesn't have an air quality benefit when analyzed with M3, M4, or M2. It would still be possible to show it has an air quality benefit using M1, because a comparison site could be chosen that is even farther away than the infill site. In addition, this methodology oversimplifies where the alternative growth will go by allocating it all to one site.

When is M1 useful?

We believe M1's primary usefulness is to illustrate the effects of location choices. M1 can be used as a sketch planning tool to show that infill growth results in fewer VMT and emissions, compared to growth that may be occurring on the edge of the region. While this method is not appropriate for SIP and conformity analysis, areas can use M1 when comparing different scenarios, such as analyzing alternative scenarios under NEPA. As a sketch planning tool, M1 may have some advantage over the more detailed approaches of M2, M3, and M4. For example, M1 is conceptually easy to understand and therefore may be the best way of demonstrating the benefits of infill to people who are not familiar with the intricacies of land use, travel, and emission models.

III. Other Methodologies

EPA recognizes that areas may develop other methodologies that are equally valid as M2, M3, and M4. For example, areas may decide that rather than add a small amount of population to both the infill and the comparison case, as occurs in these methodologies, they would prefer to retain the population total that has been established. While the approaches outlined above in most cases augment established population totals with a small amount of additional development, a preferred approach may be to add development to certain zones – "receiver zones," while simultaneously subtracting growth from other zones – "donor zones" – to retain the original approved regional land-use totals. Doing so would ensure that development scenarios may be reasonably compared against existing model estimates, which may eliminate the need for an additional model run.

IV. Conclusion

Areas should examine the information in "Comparing Methodologies" as well as this memorandum in determining how to quantify the air quality benefit of infill development. Questions regarding these methodologies should be directed to Geoff Anderson at (202) 260-5044; questions regarding this guidance memorandum should be directed to Laura Berry at (734) 214-4858.

EXECUTIVE SUMMARY

States and communities across the country are actively pursuing smart growth strategies. New transit lines are opening to higher ridership than expected. States and communities have passed hundreds of ballot initiatives preserving open space, increasing development around transit, and providing for increased redevelopment of abandoned brownfield sites. Through such strategies, smart growth -- defined as development that serves the economy, community, and the environment -- can help communities meet national environmental standards by reducing motor vehicle emissions, improving water quality, and cleaning up and reusing land that is contaminated (or suspected of being contaminated) from former uses.

This report, *Comparing Methodologies to Assess Transportation and Air Quality Impacts of Brownfields and Infill Development,* is a companion piece to recent EPA policy guidance, titled *EPA Guidance: Improving Air Quality Through Land Use Activities* (EPA 420-R-01-001; January 2001). The primary audiences of both this report and EPA's guidance document include managers and staff in state and local air quality agencies, regional transportation planning agencies, and state departments of transportation – people responsible for air quality and transportation planning. Others, including citizens and community organizations, may also be interested in the ideas, policies, and technical issues presented in these two companion reports.

When smart growth choices, such as development of brownfields and other infill sites, yield environmental benefits, states and communities are eager to have such benefits count towards achievement of nationally applicable environmental regulatory standards. The U.S. Environmental Protection Agency (EPA) is responding by developing new mechanisms to measure environmental outcomes and recognize those results in the context of the agency's programs. This study describes four possible methods for characterizing the air quality benefits resulting from infill development, compares them, and examines their individual advantages and disadvantages as well as their overall strengths and weaknesses.

Infill development, by definition, takes place within an area that is already developed or has been developed previously and subsequently abandoned. Brownfields development is an important subset of infill development. Brownfields are abandoned or underutilized properties where expansion or redevelopment is complicated by either real or perceived environmental contamination. Brownfields redevelopment and infill development can protect local air quality by reducing the length of auto trips and making other modes of transportation more convenient. They can reduce growth in regional tailpipe emissions.

Recognizing that infill can provide emissions reductions relative to the alternative of locating development elsewhere in the metropolitan area is the key to quantifying future emissions reductions. That is, many brownfield redevelopment and infill projects are expected to have air quality benefits compared with the status quo baseline. In the baseline, growth has typically been locating in suburban and exurban areas and is expected to continue doing so. Such development often produces substantially more vehicle travel and emissions than development on infill sites. The greater the difference between the travel produced from locating at an infill site versus the travel that would have been produced by locating at a suburban or exurban site, the greater the air quality benefit of the infill location.

The methodologies presented and discussed here compare the travel and air quality implications of *developing* an infill location as opposed to *not developing* the location and having the "growth increment" go elsewhere in the region. Each methodology is a different way to answer to the question, "If development does not go to a particular infill site, where would it go instead?" The answer has implications for the emissions credit that can be claimed under a State Implementation Plan (SIP) for achieving compliance with Clean Air Act requirements. To explore the advantages and disadvantages of each methodology, test applications were performed in four cities – Baltimore, Dallas, Chicago, and Atlanta.

Following are the four methodologies:

Methodology 1: Growth would have gone to a single "typical" greenfield site.

Methodology 2: Growth would have gone to the fastest-growing parts of the region.

Methodology 3: Growth would have been distributed throughout the region, as estimated by the local land-use model (applicable only where a land-use model has been adopted).

Methodology 4: Growth would have been distributed through the region, in amounts proportional to the distribution of all other growth.

The four methodologies have different strengths and weaknesses:

Methodology 1 (M1) does not provide an objective way for determining the appropriate site for comparison. Rather, it relies on expert judgment to determine which greenfield site is appropriate for comparison against the infill location. Site selection can make a substantial difference in the outcome. M1 also may be unrealistic in comparing the infill location to a single greenfield. More likely, the infill would displace growth from a number of locations. Finally, to be effective, this methodology may require the selection of a minimum development size. On the other hand, M1 provides a useful sketch planning tool and, of the four methodologies, M1 is the easiest to understand and communicate to the public.

Methodology 2 (M2) solves M1's chief problem by pulling growth from the fastest growing Transportation Analysis Zones (TAZs) in the region. M2 thus reflects local growth trends and the fact that infill is likely to draw from a number of locations. This methodology does not require the analyst to make a subjective choice of alternative location(s). M2 explicitly accounts for growth shifted from other infill locations. The proportion of growth to be shifted from other infill locations can be adjusted to reflect regional trends in growth distribution and can be made more or less conservative by adjusting the proportion of the growth allocated to infill locations. However, M2 does not provide an objective rationale for distributing growth over a set number of TAZs. It requires a minimum development size to be effective.

Methodology 3 (M3) uses the local land-use model, where there is one, and thus provides an objective method for determining locations from which growth would be shifted. Application of the land-use model does require substantial effort. M3 is not applicable in areas that do not have a land-use model.

Methodology 4 (M4) has the advantage of simulating a land-use model without running one. It compares the impacts of the infill site with the impacts of growth from all over the region—proportional to its predicted distribution. M4 requires no choice by the user of an alternative site and so provides an objective methodology for comparison. Size of development is not a concern for M4 because this methodology does not require that the analyzed growth increment be run through a model. However, where changes in travel behavior are expected from sources other than growth, these changes must be factored out, or else M4 will attribute them to the new growth, skewing the results.

Methodologies 1, 2, and 4 each require similar levels of effort, while M3 requires substantially more.

1 INTRODUCTION

Numerous states and communities are actively pursuing smart growth strategies that bring environmental gains -- such as better air quality when required automobile trips become fewer and shorter – as well as economic and community benefits. New transit lines are opening to higher ridership than expected. States and communities have passed hundreds of ballot initiatives preserving open space, increasing development around transit, and advancing redevelopment of abandoned brownfield sites. Smart growth -- defined as development that serves the economy, community, and the environment -- can help communities meet national environmental standards, such as national ambient air quality standards (NAAQS) established by EPA under the Clean Air Act.

When smart growth choices, such as development of brownfields and other infill sites, yield environmental benefits, states and communities are eager to have those benefits count towards achievement of nationally applicable environmental standards. EPA is responding by developing new mechanisms to measure environmental outcomes and recognize those outcomes in the context of the agency's programs. This study is one step forward in this ongoing process. Specifically, this study describes four methods for recognizing (quantifying) the air quality benefits that can result from brownfield revitalization and other forms of infill development.

The context for quantifying these air quality benefits is in the preparation of State Implementation Plans (SIP) and in transportation conformity determinations. A state must prepare and submit SIPs to EPA if one or more of its metropolitan areas does not meet Clean Air Act standards for specific air pollutants. The SIP serves as the state's commitment to actions that will reduce air quality problems. Specifically, each SIP must specify a motor vehicle emissions budget as part of a noncompliant area's total allowable emissions, and must include an inventory of current emissions and a forecast of future emissions. The transportation conformity process ensures that the estimated emissions produced by transportation activities are less than or equal to the motor vehicle emissions budget in the SIP.

Infill development, by definition, is development that takes place within an area that is already developed or has been developed previously. Brownfields redevelopment is an important subset of infill development. Brownfields are abandoned or underutilized property where expansion or redevelopment is complicated by either real or perceived environmental contamination. For a variety of reasons, many communities have made brownfield redevelopment and increased infill a local economic development priority. An important benefit of brownfield redevelopment and infill development is that they can protect local air quality by reducing the length of auto trips associated with new development and making other modes of transportation more convenient, thus reducing the growth of regional tailpipe emissions. EPA recently issued policy guidance that details various options available to states for recognizing these emissions reductions. [1] This report is a companion piece to that policy guidance.

Quantifying reductions in the growth of future emissions is key to the successful use of the new policy guidance. In order to examine the advantages and disadvantages of each of the four methodologies described in report, test applications were performed in four cities.

---

[1] *EPA Guidance: Improving Air Quality Through Land Use Activities* (EPA 420-R-01-001; January 2001). Online version available at >>http://www.epa.gov/otaq/traq<<. To obtain a hard copy, please cal1 EPA's National Service Center for Environmental Publications at 513 891-6561 and ask for the Guidance document by its publication number.

Methodology tests performed in each city

Region	Method 1	Method 2	Method 3	Method 4
Atlanta	✓	✓	✓	✓
Baltimore	✓	✓		✓
Chicago	✓			
Dallas	✓	✓		

This report, *Comparing Methodologies to Assess Transportation and Air Quality Impacts of Brownfields and Infill Development*, describes the results and draws conclusions from those results, to the extent possible.

For additional copies of this report, please call EPA's National Service Center for Environmental Publications at 513-891-6561, and ask for the document by its publication number (EPA-231-R-01-001).

2 DESCRIPTION OF THE FOUR METHODOLOGIES

Each methodology has the same goal: Quantify the air quality (emissions) impacts of redeveloping brownfields and developing other infill properties. However, each methodology differs in assumptions, complexity, and relative ease of application.

2.1 Starting assumptions for all methodologies

All methodologies test the proposition that *developing* an infill location will result in less growth of auto emissions relative to *not developing* the infill location and instead locating the growth elsewhere in the region. Specifically, the proposition argues the following:

1. The metropolitan region will continue to grow.

2. Growth is projected to locate mainly at the metropolitan region's edge.

3. This growth pattern is largely responsible for producing the region's current transportation patterns.

4. The infill site is an opportunity to shift some of this growth toward the center of the metropolitan area, increasing regional convenience and accessibility, and reducing future growth in travel mileage via private vehicles.

5. Shifting growth to an infill location does in fact represent a shift in growth, not additional growth within the region.

Transportation literature suggests travel emissions that would result from infill would be lower than emissions resulting from the same project built on a region's fringe. This is especially true in the following circumstances:

1. The proposed development would include higher densities, a mix of uses, and location near transit, and it would therefore generate fewer total vehicle trips than comparable amounts of development placed in locations that lack these features.

2. The proposed development would be located closer to a greater number of activities than is the case with fringe development, so vehicle trips to and from the site would be shorter on average.

Previous work by EPA has quantified the potential improvement in the transportation and environmental performance of a development if located to produce regional and transit accessibility. A 1999 study (*The Transportation and Environmental Impacts of Infill Versus Greenfield Development*, EPA 231-R-99-005) found that locating development on regionally central infill sites can produce emissions benefits when compared with locating that same development on greenfield sites on the fringe of the developed area. In three case studies, per capita vehicle miles traveled (VMT) associated with a development site were reduced by as much as 61 percent at infill sites compared with the greenfield sites, and NO_x emissions were reduced by 46 to 51 percent. This report and related literature suggest that infill projects may reduce emissions relative to a regional baseline.[2]

Because many regions' State Implementation Plans (SIPs) project continued suburban and exurban development, an increase in infill and a decrease in development at the fringe (relative to the SIP's projections) should be an emissions reduction not already anticipated in the SIP, and thus "surplus."

Naturally, in order for the emissions reduction to be "surplus," the development analyzed must represent an *increase* in infill development. If a newly proposed infill development simply absorbs growth already anticipated to go to another infill development, no new infill has occurred, and no surplus emissions reduction will be generated.

All methodologies assume a common starting point: *The shift in growth, and any resulting emissions benefits, will result from infill development located at a discrete site or set of sites*. Once a site has been located, the next question is, "What would have happened had this brownfield not been redeveloped, or incentives had not produced this infill project? Where would that increment of growth have gone instead?" The following methodologies are four different ways to answer that question.

2.2 Methodology 1: Growth would have gone to a single greenfield site

Rationale

Methodology 1 (M1) is the simplest and conceptually the most straightforward. M1 assumes that if growth were not to locate at the infill location, then it would locate at a discrete greenfield location. For example, M1 might compare the air emissions impact of a mixed-use housing and office development locating at an infill location in a suburban center versus that same development locating on a previously undeveloped site on the exurban fringe.

One can think about M1 in two ways. First, M1 can represent the likelihood that, if an infill development is not built, then a project similar to it in size and use mix will be developed on a discrete greenfield that can be identified. Perhaps the project will be built by a different developer or project consortium, but in any case it will be developed in response to market demand. In many cases metropolitan planning organizations can either forecast with some accuracy where major projects are likely to locate or explicitly guide that location process by identifying growth areas. For example, San Diego has a highly structured growth management system that designates the next development areas and can predict with some certainty the site that is "next in line" for development.

Second, M1 represents the possibility that, if an infill project is not completed, then a project similar to it in size and use mix will be developed on a greenfield *similar to* the site or sites analyzed. That is, the analyzed greenfield(s) represent(s) the location and design *characteristics* of greenfield projects likely to be built,

---

[2] William Schroeer and Eliot Allen. 1999. *The Transportation and Environmental Impacts of Infill vs. Greenfield Development: A Comparative Case Study Analysis*. Washington, DC: U.S. Environmental Protection Agency, EPA 231-R-99-005. See also *The Effects of Urban Form on Travel and Emissions: A Review and Synthesis of the Literature*, prepared by Apogee Research for the US Environmental Protection Agency, April 17, 1998, and *The Relationship between Air Quality and Land Use Patterns: A Review of Relevant Technical Studies and Analytic Tools*, prepared by Hagler Bailly for the Ozone Transport Commission, Washington, DC, June 29, 1999. The proposition that infill produces more efficient travel patterns has been examined regularly in the literature. For a somewhat older examination of the issue, see, for example, William M. Weisel and Joseph L. Schofer. 1980. *The Effects of Nucleated Urban Growth Patterns on Transportation Energy Consumption*. Prepared for the U.S. Department of Transportation, Research and Special Programs Administration, DOT-OS-50118.

even if the growth does not go to a single specific analyzed site. Thus, the greenfield is selected, based on experience in the region, to serve as a proxy for typical new development in the area.

Local planners, knowing that new growth has predominantly gone to a certain section of the metropolitan area and has been low density and single use, may choose a greenfield location and development type that mirrors those characteristics. Thus, in this methodology, the infill development may represent a shift from that greenfield location, another similar greenfield, or several greenfield sites. This methodology assumes that any greenfield and its accompanying characteristics such as regional location and site design are, from a travel perspective, essentially the same as any other likely greenfield. The resulting travel and air emissions should not differ substantively from those resulting from other likely greenfield locations.

The Baltimore, Chicago, and Dallas analyses reported in this study all used a single discrete greenfield location. However, they did not have a way to identify a greenfield that was next in line for development, so we used professional judgment to identify a greenfield site that could absorb the proposed amount of growth and would be a plausible location for it.

The Atlanta analysis selected three plausible greenfield locations, chosen to represent the general greenfield development options available in the Atlanta region and to capture important variables that help determine travel behavior:

Location	**Development Density**	**Regional Location**	**Served by MARTA Rail?**
Atlantic Steel (the infill site)	Urban	Central	Yes
Cobb/Fulton	Suburban	Suburban	No
South Henry County	Suburban	Exurban/Rural	No
Sandy Springs	Urban	Suburban Infill	Yes

The South Henry and Cobb/Fulton sites were judged consistent with the region's projected suburban and exurban growth. In other words, they are thought to be typical of the areas where new growth is being located and thus are the most reasonable comparison sites. The Sandy Springs site was judged a less likely destination for growth not absorbed at the Atlantic Steel site and was chosen as a conservative point of comparison.

Possible adjustment: Adjust for growth that would have gone to infill anyway

M1 does not necessarily assume that the infill site takes growth from any other infill site (unlike the other three methodologies, as explained below). The methodology can assume that all growth is displaced from the greenfield site. The infill development for which credit is being claimed may absorb some of that already-planned development, reducing infill in adjacent areas. On the other hand, it is also possible that the new development will spur additional infill development in the vicinity. This new infill development may be especially likely when a proposed development is designed as a catalyst and/or an anchor for other development to re-enter a brownfield zone.

To make M1 as conservative as possible, one would ignore catalyst effects and subtract from the project size all development already proposed for the infill area. Under the Atlanta pilot project, the total projected population of the infill development would be 23,000 new employees and residents. Prior to the proposed project, projected growth for the Midtown area where the project was slated to be located was 4,700 new employees and residents during the development period. If all those projected employees and residents located in the Atlantic Steel development, then only 80 percent of the infill project growth would be "new" growth in Midtown. In that case, any benefits should be scaled down by 20 percent to reflect only the new increment.

Methodology

Step 1: Select site pair

Select a site pair consisting of a greenfield site and an infill/brownfield site, each of which could absorb a similar amount of growth when constructed at locally prevailing densities.

Step 2: Model travel behavior

Run the regional travel model twice, once with development added at the infill site and once with the same amount of development added to the selected greenfield site(s).

Step 3: Model emissions

The travel model output will include VMT, which can be used as an input to the MOBILE emissions model to produce emissions under the infill scenario and the greenfield scenario.

Step 4: Adjust for growth that would have gone to infill anyway

To continue the Atlanta example, total infill development size would be 23,000 new employees and residents. Projected growth for Midtown was for 4,700 new employees and residents. Thus, one could argue that only 80 percent of the infill project growth would be "new" growth in Midtown. Thus, any benefit should be scaled down by 20 percent to reflect only the new increment. (This adjustment was applied to the Atlanta case, but not others.)

Advantages

Choosing one, or perhaps two or three, greenfield sites for comparison with the infill site has two substantial advantages:

1. It may represent the most likely development scenario, especially under a comprehensive planning program such as San Diego's.

2. It is relatively straightforward. Picking and analyzing a single site (or small number of sites) is potentially less time-consuming than the other methodologies studied.

Disadvantages

1. Growth may not locate at a single site or set of sites, resulting in an overestimate of intrazonal trips in the case of mixed use developments.

2. The process of choosing a "most-likely-to-develop" site cannot be made objective unless a region has a well-structured planning process.

The remaining three methodologies attempt to overcome these two disadvantages.

2.3 Methodology 2: Growth would have gone to the fastest-growing parts of the region

Methodology 2 assumes that growth at an infill site would otherwise have located in the fastest-growing parts of the region. Further, the methodology assumes that the growth should be allocated to both infill and suburban locations proportional to the regional distribution of new growth.

Rationale

M2 assumes that growth not located on an infill site would otherwise go to the fastest growing parts of the region, since that is where most growth locates now. M2 also assumes that regardless of regional trends, *some* growth not located on an infill site would otherwise go to other infill sites. This assumption explicitly recognizes that infill markets may be competing against one another for new development. In other words, if a developer and its customers desire to locate on an infill site, they may also have been willing to look at other infill sites.

Methodology

Step 1: Divide the region into "urban" and "suburban" Transportation Analysis Zones (TAZs)

Many TAZ-based modeling systems classify their TAZs according to the predominant development type and TAZ location (based on the TAZ's population and/or employment density and a 'distance to CBD' measure). For example:

1. Central Business District (CBD) 2. Urban High Density-Commercial 3. Urban Residential	} Urban
4. Suburban Commercial 5. Suburban Residential 6. Exurban	} Suburban
7. Rural	

In this system, types 1, 2, and 3 would be "urban," and 4, 5, and 6 would be "suburban." TAZs in type 7 would not be part of the pool of potential TAZs to receive growth.

Step 2: Find the fastest-growing urban and suburban TAZs

Calculate the percentage of new growth going to urban TAZs and the percentage going to suburban TAZs. For example, in the Atlanta case 20 percent of new growth (growth over the next 10 years) was projected to go to urban TAZs while 80 percent was projected to locate in suburban TAZs.

Select a total of 20 TAZs from urban and suburban areas. The number of urban and suburban TAZs selected should reflect the relative distribution of future growth. Those TAZs showing the fastest growth are those most attractive to the market, and thus the ones most likely to attract new growth. For the Atlanta case we selected the following:

- 4 fastest-growing urban TAZs
- 16 fastest-growing suburban TAZs

This ratio reflects the fact that 80 percent of Atlanta's new growth currently goes to the suburbs. If only 10 percent of new growth were expected to locate in the urban areas we would select only the two fastest-growing urban TAZs and the 18 fastest-growing suburban TAZs.

Step 3: Distribute infill growth to the selected urban and suburban TAZs

Distribute across the selected TAZs the proposed growth increment (the number of employees and households proposed for the infill site). For example, if the infill site is projected to add 1000 new employees and 1000 new households, then add the following to the selected urban and suburban TAZs:

	Total	Per TAZ	# of TAZs
Urban employees	200	50	4
Urban households	200	50	4
Suburban employees	800	50	16
Suburban households	800	50	16

Step 4: Model travel behavior

Run the regional travel model twice, once with development added at the infill site, and once with same amount of development added to the selected urban and suburban high growth TAZs.

Step 5: Model emissions

The travel model output will include VMT, which can be used as an input to MOBILE to produce emissions under the infill scenario and the greenfield scenario.

Step 6: Adjust for growth that would have gone to infill anyway

To continue the Atlanta example, total infill development size would be 23,000 new employees and residents. Projected growth for the Midtown area surrounding the infill site was 4,700 new employees and residents. Thus, one could argue that only 80 percent of the infill project growth would be "new" growth in Midtown. However, since we already put 20 percent of the "baseline" growth in urban TAZs, it would almost certainly be overly conservative to again scale down credit by 20 percent as we did in M1.

Advantages

1. Objective/transferable
2. Relatively straightforward
3. More conservative than M1, because it automatically allocates a percentage of the growth increment to infill. Further, if no infill is projected in the infill TAZ in M1, then no downward adjustment would be applied. Because M2 uses the urban area as a whole, rather than the individual TAZ, some of the infill development is still essentially "replacing" other infill development.
4. Flexible: the proportion of growth assumed to go to urban/suburban TAZs can be varied to reflect local projections.

Disadvantage

There is no good basis for choosing 20 fastest-growing TAZs, as opposed to some other number. The number will represent a different proportion of TAZs in different regions.

As an alternative approach to M2, we considered the following approach:

a) Rank TAZs by total growth in employment + population.

b) Find mean growth and standard deviation. Find TAZs at or more than three standard deviations greater than the mean growth.

c) Distribute the growth across those TAZs in proportion to the growth predicted to go to those TAZs in the baseline.

Defining “fastest growing” in statistical terms not only solved the problem of varying total numbers of TAZs from region to region, but also allowed the definition of “fastest” to respond to different regional growth patterns. We could also have defined “fastest” as being a certain *percentage* of total regional TAZs. However, the added complexity did not solve the fundamental weakness of this methodology, which is that there is no solid reason for choosing a cut-off above which TAZs are deemed “fast growing.”

2.4 Methodology 3: Growth would have been distributed through the region, in amounts determined by the local land use model

Rationale

Methodology 3 (M3) uses a region’s land use model, if it has one, to determine the effect of additional infill on regional growth patterns.

The model DRAM/EMPAL (Disaggregate Residential Allocation Model (DRAM) and the Employment Allocation Model (EMPAL)) were used to test M3 in Atlanta. DRAM/EMPAL does not make explicit assumptions about how a market responds to infill. Rather, the model attempts to model land use patterns as a function of transportation accessibility, land availability (both physical, and as constrained by zoning), and past growth patterns. DRAM/EMPAL does not model decision-making by individual residents or employers, nor does land economics enter the model except indirectly through historical consumption trends. Rather, the model extrapolates past trends within a set of land use and transportation constraints.

Several other land use models attempt to represent urban land use economic decision-making more explicitly. Evaluating the pros and cons of various approaches to regional land use (or transportation and land use) modeling is beyond the scope of this study. However, DRAM/EMPAL is the most commonly used land use model in the United States, and was thus the obvious candidate for use in testing M3.

Methodology

Step 1: Select infill site

As in the other methodologies.

Step 2: Obtain DRAM/EMPAL forecast

Allow DRAM/EMPAL to reallocate housing and employment from a baseline forecast, while forcing growth to the infill site. One can use DRAM/EMPAL to perform this analysis in two ways.

In either approach, one performs two DRAM/EMPAL runs; one baseline, and one with the proposed development, each with the same number of jobs and housing (the "control total"). In the baseline run, DRAM/EMPAL distributes the control total across the region with no assumption about how much development occurs at the infill site. For the "infill run," the population and housing in the analysis zone where the infill is proposed is set manually to total existing + proposed development. With the infill development set manually, that many fewer jobs and housing will be available to the model to be allocated to the rest of the region, and totals in those zones will be slightly lower than in the baseline. The difference between the two is where growth would have gone in the absence of the infill project.

The two approaches use different starting points. The first—and most conceptually pure approach—uses the region's *existing* forecast control total as its control total. The second possible approach increases the control total by the proposed infill growth increment. The baseline run adds the proposed infill increment to the existing land use forecast, and distributes the increment through the region. The "infill run" fixes the proposed infill increment at the proposed infill site. (The results of the infill run will not be simply the results of the current control total baseline with the infill added to the infill TAZs, because DRAM/EMPAL will reallocate some growth in response to the additional growth at the infill site.) The difference between the two is again where growth would have gone in the absence of the infill project.

Although the second approach uses a higher control total, the two approaches should return very similar results. Because in the case studies described here, the model was being used to gauge relative benefits rather than absolute benefits, the higher control total was not a concern. Use of this second approach as part of a SIP quantification scenario would have to account and correct for this higher control total. Finally, users of this approach will need to remind their audiences that the higher control total is a convenience for calculation's sake, and does not represent an expected increase in regional population.

Step 3: Model travel behavior

Run the regional travel model twice, once with development fixed at the infill site, and once with population and employment allocation by DRAM/EMPAL unconstrained.

Step 4: Model emissions

The travel model output will include VMT, which can be used as an input to MOBILE to produce emissions under the infill scenario and the unconstrained scenario.

Step 5: Adjust for growth that would have gone to infill anyway

The 20 percent adjustment made to benefits in M1 is an attempt to do manually—and somewhat crudely—what DRAM/EMPAL is designed to do automatically: predict how growth will respond to the placement of new development on a particular site. Therefore it is inappropriate to adjust the results of M3.

Advantages

1. Regional land use models were developed specifically to answer precisely the question "How will regional land use change in response to increased infill?"

2. Objective/transferable.

Disadvantages

1. Regional land use models require a minimum difference between employment and housing scenarios in order to show meaningful change in outputs. Otherwise the results may be overwhelmed by the noise inherent in such models. The models were not developed to react to small changes in regional zoning, and so are not appropriate for analyzing small developments.

2. Many regions do not have a land use model. Even with such a model already installed and running, individual runs are quite resource intensive. M3 is the most resource intensive methodology.

2.5 Methodology 4: Growth would have been distributed throughout the region, in amounts proportional to the distribution of all other growth

Rationale

Methodology 4 (M4) assumes that the growth at the infill site would otherwise have "followed" all other new growth in the region. Thus, for example, if five percent of regional employment growth were projected to go to a given TAZ, then five percent of the infill project's employment would have gone to that TAZ. The same allocation would be repeated for all TAZs, regionwide.

Although M4 assumes that the growth increment would have "followed" other growth, the methodology takes a shortcut past actual allocation. Since the goal of each analysis is to determine the travel associated with the growth increment, this methodology goes directly to quantifying travel and emissions.

Methodology

Step 1: Select infill site and number of jobs and households in the infill development.

As in the other methodologies.

Step 2: Calculate travel behavior and air emissions of all new growth predicted for the region, without proposed infill

Calculate the difference in total travel between two years, e.g., 2000 and 2010:

	Out year (2010) regional VMT and emissions from regional travel model, without infill project
–	Base year (2000) regional VMT and emissions from regional travel model
=	VMT and emissions associated with all new jobs and housing (between 2000 and 2010)

If regional mileage is predicted to be 1,000,000 miles in 2000, and 1,200,000 miles in 2010, then:

	2010 regional VMT from regional travel model, without infill project:	1,200,000
–	2000 regional VMT from regional travel model:	1,000,000
=	VMT associated with all new jobs and housing between 2000 and 2010:	200,000

One can do the same calculation for emissions. These calculations produce results with a difficult-to-interpret denominator: VMT/jobs+housing. These figures must be further broken down into travel behavior and emissions associated with each new employee and each new housing unit.

The Appendix gives detailed directions on how to decompose “per household VMT and emissions” and “per employee VMT and emissions” estimates from total regional VMT and emissions change.

Step 3: Calculate VMT and emissions associated with proposed infill development's jobs and housing—as if those houses and jobs did not go to the infill.

Once one knows the travel and emissions associated with each new job and employee, one can calculate:

Miles driven and emissions associated with 1 new job multiplied by the new jobs proposed for the infill site

\+ Miles driven and emissions associated with 1 new person multiplied by the new population proposed for the infill site

---

= New miles driven and emissions if infill-project growth follows average dispersal pattern

This calculation gives the VMT and emissions associated with the infill increment’s housing and employment—if that housing and employment do not go to the infill site and instead follow the average growth patterns for the region.

Step 4: Calculate VMT and emissions impacts of locating growth at the infill site.

Using the 2010 model setting (the infrastructure and population projected for 2010) calculate the VMT and emissions associated with the 2010 scenario. Next add, to the 2010 scenario, the infill development’s projected jobs and housing to the infill TAZ. Run the four-step transportation model and the MOBILE model. Subtract the 2010 regional VMT and emissions from the VMT and emissions of the “2010+Infill” scenario. This total is the VMT and emissions associated with the infill development.

Total Regional VMT and emissions associated with the 2010 scenario (population, jobs, infrastructure) plus the VMT and emissions associated with the infill.

– Total Regional VMT and emissions associated with the 2010 scenario (population, jobs, infrastructure).

= New miles driven and emissions generated by infill development.

Step 5: Calculate VMT and emissions impacts of locating growth at the infill site versus the same increment of growth locating in an average way around the region.

Subtract the VMT and emissions associated with the infill development location from the VMT and emissions associated with locating the same increment of growth in an average dispersal pattern.

VMT and emissions associated with average new growth.

– VMT and emissions associated with the infill.

= Difference between infill development VMT/emissions and VMT/emissions associated with new growth.

Step 6: Adjust for growth that would have gone to infill anyway

As in the preceding three methodologies, it could be argued that (in the Atlanta example) only 80 percent of the infill project growth is "new" growth. Thus any credit should be scaled down by 20 percent to reflect only the new increment. However, this would not be entirely true in this scenario as some of the average new growth would account for growth allocated to Midtown, as well as other infill locations across the region. In this case the 20 percent reduction would be a particularly conservative reduction, underestimating the impact of the infill.

Advantages

1. Assumes that growth is drawn proportionately from all over the region, recognizing that the entire metropolitan region is a market where development choices have a ripple effect. In other words, this method accounts for the fact that infill development can affect markets for housing or retail space in inner ring suburbs and other infill areas. These in turn may affect development choices in newer suburbs and so on throughout the region if the development is of sufficient scale.

2. Objective/transferable

3. Provides a facsimile of a scenario in which growth that would otherwise have gone to the infill site is "widely dispersed," without having either to run a land use model like DRAM/EMPAL or adjust the housing and employment characteristics of every TAZ.

Disadvantages

1. Does not separate out the effect of changing trip-making behavior for the base population, including changes produced by new roads and transit. Over long time periods this may be a significant drawback. For instance if a significant number of people *currently* living in the region begin driving more (for economic, demographic or other reasons), the resulting change in VMT will be incorrectly attributed to new residents and employees, resulting in an overstatement of infill development's benefits. Similarly, emissions reductions in the base (from fleet turnover for instance) may artificially reduce the emissions associated with new employees and residents, thereby understating the benefits of the infill project. The potential for significant changes in the base VMT and emissions increases with longer periods of analysis. Therefore it is recommended that care be exercised when using M4 over time frames in which the base is likely to exhibit significant change.

2. Does not analyze a specific land use. That is, as described, this methodology does not change a land use allocation, which is then used as a travel model input. Thus, M4 cannot produce system performance measures (average trip times, etc.). At first this may appear more a concern for regional policymakers, who find these measures useful, than for EPA, for whom these measures are not an input to a SIP decision. However, not running a travel model may mean that the policymakers and EPA evaluators miss any non-linear effects of the growth increment on the transportation system. For example, if a

region's highways are congested, the additional growth increment may have different effects than the base growth. It is likely that this disadvantage would not manifest itself for any but the largest growth increments. In order to limit the effect of new transportation infrastructure on the results, one should compare the base and out year runs with the most comparable transportation networks for each year. The assumption of little change in transportation networks may be unrealistic.

See appendix for a detailed description of Methodology #4 as applied in Atlanta.

3 RESULTS OF TEST APPLICATIONS OF THE FOUR METHODOLOGIES

The four methodologies were tested in the following cities:

Region	Methodology 1	Methodology 2	Methodology 3	Methodology 4
Atlanta	✓	✓	✓	✓
Baltimore	✓	✓		✓
Chicago	✓			
Dallas	✓	✓		

3.1 Baltimore

Methodology 1

The Baltimore pilot project tested a relatively small-scale development.

Infill site: In consultation with project consultants and the Baltimore Metropolitan Council (BMC), the pilot project selected a greenfield in Carroll County and an infill site on the harbor. The infill development would place 400 households on the site of former U.S. Steel Shipyard facilities, and 800 jobs on 80 acres at an old Exxon site nearby.

Greenfield site: The greenfield development would place the same amount of housing and jobs on 270 acres in Carroll County, a fast-growing area near Baltimore.

Results

VMT

BMC modeled travel behavior in M1 by using both a regional travel model full network run and an analysis using incremental growth in vehicle trips to and from each site to estimate change in VMT and mobile source emissions from the growth increment.

The full network model runs reported lower regional VMT with infill than with no growth or the greenfield scenario. BMC modelers spent a great deal of time ensuring that each run was done consistently and could not explain these counter-intuitive results. The regional emissions analysis also reports lower emissions in the infill scenario than in either the no build or the greenfield scenario. While these results certainly support a program of infill, we believe that they are not satisfactorily explainable, and thus are a poor basis for policy making. Therefore, we are not reporting the overall network results.

Regional travel models are designed for evaluating changes at a regional level. The small size of the development relative to the scope of the Baltimore model[3] appears responsible for the unreliable results. We and the Baltimore modeling staff believe that the variability in the model overwhelmed the changes produced by the infill development. A finer level of analysis is clearly needed.

[3] The modeled development was 800 jobs, or 0.17 percent of the 457,000 jobs in the Baltimore model, and 400 households, or 0.16 percent of the 244,000 households.

In such a case, we recommend using the analysis of incremental growth in vehicle trips to and from each site to estimate growth in VMT and mobile source emissions.

Let us call this approach Methodology 1A.[4] In this approach, we analyze impacts at the project level, rather than the full network level. First, one examines the trips predicted without the development for each TAZ affected by the proposed infill and greenfield development. The trips to and from these TAZs in the baseline are then scaled up to reflect the added development. We assume that trips generated by the development have the same characteristics as trips to and from the TAZ before development (mode split, length), and that trips in the rest of the model are not affected by the development.

That analysis produces the following results:

	Average vehicle trip distance		**New vehicle trips**		**New VMT**	
Infill site	7.68		3,895		29,914	
Greenfield site	9.86		4,688		46,224	
Difference	2.18	+28%	793	+20%	16,310	+55%

EMISSIONS

Because the network run was not deemed reliable, emissions were also estimated at the project level. Rather than performing a MOBILE analysis, trip emissions were built up from emissions component factors (cold starts, running, idling, hot start, and hot soak), using the average regional travel speed (23.9 mph) for all trips.[5] Results are shown below.

Total Project-level Emissions, in tons per day

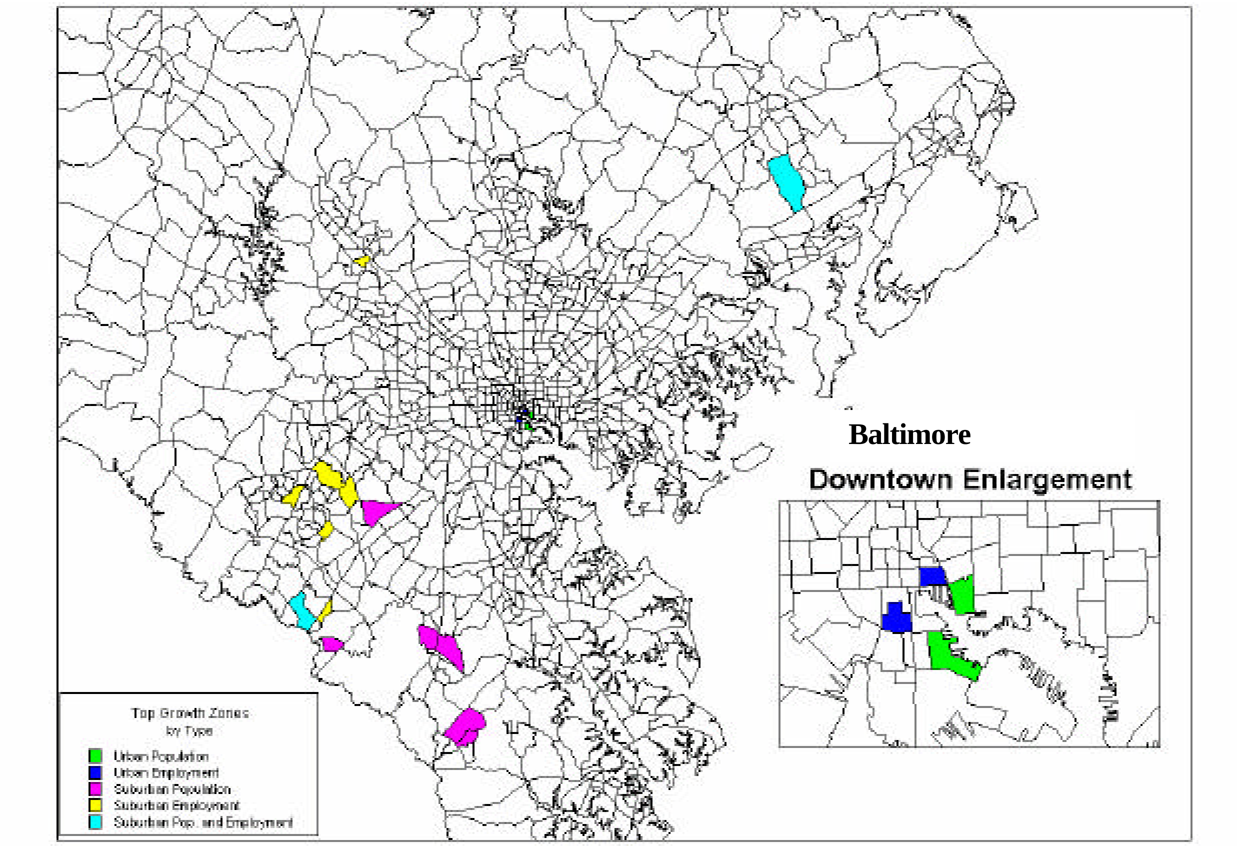
	NO_x		**VOC**	
Infill site	0.05		0.11	
Greenfield site	0.07		0.15	
Difference	0.02	+40%	0.04	+36%

Methodology 2

This scenario analyzed the same infill development analyzed in M1. However, instead of comparing the infill to one greenfield location, M2 assumed that growth is added to twenty of the fastest growing zones. BMC selected ten zones with the fastest growth in households and ten with the largest growth in employment. For each group of ten, two zones would be in the City Center or Urban land use designation, and the rest would be in the suburban category. These zones are shown below.

[4] We label it a variation of Methodology 1 because it compares an infill site to a specific greenfield site.

[5] Additional detail given in "Baltimore Infill Emissions," November 15, 1999, memo from Pihl and Schroeer to Geoff Anderson.



High-growth zones

A total of 870 new non-retail jobs[6] were distributed across the ten highest employment growth TAZs (87 per zone) and 415 new households were distributed across the population growth TAZs (41 or 42 per zone).

Differences from the baseline in the scenario are minimal.

Total regional VMT, VHT, person trips, assigned vehicle trips, and transit trips produced or originating in the Baltimore region

	Base	***Growth***	***Difference***
VMT	54,756,000	54,769,000	13,000
VHT	1,310,500	1,311,248	748
Person Trips	8,171,799	8,174,475	2,676
Vehicle trips	5,523,391	5,526,831	3,440
Transit Trips	217,677	216,403	-1,274

[6] Non-retail jobs do not generate walk-in traffic.

Emissions in tons per day

	Base	***Growth***	***Difference***
NO_x	104.4	104.4	0
VOC	47.5	47.5	0
CO	456.5	456.5	0

Results Discussion

The increase shown in the results for *vehicle* travel are intuitively correct and consistent with findings in other case studies. This is slightly surprising since the regional travel model did not give intelligible vehicle travel results when run for M1. However, *transit* ridership decreases, even though there is no reason for additional people and jobs to reduce transit ridership. Again, we see that the regional travel model may not be an appropriate tool with which to analyze small-scale growth scenarios. If the model is not robust when all the development is at a single site, there is no reason for it to be so when the development is distributed and TAZ-level population and employment changes are one-tenth as large.

Whether "correct" or not, the modeled change in regional travel is not large enough to produce a change in modeled emissions.

Methodology 4

BMC produced analyses for two different periods. The more likely completion date for the relatively small infill projects would be 2005, so BMC analyzed the behavior of new growth 1996-2005. However, BMC also analyzed the behavior of growth projected between 1996 and 2015. For those two periods, newly added employees and households in the Baltimore region are predicted to produce the following travel behavior. (1996 figures are given for comparison.)

Daily VMT	***1996 total***	***1996-2005 total***	***1996-2015 total***
Per employee	15.11	18.84	19.77
Per household	50.83	57.06	75.54

If the growth proposed for the infill sites followed average new growth in 2005, it would produce:

	Miles driven associated with 1 new job:	18.84	× new jobs proposed for the infill site	800	=	15,072
+	Miles driven associated with 1 new household	57.06	× new households proposed for the infill site	400	=	22,824
=	New miles driven if infill growth increment follows average dispersal pattern					37,896

Results discussion

Applying M4 was straightforward, and the results reasonable.

Comparing the Methodologies

VMT

Methodology	Growth scenario	VMT
Methodology 1	Infill and greenfield	Not meaningful
Methodology 1A	Infill	29,914
Methodology 1A	Greenfield	46,224
Methodology 2	20 fastest-growing TAZs	13,000, but may not be meaningful given inexplicable transit result
Methodology 4	Dispersed; follows other growth proportionately	37,896

Comparisons of these results need to be done with care.

1. Recall that the full network run for the Baltimore M1 approach did not produce meaningful results.

2. The M2 full network run produced an inexplicable drop in transit ridership with the addition of people.

3. The M1A (site-specific) VMT figures were the result of analyzing incremental growth in trips from each analyzed site, not the network.

Thus, the methodologies in the above table are not directly comparable.

1. M2 uses the network model to compare differences between two *very slightly different scenarios*, and so the results appear to be affected by substantial noise.

2. M4 uses the network model to compare two *substantially different scenarios* (1997 and 2005 full Baltimore area) and so can be expected to be far more robust.

3. M1A is not a full network model run, and so comparison with both M2 and M4 network model runs should be made with some caution.

Note that one could have used the "manual" (M1A) approach for each of the TAZs in M2, but this would have been extremely time consuming.

Taking all of the above into account, the most robust comparisons are probably the following:

		VMT	Difference from infill
Methodology 1A	Infill	29,914	
Methodology 1A	Greenfield	46,224	+55%
Methodology 4	Dispersed; follows other growth proportionately	37,896	+27%

These results are intuitively correct, since some of the growth in M4 goes to areas near the infill site, and some goes to sites similar to the greenfield site. (These results are also similar to the other M1 to M4 comparison, in Atlanta, discussed below).

Finally, the site-specific VMT figures were the result of analyzing incremental growth in trips from each analyzed site. Thus, to compare M1 and M4 is to compare a full network model run (M4) with a run that is not a full network model run, so comparison should be made with some caution.

These results suggest:

1. That network modeling may be unreliable below a certain level of development, in certain situations and using certain models. (On the other hand, as discussed below, the Dallas network modeling provided reasonable results with a small development.)

2. That the Baltimore infill project, when analyzed using a site-based approach, produces roughly the same VMT and emissions advantage as infill in several other pilot cities analyzed using a network-wide approach.

The results suggest that some—although perhaps not all—developments of small size should still be able to participate in infill benefits programs. However, as with any modeling, modelers should evaluate outputs for counter-intuitive results. In some cases it will be desirable to check network modeling using a site-level method. In general, full network modeling is preferable to snapshots of single TAZs. Single TAZ comparisons miss network effects, do not capture trip diversions, and generally provide a less complete picture of the impacts of infill versus other development.

EMISSIONS

Because emissions were not calculated from the network runs, but are simply functions of trips and VMT generated, they are of the same magnitude as the VMT change.

3.2 Dallas

Methodology 1

The study consultants, working with the North Central Texas Council of Governments (NCTCOG), the City of Dallas Brownfields staff, and other pilot project staff, selected South Side on Lamar as the infill site, and the Highway 121 corridor/McKinney area for the greenfield development. The sites epitomize their respective types of redevelopment and development. Participation by NCTCOG and the City of Dallas Brownfields staff helped ensure that the two locations were fair examples of each site type.

Infill site: South Side on Lamar, spanning several addresses on South Lamar Street, is a 17.5-acre site that formerly housed the first Sears Catalog Store. The site includes five buildings that total 1.4 million square feet and approximately 1,500 parking spaces, and is already under redevelopment.[7]

Planned site use is residential, retail, hotel, restaurant, catering business, food mart and offices. Phase I development includes construction of 175 lofts which were leased beginning in January 1998; an additional 425 will be constructed during Phase II. 100 retail jobs and 858 service employees are planned.

Thus, modeled development on the site included 1200 more persons (600 more households), 100 more retail employees, and 858 more service employees.

[7] Site description from EPA Region 6.

The site is located within 1/10 mile of Cedars Dallas Area Rapid Transit (DART) light rail station, and is representative of transit-accessible infill development in the region.

Greenfield site: The Highway 121 corridor is the fastest-growing area of the region. It includes the city of McKinney, with 13 percent growth in 1997, when it was the fourth-fastest growing city in the region. A 225-acre greenfield site was selected in McKinney. The same mix of development was placed on the McKinney greenfield as on the South Side at Lamar infill site, for the same a total of units of housing, and jobs.

NCTCOG believes that given the high growth rate in the McKinney area, this type of development could be seen in the area.

Results

Vehicle Emissions	**Greenfield site**	**Infill site**	**Difference from infill**
Total Weekday (Tons/Day)			
VOC	0.07	0.05	+48%
NO_x	0.07	0.05	+43%
CO	0.46	0.29	+61%
Vehicle Miles Traveled, Total Weekday	43,598	31,523	+38%

Results discussion

The NCTCOG network model showed a substantial performance difference between the brownfield site and the greenfield site.

Although the modeled development was fairly small, the Dallas model did not appear to encounter any of the difficulties encountered in analyzing the small development in Baltimore.

NCTCOG analyzed 62 separate measures of performance (including measures using peak and off-peak, four different travel modes (drive-alone, 2+ shared-ride, transit with walk access, and transit with drive access) and three different trip types (home-based work, home-based non-work, and non-home-based). All measures could be explained as reasonable responses to the new development and be interpreted as consistent with each other.[8] This internal consistency would be extremely unlikely to be produced by chance, and is in contrast to the Baltimore results.

Methodology 2

For the Greenfield M2 Run, TSZs were allocated additional *population and households* based on which Suburban and Urban TSZs are forecasted to have the highest Absolute growth in the number of households between 1995 and 2025. Eight Suburban TSZs and two Urban TSZs were identified, and each received an additional 120 persons and 60 households.

For the Greenfield M2 Run, TSZs were allocated additional *employment* based on which Suburban and Urban TSZs are forecasted to have the highest Absolute growth in the number of total employees,

---

[8] See Will Schroeer, "Dallas Land Use and Clean Air pilot project modeling results," memo to Geoff Anderson, June 10, 1999.

between 1995 and 2025. Eight Suburban TSZs and two Urban TSZs were identified, and each received an additional 10 retail employees and 86 (or 85) service employees.

The roadway and transit networks were identical in all model runs, as were the modeling parameters.

Results

The M2 results are presented together with M1 results for ease of comparison.

Dallas-Fort Worth Metropolitan Area, Year 2000 Travel Model Run	Associated with the development			*Difference from infill*	
	Greenfield		Infill		
	M1	M2		*M1*	*M2*
Vehicle Emissions, Total Weekday (tons/day)					
VOC	0.07	0.06	0.05	+48%	+37%
NO_x	0.07	0.06	0.05	+43%	+32%
CO	0.46	0.46	0.29	+61%	+62%
Vehicle Trips, Total Weekday	4,769	4,243	3,494	+36%	+21%
Congestion: Lane Miles with Peak Hour LOS F	3	6	-13		
Vehicle Miles of Travel, Total Weekday	43,598	38,885	31,523	+38%	+23%
Vehicle Hours of Travel, Total Weekday	2,242	1,712	1,463	+53%	+17%

Results discussion

The NCTCOG network model showed a substantial performance difference between the brownfield site and the greenfield site for M2. For M2, NCTCOG again produced a wide variety of indicators of system performance under each scenario, and again all were consistent.[9]

Comparing the Methodologies

In all but one case (CO), M2 showed smaller benefits from infill than did M1, roughly consistent with the experience in other regions where M1 and M2 were compared. Neither run raised concerns about the small development size relative to the size of the region; despite the small amount of growth added to each TSZ, the modeling gave what appear to be robust results.

The results delivery memo from NCTCOG's Ken Cervenka concluded:

> The conclusion is that, in this particular analysis, the Infill Development resulted in lower total Regional emissions than what would occur if the same level of development was placed on *one or more* Greenfield sites in Urban/Suburban areas. [emphasis added]

[9] See Will Schroeer, "Dallas Methodology 2 results", memo to Geoff Anderson, February 6, 2001. Note that the NCTCOG re-ran the earlier M1 scenario with updated emissions factors so that M1 and M2 are calculated with the same more recent emissions factors. The updated results are presented here.

3.3 Chicago

Methodology 1

The study consultants -- working with Chicago Department of the Environment (DOE), the Chicago Area Transportation Study (CATS), the regional MPO and transportation modeling agency, and other pilot project staff -- selected the West Pullman brownfield site as the infill site, and a site in suburban Aurora for the greenfield development. As with the other test cities, the sites are typical of their respective types of redevelopment and development. Participation by Chicago DOE and CATS helped ensure that the two locations were fair examples of each site type.

Infill site: The West Pullman brownfield site contains 140 acres. The City proposes to redevelop it with 3200 jobs: 1700 industrial, 400 warehouse/distribution, and 1100 research and development and general office jobs.

Greenfield site: A 210-acre suburban greenfield was selected in Aurora at the intersection of I-88 and Orchard Rd., in part to typify the kind of highly accessible site sought in suburban development. Employment was assumed to be the same as at the infill site.

Results

	Greenfield site	Infill site	Difference from infill
Vehicle Emissions			
Total regional weekday (tons/day)			
VOC	215.3	215.75	-0.21%
NO_x	360.86	361.07	-0.06%
CO	1556.05	1559.4	-0.22%
Vehicle Miles Traveled			
Total weekday VMT for the metropolitan area	195,441,119	195,594,851	-0.08%
Vehicle Hours of Travel			
Total weekday VHT for the metropolitan area	8,155,809	8,191,981	-0.44%

These results are counterintuitive and inconsistent with the results from other cities. The following tables reflecting the total weekday vehicle trips created by each scenario provide additional information that appears to contradict the above results.

Trips			
Total weekday vehicle trips (including intrazonals)			
HBW	5,125,810	5,125,333	
HNW	6,395,117	6,395,119	
NHB	5,163,577	5,163,573	
Other	2,292,943	2,242,782	
Total	*18,977,447*	*18,926,807*	+0.27%
(Infill – greenfield)		-50,640	
Total weekday person trips (including intrazonals)			
By vehicle	20,081,534	20,081,016	+0.00%
By transit	1,514,127	1,514,473	-0.02%

Results discussion

The fact that the infill site would produce 50,000 fewer vehicle trips per day than the greenfield site suggests that the infill site ought to have lower emissions. In order to take the results at face value, however, each suburban job would have to produce 15 more trips than each infill job; not just 15 trips total, but an additional 15 trips. Research on the impacts of job location on trip generation rates has found significant trip substitution, but not at this level. In other words, it is unlikely that changing the location of 3,200 jobs would lead to such a large change in vehicle trips.

The infill location showed a slight increase in regional VMT and emissions. In cases where the infill development contributes to a jobs/housing imbalance, where infill is not well served by transit, or where long trips are required to access the infill location, this might be viewed as a reasonable outcome. However, none of these phenomena are evident here. To the contrary, the model is reflecting a reduction of 50,000 trips, yet simultaneously predicts a slight increase in VMT and emissions. Like the Baltimore case study, these results suggest another approach is needed if one is to accurately gauge the impact of infill development on transportation and air quality outcomes.

CATS believes that the regional model operates at too large a scale to effectively analyze the impact of a single development consisting of 3200 jobs. The CATS transportation model covers a region of almost 9 million people.[10] In the transmission memo for the results, the CATS project head reiterated this point:

> …the difference in the measures between these two scenarios is generally not significant enough to draw any real conclusions. The measured changes are as likely to be due to differences in how the model ran (e.g. , how close to the stopping criterion) as they are to any real differences between the scenarios. The scale of your test and the state of regional travel level simulation are not properly matched.[11]

In short, the project was not large enough in a regional context to rise above the noise in the model, an explanation that is consistent with the irreconcilable results obtained.

The Chicago experience, then, is consistent with the Baltimore findings in that a project must be a certain size before the regional model is a useful tool with which to *directly* model the project's impact.

Unfortunately, we were not able to determine a minimum necessary project size for a project to register in the regional model. Further, because Chicago and Baltimore do not run the same model, we cannot say whether a Chicago-sized project in Baltimore would have been large enough to obtain robust results in Baltimore. However, the Chicago results join with the Baltimore results in suggesting that scale is an important consideration in choosing among methodologies.

It appears that the current modeling runs will not be enough to help EPA establish clear guidance on how to establish a minimum development size necessary to achieve robust modeling results. This is not entirely surprising. The original study design asked: "does development size matter," and that question has been answered "yes." The minimum size will differ from metropolitan area to metropolitan area, depending on

---

[10] For comparison, 3200/3.8 million = 0.084 percent, or half of the proportion in Baltimore (0.16 percent). On the other hand, the Dallas proportions were even smaller: 1500 jobs/2,296,200 jobs = 0.065 percent, and 400 HH (assuming 2.5 persons HH)/4,880,000 persons = 0.020 percent.

[11] Memo "Measures from infill/greenfield modeling" from Dean Englund, CATS, to Alex Holt, Chicago Department of the Environment, April 14, 2000.

the quality of the area's data, the structure and sophistication of the model, and, of course, the absolute (population) size of the area.

The lack of a defined minimum development size should not be problematic. If regions seek to recognize emissions reductions for small developments that may lie below the noise level of their particular model, the resulting reduction will be very small and the risk of accepting that as a genuine improvement is correspondingly low. As the size of the development increases, the robustness of the result will increase so that developments that are large relative to the region's population and emissions budget, such as Atlantic Steel—the next case, discussed below—are almost certainly above the model's noise threshold. The more important line of defense against misleading benefits results, however, is simply a requirement that analyses demonstrate internal consistency. The Baltimore M1 region-wide analysis showed benefits from infill, but not in a way consistent with other regional runs. Additional study, such as the site level analysis, would be required in order to recognize any reductions in the rate of emissions growth. The internal consistency criterion would similarly apply to Chicago's West Pullman analysis.

In summary, with respect to model results and the size of development:

1. Many regional travel models will give unreliable results if used to predict travel changes from changes in development patterns below a threshold size. That size varies from metro area to metro area, and can best be determined by local modeling officials.

2. As with all modeling results, outcomes should be analyzed for internal consistency and compared to basic interactions among land use, transportation, and air quality articulated in the literature.

3.4 Atlanta

Methodology 1

Infill site: The Atlanta pilot project selected as its infill site the Atlantic Steel site in Atlanta's Midtown neighborhood, where a developer proposed a mixed-used development of 17,483 jobs and 6,000 residents.

Greenfield site: Unlike the other cases, EPA compared the infill site with *three* other Atlanta area sites able to absorb projects of similar size. EPA worked with regional stakeholders to select the three sites: Sandy Springs in the Perimeter Center area, a site near the border of Cobb and Fulton counties, and a site in south Henry County. [12] The regional location of these three sites, and the Atlantic Steel site, are shown in Figure 1.

Together, the sites capture important variables that help determine travel behavior:

Location	Development Density	Regional Location	Served by MARTA rail?
Atlantic Steel	Urban	Central	Yes
Cobb/Fulton	Suburban	Suburban	No
South Henry County	Suburban	Exurban/Rural	No
Sandy Springs	Urban	Just past the perimeter	Yes

[12] For a detailed discussion of the site selection process, see Hagler Bailly, "Transportation and Environmental Analysis of the Atlantic Steel Development Proposal," November 1, 1999.

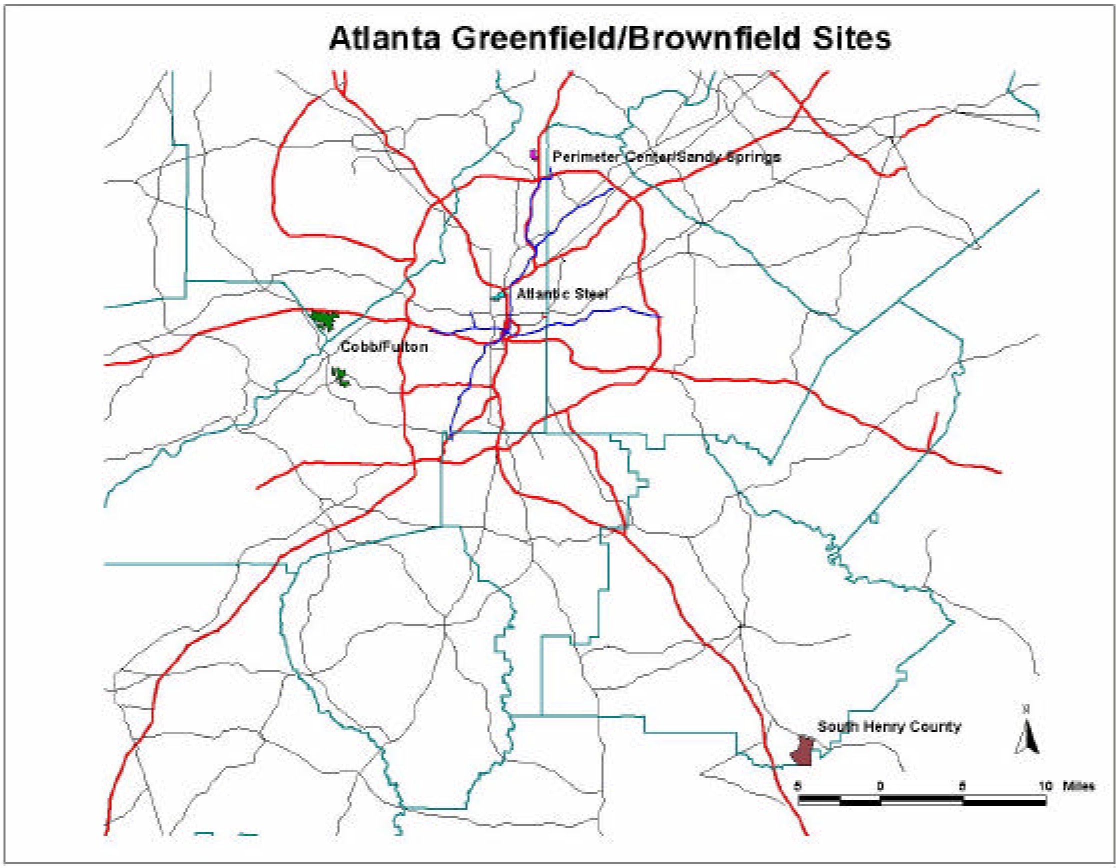


Figure 1: The four sites analyzed. The four sites represent a wide set of development options.

Although these sites do not cover all possible locational variations, they represent the available options. The South Henry and Cobb/Fulton sites were chosen because their development would be consistent with the region's projected suburban and exurban growth. The Perimeter Center/Sandy Springs site was chosen because its development would illustrate the impact of Atlantic Steel shifting growth from more unlikely locations, such as an infill site in a suburban center. Thus, this site was considered a conservative point of comparison.

Results

Vehicle Miles Traveled

Site	Regional total (VMT/day)	Associated with site (VMT/day)	Site difference from infill
Infill site: Atlantic Steel	139,172,200	340,300	
Greenfield sites:			
Sandy Springs	139,221,572	389,672	14.5%
Cobb/Fulton	139,339,398	507,498	49.1%
Henry County	139,350,097	518,197	52.3%

Using MOBILE 5, vehicle miles traveled lead to…

Emissions

	NOx			VOC		
Site	Regional total (tons/day)	Associated with site (tons/day)	Site difference from infill	Regional total (tons/day)	Associated with site (tons/day)	Site difference from infill
Atlantic Steel	191.95	0.400		153.230	-0.390	
Sandy Springs	192.10	0.548	37.00%	154.374	0.754	293.33%
Cobb/Fulton	192.24	0.690	72.50%	154.312	0.692	277.44%
Henry County	192.27	0.724	81.00%	154.464	0.844	316.41%

Results Discussion

Locating the new development on the Atlantic Steel site resulted in a modeled increase in 0.4 tons of NO_x emissions regionally, and a decrease of 0.39 tons of VOC emissions. The VOC decrease is the result of infrastructure improvements that in the short term relieve critical congestion bottlenecks. Specifically, the ramps and new bridge divert traffic from nearby points of congestion and allow it to flow more freely over the time period analyzed. Since VOC emissions change with speed changes—higher speeds generally leading to lower per mile emissions—improved traffic flow actually reduces overall VOC emissions. Literature suggests that this decrease in emissions will not be sustained over time as the new infrastructure induces additional traffic increases.[13]

Development placed on any of the greenfield sites increased emissions both absolutely and relative to the infill site. These sites would see longer trip lengths, and more vehicle trips. Traffic speeds near these sites also appear to play a role, as VOC emissions rise more than does VMT. However, the primary emission impact is from higher VMT associated with these sites' locations.

[13] See Harry Cohen, "Review of Empirical Studies of Induced Traffic," in *Expending Metropolitan Highways: Implications for Air Quality and Energy Use*, Transportation Research Board Special Report 245, National Academy Press, 1995; Mark Hansen and Yuanlin Huang, "Road Supply and Traffic in California Urban Areas," *Transportation Research*, 31 (1997):3; Fulton, Noland, Meszler, and Thomas, "A Statistical Analysis of Induced Travel Effects in the U.S. Mid-Atlantic Region, *Journal of Transportation and Statistics*, 3:1 (April 2000); and Robert Noland and William Cowart, 2000, "Analysis of Metropolitan Highway Capacity and the Growth in Vehicle Miles of Travel," *Transportation,* 27(4): 363-390.

Methodology 2

In executing M2 the Atlantic Steel jobs and housing are distributed to the region's 20 fastest growing TAZs, 16 in suburban TAZs and 4 in urban TAZs.

Results

M2 produced an increase of 409,282 VMT over the baseline, compared to 340,300 VMT at the Atlantic Steel site. Emissions were not modeled for this scenario.

Results Discussion

M2, by distributing a percentage of the new growth to urban TAZs, assumes that the infill development is shifting some growth away from other infill locations as well as suburban locations. Further, this methodology excludes rural TAZs, thus eliminating any possibility of shifting growth from those locations. As mentioned earlier, this is a conservative approach to estimating the travel impacts of infill development. First, though infill locations may compete for new development, in many instances new infill development may actually act as a catalyst thereby shifting more growth to infill locations. Second, even if infill and rural locations do not compete directly in the market, they may yet effect one another. If infill development replaces suburban development, new suburban development may in turn replace rural development. M2 does not allow for this filtering process nor does it recognize the possible catalytic effect infill may have on other downtown projects. The estimate of 409,282 VMT reflects these baseline assumptions.

Methodology 3

M3 relies upon the local land use model to determine from which locations the infill development is attracting growth. In the first scenario, DRAM/EMPAL was allowed to distribute the entire regional total. This was then compared with a scenario in which Atlantic Steel's 17,483 jobs and 6,000 residences were manually input into the Atlantic Steel site and the model was then allowed to distribute the remainder of the regional total.

Results

When DRAM/EMPAL was allowed to distribute the entirety of the regional growth, the resulting VMT was 597,629 greater than when the jobs and residents were located on the Atlantic Steel site.

Results Discussion

The analysis here concludes that the Atlantic Steel development would draw growth from the suburbs, rather than from the city center. In his letter transmitting the results of the DRAM/EMPAL run, Bart B. Lewis, Chief of the ARC Research Division, noted:

> I have given the results of this run a very quick review against the original 2010 E+C output. They appear reasonable and consistent with the assumed shift in population and jobs. The employment redirected to the Atlantic Steel site is drawn from many tracts, but most of the jobs come from areas north of the CBD. This shifts the employment center of the region slightly southward, which, in turn, moves some households from the north side of the region to the south side. The net affect of the project on central Atlanta is to increase employment while having only a small impact on population.

Based on the results of this analysis, it appears that infill and suburban locations are a reasonable substitute for one another. It is important to recall however, that the DRAM/EMPAL model is driven in large part by relative accessibility within the region, and does not account for economic factors such as land price. In Atlanta, where accessibility is rapidly becoming the paramount issue, DRAM/EMPAL's methods are likely appropriate. However, the interplay between market factors and accessibility should be analyzed for reasonableness in future analyses.

Methodology 4

M4 quantifies the VMT and air emissions impacts of all new households and employees in the region within the time frame of the analysis (typically the build-out period for the project(s) being analyzed). The result is an average impact of new employees and an average impact of new households. This average is then used as the basis for comparison with the infill location as shown following.

Results

Between 2000 and 2010, newly added employees and households in the Atlanta region are predicted to produce the following travel behavior:[14]

Daily VMT	Interzonal trips	Intrazonal trips	Total
Per employee	14.9	5.3	20.3
Per household	50.9	7.8	58.7

Thus, if the growth proposed for the Atlantic Steel infill development were instead to follow the pattern of new growth, it would produce:

	Miles driven associated with 1 new job:	20.3	× new jobs proposed for the infill site	17,483	=	354,904
+	Miles driven associated with 1 new household	58.7	× new households proposed for the infill site	2,409	=	141,408
=	New miles driven if infill-project-sized growth follows average dispersal pattern					496,312

Results discussion

In running M4 we found that the modeling produces slightly *less* VMT per household and job for new development than for existing development. Given that most national and regional data show trends toward more dispersed development and more VMT as a result, this result deserves discussion.

The travel behavior of new growth in M4 is modeled using the 2010 Expected + Committed (E+C) network. Its name notwithstanding, the Expected and Committed network is actually a smaller network than most observers expect will be built, because the E+C that could be officially designated was limited by the fact that the region was in a Clean Air Act conformity lapse during designation of the relevant E+C network.

That new development is projected to show lower VMT/household and job than existing development is likely due in part to a lack of transportation (particularly highway) enhancements over the modeled ten-

[14] See the Appendix for a detailed description of the calculations.

year period. The 2010 E+C network finds the majority of regional roadway networks operating at or near capacity. In response, the DRAM/EMPAL 2010 forecast distributes relatively more new development to existing urban areas. This concentration tends to slow growth in VMT up to a point, leading to predictions of lower VMT for new households and jobs.

These results illustrate a broader point with respect to the use of M4. When analyzing results from M4 and evaluating its appropriateness for use in the context of quantifying the impacts of infill development, it is important to remember that this methodology attributes all VMT/emissions changes in the analysis time period to new growth. The implications of this approach are clear. This methodology has the potential to attribute changes in VMT and emissions to new growth that are in fact attributable to some other cause.

For instance, if during the analysis time period, a number of existing residents are projected to dramatically increase their driving (first time car owners, or those entering the workforce, for example), this increase will be attributed to the new households and employees, artificially increasing their impact. Thus, those using this methodology must have a thorough understanding of the behavior of the base population and employment. Similarly, changes in air emissions factors over the time frame must be accounted for. If fleet turnover is leading to significantly decreased emissions during the analysis period, these reductions must not be allowed to artificially reduce the impact of new growth.

M4 will be most useful for analyzing projects where the base is unlikely to undergo significant changes (short analysis time horizons) or where those changes can be successfully accounted for by the modeling staff.

Comparing the Methodologies

VMT

The four methodologies, including each of the three alternative sites from M1, generated the following estimates of VMT generated by the same, Atlantic-Steel-sized amount of growth:

Methodology	**Modeled VMT**	**Benefit of infill, VMT**	**X 0.8 for 20% adjustment[15]**
Infill: Atlantic Steel	340,300		
M1: Sandy Springs	389,672	49,372	39,498
M1: Cobb/Fulton	507,498	167,198	133,758
M1: Henry County	518,197	177,897	142,318
M2: Dispersed to 20 fastest-growing TAZs	409,282	68,982	68,982
M3: Dispersed by DRAM/EMPAL	597,629	257,329	--
M4: Dispersed in proportion to all new growth	496,312	156,012	124,810

[15] As explained in the discussions of the individual methodologies, the 20 percent adjustment is intended to adjust for the fact that the modeled infill may absorb some development already going to the infill site. If so, modeled benefits should be reduced accordingly. The adjustment is most appropriately applied to M1. It is less appropriately applied in M2 and M4, because they distribute some growth in the non-infill scenario to infill anyway, M2 in particular. The adjustment should not be applied to M3 at all, as the land use model accounts for all growth distribution in the region by itself.

Direct comparison between the methodologies should be made with the limitations and assumptions of each in mind. Still, comparisons are revealing.

All methods show VMT/day increasing as homes and businesses locate further from the Atlanta core on greenfield locations—either concentrated or disbursed. All results show similar magnitude and direction. The more conservative M2, which explicitly attributes new growth to other infill locations, results in VMT similar to that generated in the M1 Sandy Springs site—a suburban infill site chosen as a conservative greenfield location. M4, which seeks to approximate the average of all new growth, fits well with the M1 site estimates. Most development in Atlanta is occurring farther from the core than Perimeter Center, and closer than South Henry County; that is, in a band roughly as far out as the Cobb/Fulton site, if not farther. Stakeholders in the Atlantic Steel process thus judged Cobb/Fulton to be the site that best represented the characteristics of the site or sites where the growth increment would otherwise locate. VMT associated with development at the Cobb/Fulton site using M1 was only 2.2 percent different from the VMT estimated using M4.

Finally, the VMT gain predicted in M3 struck some participants in the study as improbably high. We believe that the value of the run is its objective, modeled confirmation that infill development would draw growth in toward the center of the city and the region.

4 THE STRENGTHS AND WEAKNESSES OF THE FOUR METHODOLOGIES

The section "Describing the Four Methodologies" discussed the conceptual advantages and disadvantages of each methodology. This section discusses the strengths and weaknesses of each methodology, taking into account both the conceptual advantages and disadvantages, and also how the methodologies actually performed in the pilots.

Each of the four methodologies has different strengths and weaknesses as tools with which to quantify the air emissions impacts of brownfields redevelopment. This section compares the methods on the basis of:

- ease of implementation;
- relative accuracy; and
- tendency to over- or under-estimate emissions savings.

Finally, this section briefly discusses one additional concern: the possibility that new development could produce CO hotspots.

4.1 Strengths and Weaknesses

Method and base assumption	Objective/ Transferable	Estimates relative to other methodologies?	Possible operational or other challenges?
Methodology 1: Growth would have gone to a single greenfield site.	No.	Dependent on choice of site.	Requires expert judgment about site/s for future growth. Requires minimum size for development.
Methodology 2: Growth would have gone to the fastest-growing parts of the region.	Transferable, but no objective reason for using top 20 TAZs as opposed to some other number.	Appears conservative relative to all others.	Requires minimum size for development.
Methodology 3: Growth would have been distributed through the region, in amounts determined by the local land use model.	Yes, to regions using a land use model.	Likely similar to other dispersed methodologies, though estimates were higher in the one test performed.	Requires land use model; quite resource-intensive.
Methodology 4: Growth would have been distributed through the region, in amounts proportional to the distribution of all other growth.	Yes, though regions will have different challenges regarding changes in their base VMT and emissions.	Appears to give higher benefits estimates than M2; and seems likely to track other dispersed scenarios, though implementation showed substantially lower VMT than M3 in this instance.	Decomposing future emissions estimates into emissions per new job and emissions per new resident may be perceived as complicated by some, although it should be the least of the challenges listed here.

In this initial evaluation, strengths and weaknesses have been identified in each methodology. In selecting a particular methodology the following should be kept in mind:

- M1 does not provide an objective way for determining the appropriate site for comparison. Rather, it relies on expert judgment to determine which greenfield site is appropriate for comparison against the infill location. As can be seen from the three sites selected and compared in Atlanta, the selection of the site can make a substantial difference in the outcome. M1 also may be unrealistic in comparing the infill location to a single greenfield. It is more likely that the infill would displace growth from a number of locations. This methodology may require a minimum development size to be effective. However, intermediate model outputs (illustrated by the use of M1A in the Baltimore case) may serve where full model runs provide unreliable outcomes.

- M2 solves M1's chief problem by pulling growth from the 20 fastest growing TAZs in the region. M2 thus reflects local growth trends, reflects the fact that infill is likely to draw from a number of locations, and does not require the analyst to make a subjective choice of alternative location(s). M2 explicitly accounts for growth shifted from other infill locations. The proportion of growth to be shifted from other infill locations can be adjusted to reflect regional growth distribution trends and can be made more or less conservative by adjusting the proportion of the growth allocated to infill locations. M2 does not provide an objective rationale for distributing growth over 20 sites. It requires a minimum development size to be effective.

- M3 provides an objective method for determining locations from which growth is shifted and uses the industry tool designed specifically for that purpose. However, M3 requires substantial effort because it uses a land use model. Many regions do not have a land use model.

- M4 has the distinct advantage of simulating a land use model without running one. It compares the impacts of the infill site with the impacts of growth from all over the region—proportional to its predicted distribution. M4 requires no alternative site choice by the user, and so provides an objective methodology for comparison. Size of development is not a concern for M4 because it does not require that added jobs and households be run through a model. However, where changes in travel behavior are expected from sources other than growth, these changes must be factored out or M4 will attribute them to the new growth, skewing the results.

- M1, M2, and M4 each require a similar level of effort, while M3 requires substantially more.

- An underlying assumption in all methodologies is that growth is shifted to the infill location from other parts of the region. The total growth within the region remains the same under either scenario. Any benefits calculated are premised upon this assumption. However, in M1, M2, and M4, the increments of growth are added to the regional total. This is done only for ease of modeling. Furthermore, because the resulting benefit is a *relative* benefit rather than an *absolute* one, the addition to the regional total is not expected to be material. However, if a project were expected to add to the region's growth total this project could not be counted as reducing future growth in air emissions. M3 avoids adding to the regional total because it utilizes the land use model, which can re-allocate the growth under the original cap.

4.2 Potential to create CO hotspots

The analyses described in this paper are primarily concerned with NO_x and VOC as pollutants of regional concern. Regional planners will also want to ensure that any new project does not produce *local* pollution problems while reducing *regional* emissions. CO is a pollutant of concern at the local level.

Because these analyses were primarily concerned with investigating how the placement of development within a *region* affected *regional* emissions, the analyses did not investigate potential CO impacts at the local level.[16] Any project that will add significant amounts of traffic to an existing system—infill or otherwise—should be analyzed for potential CO hotspots.

[16] Because one of the analyzed sites, the Atlantic Steel site, has proceeded through local permitting, we have an example analysis of an infill project's impacts on CO emissions. The micro-scale traffic and CO analysis determined that the project is extremely unlikely to create a violation of ambient air quality standards for carbon monoxide. Analysis indicates that development would create no violations of EPA standards. Areas where analysis shows co would increase tend to be those that currently report a low co concentration. Analysis of a single site cannot, of course, support conclusions about whether other infill projects are likely to create CO hotspots.

ACRONYMS

BMC	Baltimore Metropolitan Council
CATS	Chicago Area Transportation Study
CBD	Central Business District
CO	Carbon Monoxide
DRAM	Disaggregate Residential Allocation Model
EMPAL	Employment Allocation Model
HBO	Home-Bound - Other (applies to vehicle trips, as do HBW, HNW, and NHB below)
HBW	Home-Bound - Work
HNW	Home - NonWork
M1	Methodology #1
M1A	A variation of Methodology #1 in which impacts are analyzed at the project level (rather than the full network level)
M2	Methodology #2
M3	Methodology #3
M4	Methodology #4
NCTCOG	North Central Texas Council of Governments
NHB	NonHome-Bound
NOx	Nitrogen Oxide
SIP	State Implementation Plan
VHT	Vehicle Hours Traveled
VOC	Volatile Organic Compounds
TAZ	Transportation Analysis Zones
TSZ	Traffic Survey Zones

APPENDIX: METHODOLOGY 4 IN ATLANTA – DETAILED DESCRIPTION

The following procedure was used to implement Methodology 4 in Atlanta, using the TRANPLAN model. Some steps may be different when implemented elsewhere.

This analytical procedure uses two data sources for the same two points in time:

- Auto-driver trip tables, and
- Socio-economic data.

The individual steps employed are:

A. Two discrete land-use data points (years 2000 and 2010) are established, and include total population, number of households and population by zone (2000 and 2010). The net difference between the two years is calculated, resulting in total 'new' employees, jobs, and households

B. Model procedures are employed to calculate the following measures (for both 2000 and 2010 model years):

   - Total vehicle trips (SOV and group) by purpose (HBW, HBO, NHB)

     Since the model doesn't assign trips by these trip purposes, run vehicle 'auto-driver' matrices through a trip-length frequency-reporting module.

   - Calculate average vehicle trip lengths calculated for HBW, HBO, and NHB restricted matrices.

C. Derive an estimate of VMT (by purpose and year) by multiplying average vehicle trip lengths by total vehicle trips. Summarize average vehicle trips as follows:

   - Average number of vehicle trips per employee = Total employees/Total HBW vehicle trips

   - Average number of vehicle trips per household = (Total households/Total HBW vehicle trips) + (Total households/Total HBO vehicle trips) + (Total households/NHB trips)

     Reflects the basic premise that all trips are a household level decision, even if they don't begin at the household level (e.g., NHB trips).

   - VMT per employee = (Total employees/Total HBW vehicle trips)* Average trip length

   - VMT per household = (Total households/Total HBO vehicle trips) * Average HBO vehicle trip length + (Total Households/Total HBW vehicle trips) * Average HBW vehicle trip length + (Total Households/Total NHB vehicle trips) * Average NHB vehicle trip length

D. The net change in (i) vehicle trips and (ii) VMT between 2000 and 2010 is determined by subtracting each year's subtotals established in step B. Revised trip lengths are calculated for all 'new trips' by dividing 'new VMT' by 'new trips.' Once new trip lengths are calculated, the average number of vehicle trips per 'new' employee and 'new' household is again estimated (part C). Total 'new' trips are multiplied by revised trip lengths to produced an average VMT estimates for each new employee' and household attracted to the region between 2000 and 2010.

E. The original estimates of 'VMT per household' and 'VMT per employee' are compared against the regionally dispersed estimates.