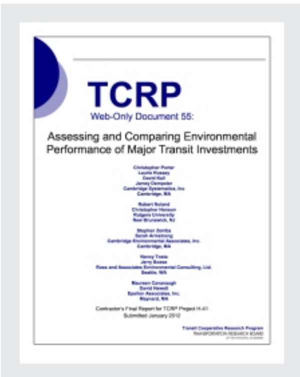

TCRP
Web-Only Document 55:
Assessing and Comparing Environmental Performance of Major Transit Investments

Assessing and Comparing Environmental Performance of Major Transit Investments

DETAILS

0 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-43508-6 | DOI 10.17226/22787

AUTHORS

Porter, Christopher; Hussey, Laurie; Kall, David; Dempster, Jamey; Noland, Robert; Hanson, Christopher; Zemba, Stephen; Armstrong, Sarah; Tosta, Nancy; Boese, Jerry; Cavanaugh, Maureen; and Hewett, David

ACKNOWLEDGMENT

This work was sponsored by the Federal Transit Administration (FTA) in cooperation with the Transit Development Corporation. It was conducted through the Transit Cooperative Research Program (TCRP), which is administered by the Transportation Research Board (TRB) of the National Academies.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

Table of Contents

Table of Contents
(continued)

Table of Contents
(continued)

List of Tables

List of Tables
(continued)

List of Tables
(continued)

List of Tables
(continued)

List of Figures

List of Figures
(continued)

Summary of Research Findings: Assessing and Comparing Environmental Performance of Major Transit Investments

Summary of Research Objectives and Findings

Transit Cooperative Research Program (TCRP) Project H-41 addresses the need for new measures of the environmental benefits of transit investments. The objective of this research is to present, evaluate, and demonstrate criteria, metrics, and methods for assessing and comparing the environmental performance of major transit investments. The research was undertaken to offer decision makers optional criteria, metrics, and methods for assessing transit projects with regard to environmental performance. [1]

The research was undertaken in two phases. The first phase included:

- A review of the literature to identify performance measures used for transit and other transportation projects, including a review of international practice in transportation environmental evaluation;
- Interviews with 20 stakeholder agencies or groups;
- A review of four recent transit project alternatives analysis (AA) documents or environmental impact statements (EIS) to identify which environmental performance measures have been emphasized and how they have been treated;
- An enumeration of potential metrics of environmental performance, data sources and calculation methods, and preliminary screening of these metrics; and

The summary of research findings for this report also has also been made available as a stand-alone publication, *TCRP Research Results Digest 105: Summary of Research Findings: Assessing and Comparing Environmental Performance of Major Transit Investments.* Readers can read or purchase TCRP RRD 105 at www.trb.org.

[1] For purposes of this research, the following definitions are used: 1) criteria – the characteristics that will be considered when performance is judged; 2) metric – a measure for something; generally a quantitative measurement or estimate, or an ordinal metric in the case of qualitative evaluation; and 3) method – a way of doing something, especially a systematic technique or process used to develop a metric.

- Development of a more detailed approach to screening and selecting metrics, including selection of a short list of less than 20 metrics to evaluate in detail.

In the second phase, six pilot projects were recruited on which to test these metrics. Data were collected for each project and metrics were computed. Next, the ease of data collection and computation, reliability, and usefulness of each metric for purposes of distinguishing among transit projects were evaluated. Metrics were then placed in three tiers according to how promising they were for use in both local and national-level project evaluation. Finally, a set of "most promising" metrics was selected from the Tier 1 and Tier 2 metrics that represented each category of environmental performance without overlapping.

The most promising metrics identified from this process are identified in Table 1. Any of these metrics could be used in the evaluation of different project alternatives. The table also identifies additional development activities that are needed before the metric is ready for use, particularly for comparing multiple projects in different regions. The metrics presented here represent broad environmental performance issues of interest for comparing across projects (including benefits), rather than a detailed enumeration of all the environmental impacts considered in the environmental documentation process. The list includes only metrics that can be computed with existing data sources and modest resource requirements, and therefore is limited in its ability to fully represent some aspects of environmental performance.

Although these metrics were tested on only a few real-world projects, an initial review suggests that projects that perform well on some measures may perform poorly on others. This suggests that it is worth looking at a variety of metrics, because they illustrate different effects that may not be closely correlated. It also suggests that the choice of weights for each metric will affect how a project rates on overall environmental performance compared to other projects.

The remainder of this section:

- Summarizes the research objectives, background research findings, and environmental performance categories and metrics considered;

- Describes and discusses the most promising metrics, including key assumptions, ease of computation, results for sample projects, pros, and cons; and

- Identifies limitations of the metrics and current evaluation framework, as well as next steps and issues for further research.

Table 1. Summary of Most Promising Metrics of Environmental Performance

Performance Category	Metric	Scope	Further Development Activities
Energy and Greenhouse Gas (GHG) Emissions	Operating energy or GHG emissions per passenger-mile	Calculated for new project Include energy/GHG from fuel production as well as direct vehicle operations	• Decide whether to use energy, GHG, or both • Develop standard energy and emission factors or guidance for developing project-specific factors
	Construction energy or GHG emissions	Calculated for new project	• Research required to develop models for nonmaterials construction energy and GHG • Consider normalizing (per passenger-mile or route-mile) if used for comparing projects
Air Quality and Public Health	Change in total project emissions	Calculated for highway and transit	• Determine pollutants of interest • Develop standard g/mi emission factors • Consider combined weighted index of all pollutants • Determine whether and how to include emissions from electricity generation
	Project air pollutant emissions per passenger-mile[a]	Calculated for transit project only	
	Change in daily nonmotorized access trips	Calculated for new project versus no-project	• Validation of consistency of results among projects/models • Consider/test total nonmotorized trips accessing new project as alternative
Ecology, Habitat, and Water Quality	Fraction of corridor land that already is developed	Project corridor (*x*-mile radius)	• Consider categorical rating system (e.g., high, medium, low) based on quantitative benchmarks

[a] This alternative air quality metric was considered too late in the process to fully test and compare it to other metrics. While the project team feels that project emissions per passenger-mile may be preferable to change in total emissions for informing comparative project evaluation, it will need to be more fully tested before a final judgment is made.

Research Objectives

Relationship to the New Starts, NEPA, and Local Planning Processes

Environmental benefits, including air quality, energy, livability, land use, and other benefits, have long been important considerations in evaluating and justifying transit investments at a local level. Potential negative impacts have also been an important consideration in project evaluation, especially since the passage of the National Environmental Policy Act (NEPA) in 1969.

Within the past two decades, the importance of environmental considerations has also been reflected in Federal programs for funding major capital investments. Specifically, FTA's New Starts program provides discretionary funds to meritorious transit projects across the country. These funds are awarded on a competitive basis based on a number of justification criteria, including environmental benefit. Consideration of environmental benefits as part of the New Starts evaluation and rating process dates back to the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), which directed that a project must be "justified based on mobility improvement, environmental benefit, cost-effectiveness, and operating efficiency." FTA policy adopted in 1996 defined a multiple measure approach for justifying New Starts projects that included changes in criteria pollutant emissions, carbon dioxide (CO_2), and energy consumption as well as current U.S. Environmental Protection Agency (EPA) air quality attainment designation.[2] Over time, however, FTA ceased to use these measures in New Starts assessment, as they found that they provided little or no basis for meaningfully distinguishing among projects and that emissions and energy consumption were closely correlated with ridership forecasts and user benefits.

The national spotlight recently has been focused again on the environmental benefits of transportation investments. In June 2009, the FTA reintroduced environmental benefits as part of its rating process, giving the current EPA air quality designation for a project's region 10 percent weight in the overall evaluation. In June 2010, FTA issued an Advance Notice of Proposed Rulemaking (ANPRM) soliciting input on a variety of questions related to the New Starts process, including how environmental benefits should be measured. FTA subsequently issued a Notice of Proposed Rulemaking (NPRM) in January 2012 proposing a new regulatory framework for the New Starts program.[3] This was accompanied by proposed guidance with new measures and suggested methods for calculating the project justification and local financial commitment criteria, including environmental criteria.[4] Energy and GHG savings have been criteria in recent competitive

---

[2] 61 Fed. Reg. 67093 (December 19, 1996).

[3] 77 Fed. Reg. 3848 (January 25, 2012).

[4] Federal Transit Administration. *Proposed New Starts/Small Starts Policy Guidance*, January 2012.

transportation funding programs including FTA's Transit Investments in Greenhouse Gas and Energy Reduction (TIGGER) program.

The land use and economic development impacts of projects are often considered in local evaluations of alternatives, as well as by FTA as part of its New Starts criteria. While specific environmental outcomes related to land use change (such as water quality or habitat preservation) are not assessed, long term changes to land use and development patterns can have a significant impact on environmental outcomes. For example, a transit project may support more compact development patterns, which can reduce impacts on open space, habitat, and water quality associated with land consumption. Conversely, a project that increases accessibility in outlying, undeveloped areas may lead to negative impacts on these environmental factors. Thus, land use and economic development impacts are related to the measurement of environmental benefits. FTA's January 2012 NPRM recognizes this issue and proposes to allow project sponsors at their discretion to estimate the vehicle miles of travel (VMT) associated with changes in development patterns enabled by a New Start project, and then incorporate that VMT into proposed environmental benefits measures.

NEPA requires disclosure of environmental impacts to determine the potential impact of the project on the natural, built, and human environments. The NEPA process has different objectives than may be set by project sponsors or by FTA for the evaluation of environmental benefits. NEPA is focused on ensuring that environmental impacts are disclosed and options for avoiding and minimizing adverse environmental impacts are identified, considering an expansive list of issues. In contrast, the purpose and need of a project may include a small number of goals to preserve or enhance aspects of these environments, and the New Starts process is focused on comparing projects nationally to guide investment decisions using a very limited set of measures.

The research performed in this project was not intended to duplicate the issues given the greatest scrutiny in the NEPA process, such as the direct, local air quality, water quality, and cultural resource impacts from project construction and operation. It is assumed that the outcomes of the NEPA process lead to acceptable avoidance or mitigation of these impacts such that they are not a major distinguishing factor from a national perspective. Instead, this research focuses on broad measures of environmental performance, including benefits as well as impacts, that may be of interest to decision makers.

Research Process

The research was guided by a 20-member project panel that included representatives from transit agencies, state departments of transportation (DOTs), a regional planning commission, a Department of Urban Planning from a major university, environmental and transportation planning consulting firms, an environmental action organization, the EPA, FTA, and several transportation industry associations including the American Public Transportation Association (APTA), American Association of State Highway and Transportation Officials (AASHTO), and the Community Transportation Association of America (CTAA).

In the first phase of this research, a literature review and review of recent environmental documents were conducted to identify candidate metrics and to review current practices in environmental evaluation for transit projects. This included a review of international practices in environmental evaluation. Opinions were also solicited from 20 stakeholders, including transit industry representatives and others, regarding how environmental performance measures should be developed and used. Finally, comments that were submitted by the August 9, 2010 deadline for public comment on the June 2010 FTA New Starts ANPRM were reviewed.

From this background research, over 120 candidate performance metrics were identified. This list was screened according to a set of evaluation criteria. In consultation with the project panel, a set of 21 metrics in four environmental performance categories was identified for further testing. The criteria used for screening the metrics included:

- Data availability and reliability;
- Ease of forecasting; and
- Environmental relevance.

A key objective of this research was to identify metrics that can be developed and assessed without placing undue burden, on decision makers. At the same time, the metrics should be robust enough to reliably distinguish among projects in direct relationship to their environmental performance.

In the second phase of the research, six pilot transit projects were recruited on which to test these metrics. These projects included light rail, diesel and electric commuter rail, and bus rapid transit projects located in a mix of urban and suburban areas. Available data were obtained from each project, and used to calculate each of the metrics. The level of effort to provide and analyze the data was evaluated. In most cases, data availability and resource limitations permitted the metrics to be tested on only a subset of the pilot projects. However, the results were judged adequate to assess the usefulness, reliability, and ease of calculation of each metric. A second screening process was then applied to classify these metrics into three "tiers" – highly promising, somewhat promising, and not promising. The most appropriate uses of each metric were also identified.

Background Research Findings

Literature Review

Types of literature reviewed included reports enumerating and discussing how to measure benefits and impacts of transit, including environmental effects; reports examining transportation performance measures and evaluation frameworks both in the United States and abroad; and reports and detailed guidance on specific environmental measures, such as greenhouse gas (GHG) reporting protocols. For example, the Strategic Highway Research Program 2, Project C02, produced a library of performance measures for highway capacity expansion investments, including environmental measures, many of which are applicable to transit as well as highway projects. An annotated bibliography is provided as Appendix I.

Environmental Performance Rating Systems. The literature review also identified environmental performance rating systems and tools. With growing interest in sustainability, a number of assessment tools have been developed to assist organizations in assessing and rating the "sustainability" or environmental performance of their operations. Most performance rating systems are not transit-specific, but many include metrics that may inform transit applications. Some of these are focused on buildings (e.g., Leadership in Energy and Environmental Design, or LEED), which could be applied to transit agency facilities. Others have been developed for infrastructure projects, primarily highways (e.g., GreenROADS), but their principles could be extended to transit project construction. International Organization for Standardization (ISO) certification is focused on environmental impacts across a full range of an agency's operations. These systems generally evaluate the extent to which the direct impacts of project construction and operation are mitigated, rather than the overall environmental benefits of the project (including effects on travel).

International Practice. In addition, the literature review included a review of the process and methods by which environmental criteria are assessed in other countries. The primary focus was on Strategic Environmental Assessment (SEA) or multicriteria analysis. SEA, which is required of European Union member states, seeks to evaluate the environmental effect of policies and plans during early stages of the planning process. One of the key features is that the analysis is a multi-attribute analysis that examines various environmental effects versus economic, equity, and other impacts of interest to policy-makers. It typically covers all transport modes instead of being transit or highway-specific. Benefits of SEA identified include early consultation and increased transparency of the planning process; actual changes in policies and plans in response to environmental problems; and reduction of the need for various mitigation procedures, due to earlier consideration of environmental impacts. This approach to strategic policy-level environmental assessment contrasts with the U.S. and Canadian focus on project-based environmental impact analysis.

Performance Measurement in Environmental Analysis

To evaluate how transit's environmental performance is currently evaluated and considered in environmental documentation and project development in the U.S., Environmental Impact Statement (EIS) and Alternatives Analysis (AA) environmental documents were reviewed in detail for four sample transit projects. The purpose of the review was to identify which environmental impact measures have been used and how they are calculated.

The specific measures evaluated and calculation methods used varied somewhat from project to project. Overall, however, the review confirmed that most (but not all) impacts are treated as negative impacts to be mitigated. Many of the impacts were considered to varying degrees in alternatives development and selection, although it was often difficult to quickly assess key differences among alternatives, or tell from the documentation how much a particular impact weighed on the selection process. Specific findings include:

- Most impacts are treated as negative impacts to be mitigated (or documented as having no significant impact). In some cases, however, impacts such as air quality or GHG emissions are treated as positive impacts (e.g., helping to avoid traffic growth). Avoiding induced growth (or inducing growth consistent with local and regional plans) also was identified as a positive impact for some projects.

- There was significant variability in how the information is reported and it was generally difficult to quickly compare the environmental impacts of different projects or alternatives.

- Most of the focus is on direct impacts from operating the system, although construction impacts (e.g., air quality, noise, water quality) are evaluated in some cases with varying degrees of rigor. If "secondary" or "life-cycle" impacts are addressed at all, the discussion is brief and qualitative, or too entangled with cumulative impacts to differentiate between what is a project impact versus other outside factors.

- When alternatives are compared, they are not always compared to one another in **all** categories (e.g., a project may be compared to an alternative with respect to wetlands alteration, but no direct comparison is made with respect to environmental justice).

- The criteria by which alternatives are compared against one another are not weighted – if a project has minor impacts on wetlands but significant impacts to historic resources, which factor "wins"?

- When comparing different projects from different parts of the country, a significant issue in one region may not even come into play in another region (e.g., earthquakes/; maintaining groundwater levels in areas where buildings are supported by wooden piles).

Feedback from Outreach to Stakeholders

Interviews were conducted with 20 stakeholder agencies or organizations in April through June 2010 to identify how transit agencies, state transportation agencies, advocacy groups, and academic researchers have evaluated the environmental performance of transit investments, beyond the evaluation and reporting conducted for the NEPA process. In addition to specific measures and methodologies, the interviews sought to obtain feedback on how environmental performance should or might be evaluated in the future.

Environmental performance measures were found to have the following uses:

- **Prioritizing transit investments –** Although the use of environmental performance measures in selecting investments was not common among the survey respondents, respondents reported innovative ways to incorporate these metrics into project evaluation.

- **Applications for Federal funding –** All transit agencies responded that in addition to improving the planning process, environmental metrics will prepare them for future funding application and reporting needs.

- **Participating in local requirements and environmental targets –** A few transit agencies participate in local environmental initiatives measuring the effects of public transportation on the regional environment.

- **Outreach and marketing –** Transit industry and advocacy groups are actively publicizing the environmental, social, and economic benefits of transit.

Stakeholders offered a variety of suggestions to consider in the development of environmental performance measures to compare and assess transit investments. Some common themes and other notable points included:

- Reductions in vehicle-miles of travel (VMT) were widely viewed as a measure that is of interest and related to environmental performance. However, many projects, particularly those in densely developed areas with an existing high transit mode share, may not result in a significant reduction of VMT but instead will improve conditions for existing transit travelers. As a result, VMT reductions alone – or related measures such as vehicle emissions and energy use – should not be the only measures to determine the project's environmental efficacy. Another way of looking at this is that projects should be rewarded for improving travel conditions in highly developed settings, helping attract and retain people in these settings where the environmental impacts of travel can be much lower.

- A number of respondents noted that the *indirect* environmental impacts of transit, related to changes in land development patterns, may be much more significant than the direct impacts and should be given important consideration.[5]

- Some also noted that the *baseline of comparison* – transit versus no-build, or transit/development versus highways and sprawl – is significant in determining whether transit provides environmental "benefits."

- Interest was expressed in measuring the *life-cycle* environmental impacts or benefits of transit, particularly with respect to energy use and GHG emissions, but further research and guidance is needed on this topic.

- Some transit agencies have developed metrics related to quality of life and view this as an important benefit, although these metrics differ from location to location.

- Some stakeholders noted that metrics and methods should be flexible to account for the unique operating environments for transit systems across the nation. At the same time, benchmarks and standards are needed for performance measures to provide guidance to transit agencies as well as consistency across projects.

■ Environmental Performance Categories and Metrics Considered

Based on findings from the literature review and stakeholder outreach, the project team established four major categories for assessing and comparing the environmental performance of major transit investments:

1. Energy use and greenhouse gas emissions;
2. Air quality and public health (including physical activity);
3. Ecology, habitat, and water quality; and
4. Community and quality of life (including livability).

This set of categories considers both the natural and human environment, consistent with practice under NEPA. However, this project was not intended to provide a detailed review of the full set of indicators of performance with respect to the human environment (including factors such as safety and security, access to affordable housing, etc.) The focus of the measures considered is on the physical environment (natural or human) which may

[5] APTA has proposed a "land use multiplier" to capture additional benefits of more compact land use, although this concept needs additional research to identify its value and applicability across a wide range of project contexts. See: APTA Climate Change Standards Working Group, *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit*, APTA CC-RP-001-09.

include human environmental factors such as noise, aesthetics, and historical resources, in contrast to social environment factors such as safety and security, which are not covered.

At a meeting of the project panel in September 2010 to select metrics for Phase 2 testing, it was determined not to include community and quality of life metrics. These were viewed as important, but not the focus of the current research project. Therefore, Phase 2 research focused only on the first three environmental performance categories.

Various dimensions of environmental performance were also identified. These include impacts related to:

- **Direct effects of vehicle operations** (changes in transit and highway vehicle travel), including both the impacts of vehicles themselves as well as production and transport of fuel to power the vehicles (full fuel cycle);
- **Impacts from other system elements –** Construction of infrastructure and vehicles (transit, as well as highways depending upon the baseline for comparison), as well as maintenance, nonvehicle operations (e.g., station power), and disposal; and
- **Indirect effects –** Land conversion, changes in building stock, and travel impacts associated with changes in land use patterns.

The relationship between the performance categories and dimensions is illustrated in Table 2.

Table 2. Environmental Performance Categories and Dimensions for Evaluation of Major Transit Projects

Performance Category	Vehicle Operations: Direct	Vehicle Operations: Full Fuel Cycle	System Construction, Maintenance, Operations, and Disposal: Facilities	System Construction, Maintenance, Operations, and Disposal: Vehicles	Indirect Effects: Land Conversion	Indirect Effects: Buildings	Indirect Effects: Travel Impacts
Energy use and greenhouse gas emissions							
Air quality and public health							
Ecology, habitat, and water quality							
Community and quality of life	(Not assessed in this research)						

This research primarily focused on vehicle operations (both highway and transit) as well as indirect environmental effects of land conversion. For energy and GHG metrics, both direct and fuel cycle energy use and emissions were included. Energy and emissions associated with system construction were also considered to the extent that data were available, but maintenance, operations, and disposal were not considered due to lack of data. Indirect effects from travel associated with land use changes resulting from the transit project are not currently considered in comparative analysis and therefore were not considered. Effects associated with changes in building stock were deemed too speculative to consider and also outside the range of typical transportation analysis.

The 120 candidate metrics identified through the background research were organized into the four performance categories shown above. The full list of metrics initially considered is documented in Appendix H. The metrics were screened to a shorter list of 21 metrics based on data availability and reliability, ease of forecasting, and environmental relevance as described above. The metrics selected for more detailed testing in Phase 2 of the research are listed and described in Table 3. This table does not include community and quality of life metrics, which were excluded from the scope of Phase 2 testing based on guidance from the project panel, but adds a category of "cross-cutting" metrics that address issues in all of the other categories.

The metrics shown in Table 3 were evaluated according to three criteria – 1) ease of data collection and computation, 2) reliability of data, and 3) usefulness for purposes of distinguishing among transit projects and project alternatives based on environmental performance. Metrics were then placed in three tiers according to their performance on these criteria:

- **Tier 1 –** Strong candidate for use;
- **Tier 2 –** Possible candidate for use; and
- **Tier 3 –** Not recommended for use at this time.

Table 1 summarizes the metrics that were considered most promising for use in comparison of project alternatives. These metrics represent a subset of the metrics identified as Tier 1 and Tier 2 that are not redundant.

Variations on some of the metrics shown in Table 3 were suggested later in the project, which precluded evaluating them in detail. Notably, these include *construction energy or GHG per dollar cost or project mile* as a variant on IE: *transit air pollutant emissions per passenger-mile* as a variant on IIA; and *total nonmotorized trips accessing the new project* as a variant on IIE.

Table 3. Metrics of Transit's Environmental Performance Evaluated in Detail

Key	Metric	Description	Tier
I. Energy and Greenhouse Gas Emissions			
IA	Operating GHG emissions per passenger-mile	Annual GHG emissions from new project divided by annual passenger-miles on project. Includes "upstream" emissions from transit vehicle operations and fuel production.	1
IB	Operating energy consumption per passenger-mile	Annual energy consumption from new project divided by annual passenger-miles on project. Includes energy use for transit vehicle operations and fuel production.	1
IC(i)	Change in operating GHG emissions	Change in annual GHG emissions for project versus no-project, considering transit and highway vehicles, including emissions from fuel production.	2
ID(i)	Change in operating energy consumption	Change in annual energy consumption for project versus no-project, considering transit and highway vehicles, including energy used in fuel production.	2
IC(ii)	Project cost per reduction in operating GHG emissions	Total annualized capital cost plus change in transit operating cost, divided by change in total annual GHG emissions.	3
ID(ii)	Project cost per reduction in operating energy consumption	Total annualized capital cost plus change in transit operating cost, divided by change in total annual energy use.	3
IE(i)	Construction GHG emissions	Total GHG emissions associated with project construction, including emissions embedded in materials.	2
IE(ii)	Construction energy consumption	Total energy use associated with project construction, including energy embedded in materials production.	2
II. Air Quality and Public Health			
IIA(i)	Change in direct operating emissions	Change in annual pollutant emissions for project versus no-project, considering transit and highway vehicles, for the following pollutants: VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and seven mobile-source air toxics.	2
IIA(ii)	Dollar of project cost per change in direct operating emissions	Total annualized capital cost plus change in transit operating cost, divided by change in total annual emissions for each pollutant.	3
IIB	Exposure Index	An index of the change in pollution weighted by potential population exposure (based on emissions and population by area). Calculated for each pollutant.	3
IIC	Health Benefit Index	An overall index of the change in pollution weighted by potential population exposure (based on emissions and population by area) and health impacts of each pollutant.	3
IID	Air Quality Index	Indicator of the severity of the air quality problem in a metropolitan area, based on air quality monitoring data.	3
IIE	Forecast change in daily non-motorized access trips	The change in daily nonmotorized access trips for the project versus no-project alternative.	2
	Level of Service and other measures of pedestrian and bicycle access to transit [a]	Measure of the extent to which the environment in proposed project station areas supports walk and bicycle access.	3

Table 3. Metrics Evaluated in Detail (continued)

Key	Metric	Description	Tier
III. Ecology, Habitat, and Water Quality			
IIIA	Percent of corridor that is already developed	Percent of land in transit corridor (defined as a two-mile radius around the project alignment) that is in land use categories identified as developed.	2
IIIB	Potentially impacted acreage of undeveloped land	Amount of land in transit corridor that is in land use categories identified as developed.	3
IIIC	Potentially impacted acreage of sensitive habitat	Amount of land in transit corridor that is in land use categories identified as sensitive (in this case, agriculture and wetland).	3
IIID	Potentially impacted acreage weighted by ecosystem service value	Amount of land in transit corridor that is in land use categories identified as sensitive, weighted by ecological value.	N/A
IIIE	Adequacy of state, regional, and local habitat protection plans	Qualitative, benchmark-based assessment of the extent to which state, regional, and local plans provide protection against development for sensitive habitat.	3
IV. Cross-Cutting Metrics			
	Environmental performance ratings for transit projects[a]	"Checklist" approach to assessing the extent to which project planning, design, construction, and operation incorporates "green" or "sustainable" practices to minimize environmental impacts.	2

[a] The pedestrian and bicycle access and environmental performance ratings metrics were not tested on the pilot projects. However, the panel asked for information on them, which was provided in white papers that are included as Appendices E and F to this report.

Description and Discussion of Most Promising Metrics

This section describes each of the promising metrics presented in Table 1, including how it is calculated, key assumptions, results from pilot-testing, pros, cons, and a summary of how it might be used. Each metric's potential is considered for use by decision makers to evaluate individual project alternatives and to compare multiple projects in different regions of the country.

Metric IB – Operating Energy Consumption: BTU per Passenger-Mile for the Proposed Project

Calculation. This metric is calculated as the total operating energy used by the proposed transit project (considering upstream energy associated with fuel production as well as direct vehicle energy use) divided by the number of passenger-miles on the proposed project. The metric does not consider increases or decreases in energy use from other elements of the transit system (e.g., changes in feeder bus service) or from trips diverted from automobiles.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Ridership forecasts;
- Transit VMT for the proposed project; and
- Transit vehicle energy consumption rates.

Ease of Computation. The measure is fairly easy to compute from data sources typically developed for project ridership forecasting and environmental analysis of individual projects and from comparative analysis of multiple projects. Project-specific energy consumption rates are rarely known or reliably estimated, however, and national default averages by mode must generally be used. Also, analysis of operating plans for the proposed project may be required to determine changes in transit VMT.

Results. Values for this metric from pilot-testing ranged from a low of 500 to 1,000 British Thermal Units (BTU) per passenger-mile for a BRT project to a high of 3,200 BTU per passenger-mile for a diesel commuter rail project. An electrified alternative of the commuter rail project showed a significantly lower value than the diesel alternative of 1,800 BTU per passenger-mile. Estimates for two light rail projects were in the range of 1,400 to 1,800 BTU per passenger-mile.

Pros. BTU per passenger-mile has a number of advantages and seemed to be a useful metric. It is understandable and logical as a measure of the "efficiency" of travel. It clearly differentiates among projects, because it is not diluted across a system or broad area, and shows a range of values across projects. It can be compared with the efficiency of other projects and other modes (for example, the average single-occupancy vehicle on the road today uses about 4,600 BTU per passenger-mile). It rewards both efficient vehicle technology and high-ridership density. It eliminates some uncertainty factors present in other energy and GHG metrics that consider diverted automobile trips, including fuel efficiency of the future automobile fleet, forecast VMT and speed changes for highway vehicles, and choice of appropriate GHG factors. It addresses concerns from project sponsors who are improving travel conditions for a largely captive ridership base rather than shifting riders from automobiles to transit, since the value of the metric does not depend upon mode-shifting. Energy consumption as a metric may appeal to a broader set of constituents, including those interested in energy security issues, than GHG emissions.

Cons. BTU per passenger-mile is not a complete measure of the energy impacts of a project, as it does not account for nonproject operational changes (transit or highway) or the benefits of riders who shift modes from automobile to transit. It only indirectly measures environmental impacts, since different fuel sources will have different environmental impacts (including GHG emissions and air quality) per BTU. It does not indicate the *relative* benefits or cost-effectiveness of the investment, i.e., how much energy use is being reduced as a result of Federal and local spending. The use of national default vehicle energy consumption rates (BTU per vehicle-mile), while improving consistency, may not be appropriate as individual transit projects have different levels of energy consumption depending upon vehicle technology as well as operating characteristics.

Summary. The transparency of this metric, limitations on uncertainty, and ability to distinguish among projects in a way that is clearly related to environmental impacts make this a promising metric. If the metric is adopted for use in comparative project evaluation, consistent and appropriate energy consumption factors for different types of transit vehicles will be needed, reflecting current and anticipated future transit vehicle technology, and/or close scrutiny of energy consumption estimates provided by the project sponsor.

Metric IA – Operating GHG Emissions per Passenger-Mile (Measured for the Proposed Project)

Calculation. This metric is calculated as the total transit operating GHG emissions from the proposed project (considering upstream fuel emissions as well as direct vehicle emissions) divided by the number of passenger-miles on the proposed project. The metric does not consider increases or decreases in GHG emissions from other elements of the transit system (e.g., changes in feeder bus service) or from trips diverted from automobiles.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Ridership forecasts;
- Transit vehicle VMT;
- Transit vehicle energy consumption rates; and
- Upstream GHG emissions per unit of energy for alternative energy sources, including electricity.

Ease of Computation. The measure is fairly easy to compute from data sources typically developed for project ridership forecasting and environmental analysis of individual projects, and from comparative analysis of multiple projects. As is also the case for the BTU per passenger-mile measure, project-specific energy consumption rates are rarely known or reliably estimated, however, and national default averages by mode must generally be used. GHG emission rates must also be used from national or regional sources. Analysis of operating plans for the proposed project is required to determine changes in transit VMT.

Results. Values for this metric in pilot-testing ranged from a low of 0.04 to 0.08 kilograms CO_2e per passenger-mile for a BRT project to a high of 0.25 kilograms CO_2e per passenger-mile for a diesel commuter rail project. An electrified alternative of the commuter rail project showed a significantly lower value than the diesel alternative – 0.13 kilograms per passenger-mile. Estimates for two light rail projects were in the range of 0.10 to 0.18 kilograms per passenger-mile.

Pros. The pros of this measure are largely similar to the pros of BTU per passenger-mile. This measure has an added benefit of relating directly to a particular environmental impact (GHG emissions) and considering the GHG intensity of different fuel types.

Cons. Cons are also largely similar to BTU per passenger-mile. The benefit of introducing GHG as a measure must be weighed against the challenges of fairly assessing differences in the GHG intensity of the same type of fuel among project sponsors – e.g., electricity generation by region of the country; as well as accounting for uncertainty in GHG intensity forecasts and current and future life-cycle GHGs associated with biofuels.

Summary. This metric should be considered as an alternative or supplement to BTU per passenger-mile. The transparency of this metric, limitations on uncertainty, and ability to distinguish among projects in a way that is clearly related to environmental impacts make this a promising metric. If the metric were adopted for comparing projects in different regions of the country, attention would need to be given to developing consistent and appropriate energy consumption factors for different types of transit vehicles as well as appropriate life-cycle GHG emission factors (current and future) for alternative fuels. A decision would also need to be made as to whether to use average national GHG intensity factors for electricity generation or regionally specific factors, which would reward projects in regions of the country with a "clean" electricity mix.

Metric IE(i) – Construction GHG Emissions

Calculation. This metric includes emissions from materials and equipment used in construction of the transit project. Due to data limitations, it was not fully tested on the pilot projects. The metric could be reported in total or normalized per route-mile, per passenger-mile, or per dollar of project cost. It could also be annualized and combined with operating emissions for a life-cycle GHG metric.

Key Assumptions. Key assumptions and areas of uncertainty include:

- All key assumptions for change in operating GHG emissions;
- GHG emissions embodied in materials used in construction, per unit of material;
- Type and amount of materials used in construction (e.g., steel per track-mile);
- Activity of equipment used in project construction, by type of equipment;
- GHG emission factors by type of equipment;
- Other construction-related GHG emissions, including staging, lighting, and work zone traffic delays; and
- Appropriate factors for annualizing construction GHG emissions over the project lifetime.

Ease of Computation. The research team for this project developed a model of GHG emissions embodied in materials used in transit projects, based on general estimates of materials use. This model allows for calculation of embodied GHG based on parameters generally available in transit project planning, such as new track-miles, miles of overhead catenary, number and type of stations, etc. However, data were not available to permit the estimation of emissions from construction equipment activity or other nonmaterial emissions, and therefore a complete estimate of construction GHG emissions could not be developed. A research project initiated in fall 2011 by the Federal Highway Administration (FHWA) is intended to develop a model that includes all construction-related activities and can be used at a planning level for transit as well as highway projects.

Results. A sample calculation for one of the pilot projects was performed that resulted in an estimate of 268,000 tons CO_2e for a light rail project of roughly 10 miles in length. (All references to tons are to metric tons.) This equates to approximately 5,000 tons per year when annualized over a 50-year period, which is a common expected lifetime for many project components. This can be compared to increases in transit operating GHG emissions in the range of 5,000 to 25,000 tonnes per year, and decreases in highway vehicle operating emissions in the range of 5,000 to 40,000 tonnes per year, for the pilot rail projects. This calculation suggests that construction emissions are a nontrivial contributor to the life-cycle GHG emissions of a transit project, and will to some extent offset savings in combined highway and transit operating emissions.

Pros. Including construction emissions has the advantage of more fully presenting the impacts of a project, and also helping to differentiate projects that have more or less GHG-intensive construction practices. Furthermore, it is likely that within the next two years, a model will be publicly available that is suitable for making estimates of transit construction emissions based on data that are readily available once a project, mode, alignment, and station locations have been selected. This model is likely to allow testing of the impacts of alternative, GHG-reducing construction methods in addition to standard methods.

Cons. The use of average factors (e.g., GHG per track-mile of surface alignment) makes data collection practical at a planning level but also means that details of project construction that may have significant effects on construction GHG emissions (such as amount of cut-and-fill required, or extent to which highway traffic is affected) are ignored. Including construction GHG emissions in a life-cycle metric may paint a misleading picture of the project if the results are used in comparisons with other projects (such as highway projects) that do not include full life-cycle emissions.

Summary. This metric is promising, but needs further supporting research and development. Different ways of normalizing the metric (such as per dollar cost, per route-mile, or per passenger-mile) should be explored to allow comparison among projects of different sizes. At this point, the primary value of this metric is to compare different transit projects against each other to evaluate the GHG efficiency of their construction methods, or for evaluation of different project alternatives that include different amounts of underground versus above-ground construction, station configurations, etc. It is not recommended that construction emissions be combined with operating emissions for an overall life-cycle GHG metric, since such life-cycle evaluation is not a standard practice in transportation project analysis.

Metric IIA(i) – Change in Direct Operating Emissions

Calculation. This metric was originally defined as the total change in direct operating emissions from highway and transit vehicles, measured in kilograms of pollutant per year. Towards the end of the research, the research team suggested an alternative approach of taking only emissions for the new transit project and dividing by passenger-miles to get a metric similar to the proposed energy and GHG per passenger-mile metrics.

Emissions can be calculated for individual criteria pollutants or precursors, including oxides of nitrogen (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), and coarse and fine particulate matter (PM_{10} and $PM_{2.5}$). It can also be computed for a number of significant air toxics which are not currently regulated but nonetheless known to be a health concern. The U.S. EPA has identified six Mobile Source Air Toxics (MSATs) that contribute significantly to health risk estimates and are released to air mostly by transportation: acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel engine exhaust, and formaldehyde. The metric as originally calculated did not include air pollution from electricity generation facilities, primarily because of lack of data, but also because these pollutants are also likely to be generated in non-urban areas where exposure to population and consequent health effects are less than for direct emissions from vehicles. However, to make emissions per passenger-mile a meaningful metric for comparing electric rail projects (for which direct emissions are zero), electricity generation emissions should be included.

Key Assumptions. Key assumptions and areas of uncertainty for calculating total emissions changes include:

- VMT forecasts;
- Vehicle emission rates, including current and future emissions for both highway and transit vehicles reflecting local conditions (traffic flow, fuel, vehicle fleet mix, climate, etc.), and emission rates for alternative fuel vehicles not included in current emissions models; speed changes on the roadway network due to impacts on congestion, and subsequent effects on emissions; and
- Emissions of air pollutants from electricity generating power plants (if included).

Highway vehicle data are not required if only emissions per passenger-mile for the new project are calculated.

Ease of Computation. The ease of computing changes in pollutants depends upon the region's air quality modeling requirements and capabilities. Regions in nonattainment or maintenance status are likely to have developed emission factors for the pollutants of local concern, and may have already computed changes in these pollutants for environmental documentation purposes. If emission factors and/or pollutant changes have not been calculated, they can still be calculated by an analyst skilled in the use of an emission factor model (EPA's MOVES model or CARB's EMFAC model) using default assumptions in conjunction with travel demand forecasts developed for the project. Air toxics emissions factors are unlikely to have been calculated already and would need to be developed. Existing emission factor models only include diesel and compressed natural gas options for buses, and the project sponsor, in consultation with the transit vehicle manufacturer or using literature sources, must develop appropriate emission factors for any alternative technologies or fuels. As with the energy and GHG calculations, transit operating plans must also be identified in order to calculate VMT changes for all transit services affected by the project. Projects that improve conditions for existing riders, rather than generating new transit trips, will not perform well on this metric.

Once total emissions for the project are calculated, emissions per passenger-mile can be easily calculated based on the same ridership data as used in the energy and GHG metrics.

Results. Only four projects were evaluated for total emissions (of which two were variations on the same project) due to difficulties in collecting and processing data from some projects. All four projects showed reductions in all pollutants. The maximum changes observed were a reduction of 14 tons per year of NO_x, a reduction of 18 tons per year of VOC, and a reduction of 1.9 tons per year of PM_{10}. To provide scale, pollutant changes as a percentage of regional or subregional (modeled area) emissions from highway vehicles were computed for all four projects and found to be in the range of -0.05 to -0.2 percent for most pollutants. Emissions for one project were found to be somewhat more significant when measured as a percentage of corridor emissions (TAZs within a two-mile buffer of the project alignment), where a project resulted in a 22 percent decrease in transit emissions in the corridor due to replacing bus service with electric rail. However, transit emissions were dwarfed by highway vehicle emissions in the corridor and the net effect was a reduction of less than 0.2 percent in combined highway and transit emissions. Subregional percent changes of NO_x for the BRT project differed from its percent changes for other pollutants because an increase in NO_x from the BRT service offset about half the savings from highway vehicles.

Emissions per passenger-mile were calculated for two projects, an LRT project and an electric commuter rail project, using forecast national average pollutant emissions rates identified in a private-sector study. Only forecasts of VOC, NO_x, and PM_{10} were available. (The metric was introduced for consideration after most of the research was completed, which is why it was not tested on all projects.) Coincidentally, both projects showed approximately the same emission rates per passenger-mile. For one electric commuter rail project, the transit project emissions per passenger-mile were about one-third of highway vehicle emissions (per vehicle-mile) for NO_x and one-quarter for PM_{10}. For another light rail project, emission rates were about one-half of highway-vehicles for NO_x and similar for PM_{10}. VOC emissions from electricity generation were very small relative to highway vehicle emissions and were not calculated.

Pros. Total emissions changes are a direct measure of air quality benefits. Changes in VOC, CO, NO_x, and PM emissions are familiar to air quality planners who often use them for evaluating projects for air quality program funding. Evaluating individual pollutants and examining transit and highway emissions separately can demonstrate the effects of differences in transit vehicle technology, e.g., diesel versus electric rail. This metric does not require the spatial allocation of emissions, as do the Exposure Index and Health Benefit Index metrics described below.

Emissions per passenger-mile have the benefit of showing potentially meaningful differences among projects, considering both passenger loading and vehicle technology. It rewards “clean” and highly productive projects whether they attract new riders, or improve service for existing riders. It is a “normalized” metric whose value does not depend upon the scale of the project.

Cons. Changes in kilograms or tons of pollutant emissions is not a metric that most lay-people can readily grasp the significance of, and in fact, a ton of one pollutant may be much more or less important than a ton of another pollutant depending upon the relative health effects of each pollutant. As has proven to be a problem in the past, the change in pollutant emissions for a single project tends to be small when compared with total regional emissions. Furthermore, there are multiple pollutants of interest (particularly when air toxics are considered) and they cannot easily be combined into a single metric, leading to a proliferation of different metrics that are often (but not always) correlated. While an individual region may be able to focus on two or three pollutants of particular concern to them, pollutants of local concern will vary from region to region, which poses a challenge for evaluating multiple projects consistently. The exclusion of emissions from electricity generation may be viewed as a bias in favor of electrically powered projects; these emissions could in theory be calculated, but more work would be required to identify local powerplants and corresponding emissions rates.

Emissions per passenger-mile do not consider benefits from reduced highway vehicle travel, and does not indicate the aggregate air quality benefits of the project.

Summary. This metric is proposed as a second-tier metric. Change in total emissions has been used in the past (and therefore has been proven feasible), and is often used by regional planners to evaluate projects being considered for air quality improvement purposes. However, it was not found helpful for distinguishing among projects in the context of comparative evaluation. If it is used, consideration might be given to developing a single pollutant index based on relative toxicity weightings for current criteria pollutants and precursors (VOC, NO_x, CO, PM_{10}, and $PM_{2.5}$). A determination would also need to be made whether to include air toxics. While these are of increasing concern, they are currently not regulated from transportation sources and in general will be closely correlated with VOC and PM emissions, meaning that introducing MSATs into the evaluation is unlikely to further affect decision-making.

The variation of this metric, project emissions per passenger-mile, should be considered as an alternative air quality indicator, as it will help show meaningful differences among projects, considering both transit vehicle technology/control and the efficiency of loading.

Metric IIE – Forecast Change in Daily Nonmotorized Access Trips

Calculation. This metric is calculated as the difference in nonmotorized transit access trips (usually walk trips) for the project versus no-project alternative, as determined from the travel demand forecasting model used for the project. This metric is proposed as the most direct measure of physical activity actually "generated" by the transit project. A variation of this metric, *total nonmotorized trips accessing the new project*, might be considered to alleviate concerns about projects that primarily improve conditions for existing riders.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Accuracy and resolution of the access mode choice model included in the travel demand model (e.g., trip purposes differentiated, calibrated based on local versus transferred data, bicycle versus pedestrian included);
- Lack of detailed data on the pedestrian environment/walkability, or other factors (such as parking availability) that may affect access mode choice; and
- Models do not account for spatial distribution of trip generators below a TAZ level (e.g., concentration within walking distance of the transit station versus dispersed throughout the TAZ).

Ease of Computation. This metric can usually be easily calculated from the data produced by the travel demand forecasts which are developed for ridership forecasting and traffic impact assessment.

Results. The forecast change in daily nonmotorized trips across six pilot projects ranged from 2,600 for a commuter rail project to 15,000 for an urban/suburban light rail project. An assessment of the model structures suggested that all should produce reasonable forecasts, but nonetheless some models had clear limitations compared to others. It was therefore impossible to say with confidence that a rank-ordering of projects based on modeled walk trips would be proportional to the actual benefits of the projects, versus differences in the quality of the model or its underlying data.

Pros. As a proxy for physical activity and related health benefits, this metric is preferable to measures of the built environment, which indicate how much *potential* there may be for "active" modes of transport, but not the actual use of such modes. For most projects it can be calculated from available travel forecast data.

Cons. This metric is an absolute measure and is not scaled by size of the project. (Scaled metrics such as walk trips per project-mile or per dollar invested could be developed, but would be less intuitive.) Differences in mode choice forecasting models mean that it may be difficult to reliably attribute differences in forecast nonmotorized trips to the actual benefits of the project rather than model limitations or sensitivities, when comparing across projects sponsored by different agencies. Projects that improve conditions for existing riders, rather than generating new transit trips, will not perform well on this metric.

Summary. This metric is clearly appropriate for decision makers to use to evaluate project alternatives. If used for comparative evaluation of multiple projects in different regions, it might benefit from sensitivity testing to assess how values will vary depending upon modeling methods (as opposed to project conditions). Development of standards for access mode choice models would provide more confidence that results across projects can be compared.

Metric IIIA – Fraction of Corridor Land That Is Already Developed

Calculation. This metric indicates the extent to which the project serves existing communities/developed areas versus undeveloped areas. It is computed as the ratio of land in the corridor that is already developed to total land in the corridor. For purposes of pilot-testing, the "corridor" was defined as a two-mile radius around the project alignment. A higher value for this metric is hypothesized to relate to lower environmental impact, since any project-related development pressures are more likely to occur in already developed areas rather than "greenfields" areas.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Spatial resolution of land use data to identify developed versus undeveloped land, and ambiguity over whether or not certain areas or land use classifications are considered "developed" (e.g., parks, rural residential parcels that could be subdivided);
- Presence of undeveloped land as a proxy for potential environmental impacts (depends upon environmental quality of undeveloped land, existence of land protections, and influence of the project on development); and
- Whether land use data are up-to-date.

Ease of Computation. Land use databases in geographic information systems (GIS) format are available covering most metropolitan areas, including most of the pilot project regions, at zero or minimal cost from regional or state agencies. However, the land use or land cover categories in these databases must be manually classified to identify "developed" versus "undeveloped" categories. Once that is done, the metric can be calculated relatively easily using standard GIS software.

Results. For most of the pilot projects, this metric had a value of 90 percent or higher, meaning the corridors are already highly developed. However, one suburban commuter rail project had a value of 36 percent. This appeared to be due in part to a state land use database that was based on polygons derived from satellite imagery of land cover, rather than parcel-level use data. For example, a wooded two-acre residential parcel might be identified as one acre of forest and one acre of residential, whereas in another region it would be identified as two acres of residential. Also, in one region, existing land use data could not be obtained, and existing zoning was used as a proxy, which probably inflated the value of the metric (land might be zoned for development but not actually developed).

Pros. The values reported for this metric do not depend upon making (highly uncertain) inferences about the potential impact of the project on development. Even if its relationship to direct environmental impact is questionable, it can serve as a measure consistent with "livability" goals by objectively describing the extent to which the project serves existing communities.

Cons. This metric is only a rough proxy for environmental impacts rather than a direct measure. It is not clear that the additional effort involved in computing this measure is worthwhile compared to a simple qualitative assessment of the extent to which existing communities are served (as can be done using information already reviewed in the land use assessment). Not all decision makers are likely to agree that serving existing communities is environmentally preferable to serving new, growing communities, where transit might help shape patterns of sprawl into patterns of more compact growth. Different projects are likely to have different land use-related environmental impacts depending upon growth pressures, land use policies, and other factors not captured, even if corridor land use conditions are similar.

Summary. This metric is recommended largely because of its potential utility as a quantitative measure related to livability, and because it is a relatively simple (if crude) indicator of the project's potential positive versus negative impacts on new development and associated environmental effects. While it might be used for local evaluation, it may be best suited for comparing multiple projects in different corridors or regions, since it is not likely to vary much between project alternatives in the same corridor. If it were used, guidance would be needed on which land use categories to classify as developed versus undeveloped. A categorical rating system (e.g., high, medium, low) should be considered based on quantitative benchmarks (e.g., less than 50 percent, 50 to 75 percent, greater than 75 percent). As an alternative to obtaining and quantitatively analyzing land use data, a qualitative assessment could be performed based on review of land use data and aerial imagery.

■ Evaluation of All Phase 2 Metrics

Table 4 presents the factors used to evaluate the metrics, on a low – moderate – high scale, with high being a favorable rating. Table 5 summarizes the ratings for all of the metrics evaluated, including each metric's "tier" as well as an assessment of ease of calculation, reliability, and usefulness according to the factors listed in Table 4. Table 5 also identifies the advantages of each metric as well as any key drawbacks or concerns.

Table 4. Description of Final Evaluation Factors

Evaluation Factor	Description
Ease of Forecasting	
High	Can be calculated with relative ease from data and models typically available from the environmental analysis and/or New Starts process. • A few hours of project sponsor staff time. • Additional (one-time) work may be required to produce standard inputs and guidance, which will minimize work for project sponsors.
Moderate	Some new data collection and analysis required. • One to two days of decision maker staff time per project.[a]
Low	Significant new data collection and/or new analysis effort required. • More than three days of decision maker staff time per project.[a]
Reliability	
High	Modest uncertainty in key assumptions/inputs; level of uncertainty consistent with other existing factors such as ridership forecasts.
Moderate	Moderate uncertainty in key assumptions/inputs.
Low	High uncertainty in key assumptions/inputs.
Usefulness	
High	Capable of clearly distinguishing among projects or alternatives, and clear/interpretation of metric.
Moderate	Some limitations to ability to distinguish among projects or alternatives, or some lack of clarity/meaningfulness in interpretation of metric.
Low	Not capable of distinguishing among projects or alternatives, or interpretation of metric unclear/not meaningful.

[a] The level of effort required of decision makers would depend upon whether project sponsors are required to compute the metric directly, or simply to provide datasets so that others can compute the metric.

Table 5. Summary Evaluation of Metrics

Key	Metric Description	Tier	Ease of Calculation	Reliability	Usefulness	Benefits/Advantages	Key Drawbacks/Concerns
I. Energy and Greenhouse Gas Emissions							
IA	Operating GHG emissions per passenger-mile	1	High	Moderate/ High	High	• Rewards both efficient vehicle technology and high ridership/load factors	• Does not consider benefits from reduced automobile travel
IB	Operating energy consumption per passenger-mile	1	High	Moderate/ High	High		
IC(i)	Change in operating GHG emissions	2	Moderate/ High	Moderate	Low/ Moderate	• Considers benefits from all modes	• Small change relative to regional emissions • Sensitive to future uncertainties in relative modal energy and emission rates
ID(i)	Change in operating energy consumption	2	Moderate/ High	Moderate	Low/ Moderate		
IC(ii)	Project cost per reduction in operating GHG emissions	3	Moderate/ High	Low/ Moderate	Low/ Moderate	• Cost-effectiveness – reports GHG benefit per dollar spent	• Unstable/not meaningful for low or negative energy and GHG benefits • May be misleading if project is compared with other air pollution reduction measures based only on cost-effectiveness
ID(ii)	Project cost per reduction in operating energy	3	Moderate/ High	Low/ Moderate	Low		
IE(i)	Construction GHG emissions	2	Low	Unknown[a]	Moderate	• Expands scope of energy and GHG emissions considered • Rewards efficient construction practices	• Data/methods still under development
IE(ii)	Construction energy consumption	2	Low	Unknown[a]	Moderate		

Table 5. Summary Evaluation of Metrics (continued)

Key	Metric Description	Tier	Ease of Calculation	Reliability	Usefulness	Benefits/Advantages	Key Drawbacks/Concerns
II. Air Quality and Public Health							
IIA(i)	Change in direct operating emissions	2	Moderate	Moderate	Low/ Moderate	• Commonly used metric in air quality planning	• Small change relative to regional emissions • Previously not found useful in comparing multiple projects in different regions
IIA(ii)	Dollar of project cost per change in direct operating emissions	3	Moderate	Low/ Moderate	Low	• Cost-effectiveness – reports pollution reduction benefit per dollar spent	• Unstable/not meaningful for low or negative emissions benefits • May be misleading if project is compared with other air pollution reduction measures based only on cost-effectiveness
IIB	Exposure Index	3	Low	Unknown[a]	Low/ Moderate	• Weights emissions by exposure to population	• Difficult to calculate • Unclear interpretation/ significance
IIC	Health Benefit Index	3	Low	Unknown[a]	Low/ Moderate	• Additional weighting of emissions by toxicity	
IID	Air Quality Index	3	High	High	Low	• Indicates severity of regional air quality problem	• Not related to benefits of project
IIE	Forecast change in daily nonmotorized access trips	2	High	Moderate	Moderate/ High	• Reasonable proxy for physical activity generated by project	• Interproject consistency in modeling methods
	Level of Service and other measures for assessing pedestrian and bicycle access to transit	3	Low/ Moderate	Moderate/ High	Unknown[a]	• Indicates extent to which station area environments are conducive to physical activity	• Already considered qualitatively under land use/ economic development • Does not indicate actual physical activity levels

Table 5. Summary Evaluation of Metrics (continued)

Key	Metric Description	Tier	Ease of Calculation	Reliability	Usefulness	Benefits/Advantages	Key Drawbacks/Concerns
III. Ecology, Habitat, and Water Quality							
IIIA	Percent of corridor that is already developed	2	Moderate/ High	Moderate	Moderate	• Relates to livability principle, supporting existing communities • Proxy for potential to support infill versus greenfields development	• May not relate to actual environmental impacts
IIIB	Potentially impacted acreage of undeveloped land	3	Moderate/ High[b]	Moderate	Low/ Moderate	• Proxy for potential to induce greenfields development	• May not relate to actual environmental impacts
IIIC	Potentially impacted acreage of sensitive habitat	3	Moderate[c]	Low	Moderate	• Proxy for potential to induce development in areas of sensitive habitat	• No good, easy to obtain proxies for sensitive habitat
IIID	Potentially impacted acreage weighted by ecosystem service value		N/A – not calculated			• Weights potentially impacted land use by ecological importance	• Land use data not consistent enough to evaluate ecosystem service value
IIIE	Adequacy of state, regional, and local habitat protection plans	3	Low	Low/ Moderate	Moderate	• Assesses extent to which sensitive habitat is protected, without attempting to judge specific development impacts of project	• Interproject consistency in assessment • Level of effort required for assessment • Very indirect connection to potential impacts of project
IV. Cross-Cutting Metrics							
	Environmental performance ratings for transit projects	2	Low	Unknown[a]	Unknown[a]	• Indicates extent to which projects sponsors are taking measures to mitigate, avoid, or offset negative impacts • Primarily useful for self-assessment and possible extra credit	• Does not indicate benefits of project, just reduction of negative impacts from construction and operation • Level of effort to assess and interproject consistency in assessment

[a] Unknown because not fully tested in this research or not enough projects tested to gauge reliability.

[b] Assuming this is calculated simply as undeveloped land in the corridor. If weighted by accessibility or another indicator of potential impact, "low" ease of calculation.

[c] Assuming this is calculated simply as agricultural and wetland land area in corridor. If weighted by indicator of development potential or using a better indicator of ecological sensitivity, "low" ease of calculation.

■ Limitations of the Metrics and the Current Evaluation Framework

Two significant challenges were encountered in attempting to develop meaningful and reliable project-level metrics of environmental performance.

First, **the impacts of any individual project generally look small when compared on a regional basis.** For the projects evaluated in this research, energy, GHG, and emissions changes were typically less than 0.2 percent of regional or subregional totals. The relatively small impacts were also manifested in cost-effectiveness metrics that are not favorable when compared to other air quality and GHG improvement projects on a stand-alone basis. This can lead to the potentially erroneous conclusion that the project is not worth doing. The small size of benefits reflects multiple factors:

- To some extent, this is the reality of the situation – most individual projects make a relatively small dent in regional travel patterns and associated environmental benefits.
- However, it also reflects a potentially incomplete accounting of the project's benefits due to the current evaluation framework. This framework assumes that land use patterns are the same with or without the project. Secondary, longer-term benefits associated with land use changes that the project may induce or support, and further changes to travel patterns because of these land use changes, are not considered.
- The individual project versus no-project approach also does not consider potential synergistic benefits of multiple coordinated transit projects, combined with supportive land use policies.
- The poor cost-effectiveness of the projects when measured just on air quality or GHG effects does not account for the multiple other benefits of the project, including mobility – environmental benefits are just one of multiple reasons to undertake a transit project.

The second major challenge is that **it is not possible to reliably predict the secondary benefits or impacts of a transit project for ecology, habitat, and water quality**. The factors affecting the secondary, growth-inducing impacts of transit projects (or highway projects for that matter) are complicated and include economic/as well as policy factors and physical constraints. Models to predict the effects of transportation investments on land use patterns do exist, but they are resource-intensive to apply, and a recent evaluation for FTA found that they were not yet suitable for evaluating individual projects, including transit projects.[6] Two TCRP projects currently underway are continuing

---

[6] *Deriving Economic Development Benefits of Transit Projects from Integrated Land Use Transportation Models: Review of Models Currently Used in the U.S. and Recommendations.* Prepared by Cambridge Systematics, Inc. and Dr. John Gliebe for Federal Transit Administration, April 2009.

to investigate methods for predicting land use and economic development impacts, using very different approaches.[7] Even if general growth patterns can be predicted, the level of detail required to assess specific environmental impacts (such as impacts to sensitive habitat or water quality) is generally not available. It may be that a qualitative assessment of supportive land use policies, such as FTA already performs in its assessment of the land use and economic development criteria, is the best that can be done with respect to this factor at the current time.

Closely related to this challenge is the difficulty of quantifying benefits from projects that serve heavily built-up areas and primarily improve conditions for existing riders, rather than diverting travelers from automobiles. The environmental benefit in this situation can be characterized as a long-term strengthening of the urban core through improved travel conditions, helping attract and retain people in these settings where the environmental impacts of travel and development can be much lower. However, most current models are not well suited to forecasting the impacts of transportation improvements on metropolitan development patterns, including retaining or increasing population and jobs in urban core areas.

These two challenges suggest that **a different evaluation framework may be required** to provide a meaningful evaluation of transit's full environmental benefits. Specifically, this framework might assess and compare the *life-cycle impacts* (construction and operation) of *all modes* (including highways and transit) on a *network or systems* level. Such an assessment would consider differences in land use patterns that support, or would be influenced by, alternative transportation networks. In fact, multimodal, systems-level assessments have already been performed in many areas of the country as part of regional scenario planning exercises. Regional scenario planning studies have found long-term air quality and energy benefits ranging from 5 to 25 percent or more for regional scenarios of compact growth and transit investment, compared to business-as-usual scenarios with highway investment.[8] These regional scenario evaluations could be further enhanced by incorporating life-cycle emissions and energy use (including construction, maintenance, fuel production, etc.) as better information on these factors becomes available. At a project level, evaluation could be performed by considering the consistency of the project with a regional plan that achieves substantial environmental benefits.

[7] *TCRP H-39: Methodology for Determining the Economic Development Impacts of Transit Investments*, http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2364; and TCRP Project H-46, *Quantifying Transit's Impact on GHG Emissions and Energy Use: The Land Use Component* http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3092.

[8] A recent review of scenario planning studies using travel forecasting models found that land use changes, combined with supportive transit investments, were estimated to reduce metropolitan VMT by a median of 8 percent below forecast levels over a 20-year time horizon and 16 percent over a 40-year horizon. Forty-year reductions ranged from 3 to 28 percent across studies. See: Rodier, C. (2009), *Review of International Modeling Literature: Transit, Land Use, and Automobile Pricing Strategies to Reduce Vehicle Miles Traveled and Greenhouse Gas Emissions*, Transportation Research Record No. 2132.

There are admittedly many challenges to moving towards this type of evaluation. For example, the ability to do regional scenario planning that includes land use as well as transportation will vary from region to region. Land use decisions are typically made at the local (municipal) level, whereas transit planning is part of a regional process. Even if a preferred transportation and land use scenario can be developed and "adopted" at a regional scale there may be no way to ensure that it is implemented, and therefore that the full benefits of the transit project are realized. Also, to ensure consistency in methods across projects, closer attention would need to be given to the travel demand forecasting and land use assumptions across the region, rather than just the project corridor.

A regional scale approach, however, may be the only way to achieve a complete accounting of transit's environmental benefits. This type of evaluation framework would also be consistent with best international practice for transportation project evaluation, as identified in the literature review for this research. In its January 2012 NPRM and proposed policy guidance, FTA is proposing to allow project sponsors the option of submitting alternative land use forecasts and associated estimates of environmental impacts, which would begin to move the process in this direction.

It would still be necessary for decision makers to evaluate individual projects on their merits. However, this evaluation might be done considering benefits that occur when the project is implemented in conjunction with other supportive projects and policies. The relative contribution of the project to the benefits of the overall regional plan might be assessed based on some factor such as ridership or passenger-miles.

If this approach were taken, transit agencies might have concerns about the fact that their project is being evaluated based on factors beyond their control (i.e., regional transportation and land use decisions made by the metropolitan planning organizations and local governments). On the other hand, this is already true within the current national land use and economic development evaluation criteria. Regional and local decisions also influence other benefits of the project, such as ridership, even within the current evaluation framework. A question that would need to be addressed is whether just the project would be evaluated, or whether the evaluation would also consider the broader regional planning context and the extent to which it supports the project.

■ Next Steps and Issues for Further Research

This research has provided an overview of the use of different metrics of environmental performance, but has left a number of issues unaddressed. These can be grouped into next steps for implementation, and issues for further research.

Next Steps for Implementation

The following issues will need to be addressed by decision makers and others who choose to apply these metrics.[9]

- Which metrics (if any) will an individual agency use for its own project evaluation purposes? How will they be used to inform project decision-making, including weighting them in relation to other measures of performance?

- Which metrics (if any) will be used for comparative evaluation of projects, and how will they be incorporated into the evaluation and reporting framework? What weights would be set for each metric within the environmental performance category, and how would this overall category be weighted in comparison to other categories?

- If a GHG metric is selected, will GHG be calculated based on regional emission factors, or national average factors? ICLEI's protocol for development of GHG inventories by local governments specifies the use of local/factors,[10] although decision makers would not necessarily need to be consistent with this practice.

- If an air quality metric is selected, which pollutants are included? Are emissions from powerplants from electricity generation included? Again, if the metric is applied comparing projects in different regions of the country, are national or regional emission factors used?

Issues for Further Research

Technical issues that warrant further research – some shorter term and easier to address, others longer term in nature – include the following:

- What are the most appropriate energy and GHG emission factors, particularly for future energy use and emissions from all types of transit vehicles (including electricity generation)?

---

[9] FTA's January 25, 2012 Notice of Proposed Rulemaking and accompanying Proposed New Starts/Starts Policy Guidance address some of these issues. For example, the policy guidance proposes the specific environmental metrics to be examined, how they will be combined and weighted, general methods for calculating these metrics, and the use of national rather than regional emissions, energy, and GHG factors. Details of data sources and calculation methods remain to be developed.

[10] ICLEI (2009). *International Local Government GHG Emissions Analysis Protocol (IEAP), Version 1.0.*

- What is the full range of energy use and GHG emissions from transit construction? (This may be addressed by research underway for FHWA).

- Can the Exposure Index and/or Health Benefits Index be further developed so that they are useful for transportation project and/or plan evaluation, considering health effects?

- How do different models of nonmotorized access mode choice affect the reliability of access mode choice forecasts? To what extent do transit projects induce nonmotorized trips in addition to those accessing the transit project (e.g., by allowing households living in transit station areas to have fewer vehicles)?

- Can systems-level forecasting methods (considering regional transportation and land use systems) provide information on the environmental benefits of projects that is significantly different than that provided by project-level methods that simply compare the project versus no-project alternative in isolation from other changes?

- To what extent are the environmental benefits of transit increased by the "trip not taken" (or the "land use multiplier")? That is, to what extent are our current evaluation methods not capturing the benefits of more compact development and associated changes in travel patterns? Some research is underway through TCRP H-46, *Quantifying Transit's Impact on GHG Emissions and Energy Use: The Land Use Component*, but further research is likely to be required because of the complexity of the topic and the variability of the relationships in different situations.

- What are the advantages, drawbacks, and implications of evaluating the environmental benefits of a project as part of a regional plan (i.e., in comparison to a no-plan or alternative plan), rather than in isolation from other changes?

1.0 Introduction and Overview

1.1 Overview

Transit Cooperative Research Program (TCRP) Project H-41 addresses the need for new measures of the environmental benefits of transit investments. The objective of this research is to present, evaluate, and demonstrate criteria, metrics, and methods for assessing and comparing the environmental performance of major transit investments. The research was undertaken to offer decision makers optional criteria, metrics, and methods for assessing transit projects with regard to environmental performance.[1]

The research was undertaken in two phases. The first phase included:

- A review of the literature to identify performance measures used for transit and other transportation projects, including a review of international practice in transportation environmental evaluation;
- Interviews with 20 stakeholder agencies or groups;
- A review of four recent transit project alternatives analysis (AA) documents or environmental impact statements (EIS) to identify which environmental performance measures have been emphasized and how they have been treated;
- An enumeration of potential metrics of environmental performance, data sources and calculation methods, and preliminary screening of these metrics; and
- Development of a more detailed approach to screening and selecting metrics, including selection of a short list of less than 20 metrics to evaluate in detail.

In the second phase, six pilot projects were recruited on which to test these metrics. Data were collected for each project and metrics were computed. The ease of data collection and computation, reliability, and usefulness of each metric for purposes of distinguishing among transit projects were then evaluated. Metrics were then placed in three tiers according to how promising they were for use in both local and national-level project

[1] For purposes of this research, the following definitions are used: 1) criteria – the characteristics that will be considered when performance is judged; 2) metric – a measure for something; generally a quantitative measurement or estimate, or an ordinal metric in the case of qualitative evaluation; and 3) method – a way of doing something, especially a systematic technique or process used to develop a metric.

evaluation. Finally, a set of "most promising" metrics was selected from the Tier 1 and Tier 2 metrics that represented each category of environmental performance without overlapping.

The research was guided by a 20-member project panel that included representatives from transit agencies, state departments of transportation (DOTs), a regional planning commission, a Department of Urban Planning from a major university, environmental and transportation planning consulting firms, an environmental action organization, the EPA, FTA, and several transportation industry associations including the American Public Transportation Association (APTA), American Association of State Highway and Transportation Officials (AASHTO), and the Community Transportation Association of America (CTAA).

History of Considering Environmental Benefits for Major Transit Capital Investments

Environmental benefits, including air quality, energy, livability, land use, and other benefits, have long been important considerations in evaluating and justifying transit investments at a local level. Potential negative impacts have also been an important consideration in project evaluation, especially since the passage of the National Environmental Policy Act (NEPA) in 1969.

Within the past two decades, the importance of environmental considerations has also been reflected in Federal programs for funding major capital investments. Specifically, FTA's New Starts program provides discretionary funds to meritorious transit projects across the country. These funds are awarded on a competitive basis and projects must demonstrate achievement of a number of justification criteria to be recommended for funding. One of these criteria is environmental benefit. Consideration of environmental benefits as part of the New Starts evaluation and rating process dates back to the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), which directed that a project must be "justified based on mobility improvement, environmental benefit, cost-effectiveness, and operating efficiency." Many, although not all, major transit capital investments receive funding through the New Starts program and therefore the criteria applied in this program are directly relevant to most project sponsors.

FTA policy adopted in 1996 defined a multiple measure approach for justifying New Starts projects.[2] Environmental benefit measures were identified as:

- Change in criteria pollutant emissions, including volatile organic compounds (VOC), oxides of nitrogen (NO_x), carbon monoxide (CO), and particulate matter (PM);
- Change in energy consumption (British Thermal Units);

[2] 61 Fed. Reg. 67093 (December 19, 1996).

- Change in carbon dioxide (CO_2) emissions; and
- Current U.S. Environmental Protection Agency (EPA) air quality attainment designation.

Over time, FTA ceased to use these measures in New Starts assessment, as they found that they provided little or no basis for meaningfully distinguishing among projects and that emissions and energy consumption were closely correlated with ridership forecasts and user benefits.

The national spotlight recently has been focused again on the environmental benefits of transportation investments. The U.S. DOT has named livability and sustainability as two of the Administration's priorities. The Government Accountability Office's (GAO) annual reports on the Section 5309 program increasingly call for fuller consideration of environmental benefits. In June 2009, the FTA reintroduced environmental benefits as part of its rating process, giving the current EPA air quality designation for a project's region 10 percent weight in the overall evaluation. In June 2010, FTA issued an Advance Notice of Proposed Rulemaking (ANPRM) soliciting input on a variety of questions related to the New Starts process, including how environmental benefits should be measured. FTA subsequently issued a Notice of Proposed Rulemaking (NPRM) in January 2012 proposing a new regulatory framework for the New Starts program.[3] This was accompanied by proposed guidance with new measures and methods for calculating the project justification and local financial commitment criteria, including environmental criteria.[4] Legislation addressing climate change and clean energy has also been debated, and energy and GHG savings have been criteria in recent competitive transportation funding programs including FTA's Transit Investments in Greenhouse Gas and Energy Reduction (TIGGER) program.

FTA also requires project sponsors to report on measures of transit-supportive land use and economic development. The land use measure considers the transit-supportiveness of existing land use patterns. The economic development measures (considered as part of the land use measure prior to 2009) include transit-supportive land use plans and policies, and performance and impacts of these policies. While specific environmental outcomes related to land use change (such as water quality or habitat preservation) are not assessed, long-term changes to land use and development patterns can have a significant impact on environmental outcomes. For example, a transit project may support more compact development patterns, which can reduce impacts on open space, habitat, and water quality associated with land consumption. Conversely, a project that increases accessibility in outlying, undeveloped areas may lead to negative impacts on these environmental factors. Thus, land use and economic development criteria are related to the measurement of environmental benefits. FTA's January 2012 NPRM recognizes this issue and proposes to allow project sponsors at their discretion to estimate the vehicle-miles of travel (VMT) associated with changes in development patterns enabled by a New Start project, and then incorporate that VMT into proposed environmental benefits measures.

---

[3] 77 Fed. Reg. 3848 (January 25, 2012).

[4] Federal Transit Administration. *Proposed New Starts/Small Starts Policy Guidance*, January 2012.

This project focuses in part on how land use changes related to a proposed transit project may affect environmental outcomes. It also recognizes that an assessment of transit-supportive land use plans and policies may serve as a proxy for land use-related environmental impacts, if such impacts cannot be directly assessed.

Relationship between This Research and NEPA

The National Environmental Policy Act requires disclosure of environmental impacts to determine the potential impact of the project on the natural, built, and human environments. Under NEPA, Federal agencies must conduct environmental reviews for Federal actions that have the potential to cause a significant impact on the human and natural environment. For projects that are funded by FTA, NEPA reviews are normally conducted for capital improvements.

While NEPA plays an important role in Federal decision-making, ensuring that environmental factors are considered prior to Federal action, the NEPA process often has different objectives than may be set by project sponsors or by FTA for the evaluation of environmental benefits for New Starts projects. NEPA is focused on ensuring that environmental impacts are disclosed and options for avoiding and minimizing adverse environmental impacts are identified, considering an expansive list of issues. In contrast, the purpose and need of a project may include a small number of goals to preserve or enhance aspects of these environments, and the New Starts process is focused on comparing projects nationally to guide investment decisions using a very limited set of measures.

The research performed in this project was not intended to duplicate the issues given the greatest scrutiny in the NEPA process, such as the direct air quality, water quality, and cultural resource impacts from project construction and operation. It is assumed that the outcomes of the NEPA process lead to acceptable avoidance or mitigation of these impacts such that they are not a major distinguishing factor from a national perspective. Instead, this research focuses on broad measures of environmental performance, including benefits as well as impacts that may be of interest to decision makers.

NEPA review for most transit projects is conducted through an environmental assessment (EA) or through an Environmental Impact Statement (EIS). FTA may also consider information submitted by a project sponsor and issue a categorical exclusion. Some environmental effects are quantified where possible, while others are presented in a qualitative manner. Key issues covered in an EA or EIS include:[5]

---

[5] FTA Office of Planning and Environment. *Environmental Resource Information*. http://www.fta.dot.gov/planning/planning_environment_5222.html. Cited in TCRP Legal Digest 30, pages 16-18.

- Air quality;
- Endangered species;
- Environmental justice;
- Floodplains;
- Hazardous materials and brownfields;
- Historic, archeological, and cultural resources;
- Navigable waterways and coastal zones;
- Noise and vibration;
- Parklands;
- Social and economic impacts;
- Land acquisition;
- Community impacts;
- Land use and development;
- Economic impacts;
- Safety and security;
- Visual impacts;
- Transportation impacts/traffic;
- Water quality; and
- Wetlands.

Some states also have their own environmental review and permitting requirements. In these cases, the types of impacts that must be evaluated are generally similar to those evaluated under NEPA. Some state requirements may be in addition to what is typically evaluated in NEPA; for example, California, Massachusetts, and Washington all require GHG analysis for major projects.

In the course of this research, the question arose as to whether information from the NEPA process could be used to inform environmental performance evaluations by the project sponsor using the metrics developed here. While project sponsors clearly use environmental information for their own decision-making purposes as well as NEPA documentation, the relationship between the NEPA and New Starts processes is not always consistent among projects. The transit project development process includes five key steps:

1. Systems Planning, in which a priority corridor or subarea is defined;
2. Alternatives Analysis, to determine mode and alignment within the corridor or subarea;
3. Preliminary Engineering (PE), to focus on final scope and cost;
4. Final Design, to finalize project development; and
5. Issuance of a Full Funding Grant Agreement (FFGA), to establish terms and conditions of Federal funding and finally construct the project.[6]

FTA approval is needed to advance the project from AA into PE to advance into Final Design and for an FFGA. However, the project sponsor must choose whether to prepare environmental documentation (including a draft and final EIS or EA) as part of either the AA or the PE phase. FTA provides guidance on the choice of the most appropriate stage which depends on the breadth of solutions considered in the Alternatives Analysis.

[6] TCRP Legal Research Digest 30, page 6.

Therefore, the amount of information available from the NEPA process to inform the New Starts process varies depending upon the stage of the project, and is not consistent from project to project.

While NEPA requires environmental issues to be evaluated in detail, environmental issues also may be considered at earlier stages of the project development process (Systems Planning and Alternatives Analysis). Federal legislation and planning regulations require that the systems planning process – development of a metropolitan or statewide long-range transportation plan – consider eight "planning factors," including one that is focused on the environment:

> *"Protect and enhance the environment, promote energy conservation, improve the quality of life, and promote consistency between transportation improvements and state and local planned growth and economic development patterns."*[7]

Regional and statewide transportation plans may have more specific goals and objectives related to environmental impacts. While localized environmental impacts are generally not considered in detail at the systems level, broad regional impacts such as air quality, greenhouse gases, and land use are frequently considered – either qualitatively or quantitatively if data are available – in the selection of projects to include in a long-range plan or transportation improvement program. The Alternatives Analysis phase also may include consideration of various environmental factors prior to their detailed analysis in environmental documentation for NEPA.

1.2 Research Products

Two interim products were produced from this research effort: an Interim Report detailing the findings of Phase 1, and a literature review that was published as a stand-alone document. Additional working material was prepared in the form of internal white papers. Sections of the Interim Report and white papers that are still relevant are included as various appendices to this Final Report.

[7] SEC. 3005. Metropolitan Transportation Planning and SEC. 3006. Statewide Transportation Planning of Title III – Public Transportation in the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users* (PL 109-59).

2.0 Background Research Findings

This section describes the findings of the literature review and stakeholder outreach that were conducted to inform the development of potential metrics and methods.

■ 2.1 Literature Review

The literature review included four parts:

1. A review of published literature from the United States and elsewhere related to transportation environmental performance measurement;

2. A review of environmental performance rating systems and tools;

3. A review of international practice in transportation environmental performance measurement; and

4. A detailed review of environmental documentation from four sample transit projects, to examine current practices.

In addition to reviewing literature sources, team members drafted white papers on particular technical topics, including measures of air quality and health benefits, measures of ecological impact or benefit, and assessing energy and GHG emissions from construction. The paper on measures of ecological impact or benefit is included as Appendix K to this report; the other papers have been superseded by material contained in Appendices C and G. All of this information was considered in developing the proposed list of environmental performance categories and metrics.

Published Literature

Nineteen relevant literature sources are described in more detail in Appendix I. Types of literature reviewed included:

- Reports enumerating and discussing how to measure benefits and impacts of transit, including environmental effects (e.g., TCRP Reports 20 and 88, Volpe Colloquium);

- Reports examining transportation performance measures and evaluation frameworks both in the United States and abroad; and
- Reports and detailed guidance on specific environmental measures, primarily greenhouse gases (e.g., GHG reporting protocols).

Measuring emissions – in particular GHG – and the base measure of changes in VMT due to transit investments were covered the most in the literature review. This literature included studies describing and quantifying the direct and indirect effects of transportation on changes in GHG and VMT, with some reports monetizing these measures. These documents were the most specific in identifying steps and data needed to complete the measures and apply them to transit agencies.

Broad catalogues of environmental performance measures tended to offer key categories and issues to consider such as scale of analysis. The most useful of these identified specific measures, data sources and how to calculate the results. For example, the Strategic Highway Research Program 2, Project C02, produced a library of performance measures for highway capacity expansion investments, including environmental measures, many of which are applicable to transit as well as highway projects.

Environmental Performance Rating Systems and Tools

With growing interest in sustainability, a number of assessment tools have been developed to assist organizations in assessing and rating the "sustainability" or environmental performance of their operations. Most performance rating systems are not transit-specific, but many include metrics that may inform transit applications. Some of these are focused on buildings (e.g., LEED), which could be applied to transit agency facilities. Others have been developed for infrastructure projects, primarily highways (e.g., Greenroads), but their principles could be extended to transit project construction. ISO certification is focused on environmental impacts across a full range of an agency's operations. Still others are focused at the community level (e.g., STAR) and include measures of transportation system performance and impacts (including transit). A white paper on the potential application of two particularly promising highway-focused systems to transit projects is included as Appendix F.

International Practice: Strategic Environmental Assessment

Rutgers University conducted a review of the process and method by which environmental criteria are assessed in a number of countries (Appendix J). The primary focus is on Strategic Environmental Assessment (SEA) or multicriteria analysis. Directive 2001/42/EC of the European Parliament and of the Council on the assessment of the effects of certain plans and programs on the environment ("the SEA Directive") requires all member states to assess environmental impacts of all policies, plans, and programs that are subject to being prepared or adopted by a governmental authority and by legislative procedure, and which are required by legislative, regulatory or administrative provisions.

All member states have now adopted legislation to comply with the directive (CEC, 2009). Australia and New Zealand have both adopted similar procedures, but Canada and Chile follow U.S. practice of project-based environmental impact analysis, rather than at the strategic policy level.

Strategic Environmental Assessment seeks to evaluate the environmental effect of policies and plans during early stages of the planning process. The method requires an alternatives analysis and public involvement. One of the key features is that the analysis is a multi-attribute analysis that examines various environmental effects versus economic, equity, and other impacts of interest to policy-makers.

No country seems to have a procedure that is specific to public transit planning. Instead, all transport modes are considered. For example, in the United Kingdom it is often a collection of various plans and projects within a Local Transport Plan that is the basis of a multi-attribute analysis. Thus, in theory, all modes are evaluated equally.

The effectiveness of the SEA directive was recently reviewed by the Commission (CEC, 2009). Various difficulties have been found but most of these represent a learning process as various countries develop the capacity to engage in SEA. Difficulties include variation in defining alternatives to evaluate, lack of good quality information for analysis, and a lack of standardized indicators for comparison (CEC, 2009). Insufficient analysis of cumulative effects also has been identified as an issue (Tricker, 2007).

Climate change impacts are dealt with by most countries on a case-by-case basis, with a goal of maintaining carbon neutrality or reductions. Specific guidelines for climate analysis do not yet exist (CEC, 2009).

Several benefits of the SEA process have been mentioned. These include benefits from early consultation and increased transparency of the planning process; actual changes in policies and plans in response to environmental problems; and reduction of the need for various mitigation procedures, due to earlier consideration of environmental impacts (CEC, 2009). Therefore, as a means of improving environmental outcomes, it is widely regarded as effective.

Review of Environmental Documentation for U.S. Transit Projects

EIS or AA environmental documents were reviewed in detail for four sample transit projects: The East Link Project in Seattle, Washington (light-rail transit, or LRT); the South Coast Rail Project in Massachusetts (commuter rail); the Northwest Corridor in Dallas, Texas (LRT); and the Purple Line project in the Maryland suburbs of Washington, D.C. (LRT or bus rapid transit, BRT). The purpose of the review was to identify which environmental impact measures were used and how they were calculated.

For each project and a standard set of environmental performance categories and measures, the following five items were identified:

- Was the measure evaluated?
- If so, quantitatively or qualitatively?
- What was the scope of impacts were evaluated – construction, direct operations, and/or indirect impacts?
- Did the transit project alternatives have a positive or negative impact versus the no-build?
- Was the measure used to compare and select among alternatives?

The specific measures evaluated and calculation methods used varied somewhat from project to project. Overall, however, the review confirmed that most (but not all) impacts are treated as negative impacts to be mitigated. Many of the impacts were considered to varying degrees in alternatives development and selection, although it was often difficult to quickly assess key differences among alternatives, or tell from the documentation how much a particular impact weighed in the selection process. Specific findings include:

- Most impacts are treated as negative impacts to be mitigated (or documented as having no significant impact). In some cases, however, impacts such as air quality or GHG emissions are treated as positive impacts. For example, the final EIS for the Dallas Northwest Corridor LRT identified the project as reducing public health impacts attributable to strong growth in vehicle traffic that the project would help to mitigate. Avoiding induced growth (or inducing growth consistent with local and regional plans) also was identified as a positive impact for some projects.
- There was significant variability in how the information is reported and it was generally difficult to quickly compare the environmental impacts of different projects or alternatives. While the EIS format is helpful, the organization of the documents can vary; in some, alternatives are compared in relationship to individual technical areas throughout document, while in others, the alternatives are analyzed in a single chapter. For projects that are at the Alternatives Analysis stage and, therefore, do not have an EIS, it can be difficult to find information quickly and efficiently. Final EIS documentation may allude to more comprehensive analysis undertaken at an earlier phase, but those findings may not be summarized in the final EIS. If AA/are reviewed electronically, maneuvering through documentation is often very cumbersome.
- Most of the focus is on direct impacts from operating the system, although construction impacts (e.g., air quality, noise, water quality) are evaluated in some cases with varying degrees of rigor. If "secondary" or "life-cycle" impacts are addressed at all, the discussion is brief and qualitative, or too entangled with cumulative impacts to differentiate between what is a project impact versus other outside factors.

- When alternatives are compared, they are not always compared to one another in **all** categories (e.g., a project may be compared to an alternative with respect to wetlands alteration, but no direct comparison is made with respect to environmental justice).

- The criteria by which alternatives are compared against one another are not weighted – if a project has minor impacts on wetlands but significant impacts to historic resources, which factor "wins"?

- When comparing different projects from different parts of the country, a significant issue in one region may not even come into play in another region (e.g., earthquakes/; maintaining groundwater levels in areas where buildings are supported by wooden piles).

2.2 Stakeholder Outreach

Interviews were conducted with 20 stakeholder agencies or organizations in April through June 2010 to identify how transit agencies, state transportation agencies, advocacy groups, and academic researchers have evaluated the environmental performance of transit investments. In addition to specific measures and methodologies, the interviews sought to obtain feedback on how environmental performance should or might be evaluated in the future.

The study team was interested in how transit agencies and others have evaluated the *environmental performance* of transit investments. The participants were encouraged to discuss situations where their organization went beyond the basic reporting required for Federal and state environmental permit processes and used environmental performance as a way of justifying a project or making comparisons among various transit and/or highway alternatives.

A list of contacts by organization type is included in Appendix L. This list was developed considering input from project panel members and from respondents' suggestions during interviews. The respondents were chosen in part due to their experience in measuring the environmental performance of public transportation investments, and also to obtain a cross-section of responses from different areas of the country and from transit agencies operating different modes. Twenty organizations were contacted in total, including eight transit agencies, the FTA, the American Public Transportation Association (APTA), two state departments of transportation, two metropolitan planning organizations (MPO), three advocacy groups, and two academics. Interviews with the New York City Metropolitan Transportation Authority, TriMet, Natural Resources Defense Council, FTA, and EPA were conducted with groups of staff.

The interview guide (Appendix M) included 19 questions in six sections. While questions were e-mailed to respondents, nearly all discussions took place by telephone. Questions covered the types of environmental impacts evaluated for transit or other types of transportation-related projects, and metrics used; the points in the decision-making and planning process at which environmental performance measures had been used; the methods used to collect data and calculate the metrics; what they would change about their process; and resources they used to develop their evaluation program. After first summarizing key findings, the following sections describe the responses to the survey questions in more detail.

Respondents provided detailed and in-depth information on their efforts to incorporate environmental performance measures into their work and relate these efforts to how projects could be compared at regional, state, and national scales. The paragraphs below provide a brief summary of the responses regarding how and what environmental performance measures are being used to assess transit projects.

Uses of Performance Measures

Prioritizing Transit Investments. Although the use of environmental performance measures in selecting investments was not common among the survey respondents, respondents reported innovative ways to incorporate these metrics into project evaluation. While nearly all operating agencies noted using environmental measures from NEPA reviews to decide between project alignments during the design phase, some noted that the same data, with additional analysis, is part of prioritization processes. In all cases, environmental benefits of transit are recognized when comparing across modes.

Applications for Federal Funding. All transit agencies responded that in addition to improving the planning process, environmental metrics also will prepare them for future funding application and reporting needs. Respondents from metropolitan areas are working to ensure that applications fully take into account the importance of transit investments.

Participating in Local Requirements and Environmental Targets. A few agencies participate in local environmental initiatives measuring the effects of public transportation on the regional environment. In some cases, an MPO or municipality has developed specific targets and methodologies to assess regional data; in others, the transit agencies are actively participating in local efforts to develop new environmental metrics and targets.

Outreach and Marketing. Organizations are actively publicizing the environmental, social, and economic benefits of transit. Locally, the efforts inform the public about plans for new infrastructure investments, while at the state or national scale the information builds a case for policy initiatives.

Types of Performance Measures

Greenhouse Gas Emissions. Greenhouse gas (GHG) emission is the environmental performance measure for public transportation most commonly cited by participants in this study and currently is being used by all transportation organizations contacted. The methodologies are still in development but consistently based on vehicle-miles traveled less avoided automobile trips. The data have been used to assist with public outreach, to apply for Federal funding, and to assist with tracking progress toward local environmental goals. Methodologies for quantifying GHG have been provided by The Climate Registry (TCR) and APTA, as well as the California Air Resources Board (CARB).

Land Use and Development. Despite a lack of established national standards and methodologies, six respondents, including three transit agencies have incorporated measures of development resulting from transit projects to complement environmental and economic evaluations required as part of existing reviews. Some efforts have targeted quantitative models, while some use qualitative descriptions to better describe local historical development. In all cases, respondents noted the need for new ways to compare transit investments in quickly expanding cities to those that support dense populations. Given recent Federal programs aimed at sustainable, transit-oriented development, interviewees noted the importance of developing evaluation tools of land use effects.

Life-Cycle Environmental Impact Analysis. Perhaps the least developed metric with the most obstacles to implementation, assessing full environmental performance over the lifetime of the project infrastructure is still a topic of studies and of interest to many participants. Four organizations incorporate elements of life-cycle environmental impact, but do so qualitatively, or for select parts of construction and operations that are not comparable across projects or between agencies. The issue is seen as important, however, given the development of new vehicles, materials, and fuel.

Quality of Life. Quality of life is a general term that applied to a variety of metrics discussed during the interviews. At least five participants discussed how a new measures such as "quality of life," "utility," "accessibility," and "livability" could be used to quantify on-the-ground design and operations benefits that otherwise escape standard measures of environmental performance. Respondents considered these measures in that they involve the natural and built environments in which transit operates, and because well performing quality of life issues will increase transit ridership, which has been shown to contribute positively to environmental quality as reflected in other performance measures discussed here.

Consistency with Related Plans. While considering regional plans is often part of a transit agency's early project development work, some agencies and transportation planning organizations have made this relationship explicit. In addition, these organizations have gone beyond transportation-specific documents to consider environmental and land use planning efforts. Only two organizations include planning consistency in their project reviews and report that it has expedited the project review, avoided costly delays, and constructively involved more community members.

Recommendations for Performance Measures

Survey participants offered a variety of suggestions to consider in the development of environmental performance measures to compare and assess transit investments. Some common themes and other notable points included:

- A number of respondents noted that the indirect environmental impacts of transit, related to changes in land development patterns, may be much more significant than the direct impacts and should be given important consideration.
- Some also noted that the baseline of comparison – transit versus no-build, or transit/development versus highways and sprawl – is significant in determining whether transit provides environmental "benefits."
- Reductions in vehicle-miles of travel (VMT) were widely viewed as a measure that is of interest and related to environmental performance. However, many projects, particularly those in densely developed areas with an existing high transit mode share, may not result in a significant reduction of VMT but instead will improve conditions for existing transit travelers. As a result, VMT reductions alone – or related measures such as vehicle emissions and energy use – should not be the only measures to determine the project's environmental efficacy. Another way of looking at this is that projects should be rewarded for improving travel conditions in highly developed settings, helping attract and retain people in these settings where the environmental impacts of travel can be much lower.
- Interest was expressed in measuring the life-cycle environmental impacts or benefits of transit, particularly with respect to energy use and GHG emissions, but further research and guidance is needed on this topic.
- Some agencies have developed metrics related to quality of life and view this as an important benefit, although these metrics differ from location to location.
- A number of respondents reacted favorably to the concept of a "checklist" approach rewarding local agency actions, as a replacement or supplement for quantification of project impacts.
- Some transit agencies noted that metrics and methods should be flexible to account for the unique operating environments for transit systems across the nation. At the same time, benchmarks and standards are needed for performance measures to provide guidance to transit agencies as well as consistency across projects.
- One respondent noted that benefits that are viewed as significant should be acknowledged and accounted for in the New Starts evaluation process somehow, even given the current lack of good analytical methods to quantify these benefits.

3.0 Screening, Testing, and Evaluation Process

3.1 Environmental Performance Categories and Dimensions

Performance Categories

To develop a list of metrics, the project team first established four major *categories of environmental performance*:

1. Energy use and greenhouse gas emissions;
2. Air quality and public health;
3. Ecology, habitat, and water quality; and
4. Community and quality of life.

Public health has two distinct components – the first directly related to air quality, and the second related to physical activity. Physical activity was considered as part of "community and quality of life" in the preliminary list of metrics, but panel comments suggested that it be more appropriately combined with air quality. Land use also was considered as a separate category, but instead was merged with the above categories. Land use impact is not really a stand-alone environmental performance metric, but rather an indicator of (or related to) other metrics, both for the natural environment (ecology, habitat, water quality) and for the human environment (livability).

This set of categories considers both the natural and human environment, consistent with practice under NEPA. However, this project was not intended to provide a detailed review of the full set of indicators of performance with respect to the human environment (including factors such as safety and security, access to affordable housing, etc.). The focus of the measures considered is on the *physical environment* (natural or human) which may include human environmental factors such as noise, aesthetics, and historical resources, in contrast to *social environment* factors such as safety and security, which are not covered.

At the interim meeting of the Project Panel in September 2010 at which the results of the Phase 1 literature review and screening were discussed, it was determined not to include community and quality of life measures in the Phase 2 testing. The Panel viewed these measures as important, but not the focus of the current research project. Therefore, Phase 2 research focused only on the first three environmental performance categories.

Performance Dimensions

Various *dimensions of performance* also are identified. These include impacts related to:

- **Direct effects of vehicle operations** (changes in transit and highway vehicle travel), including both the impacts of vehicles themselves as well as production and transport of fuel to power the vehicles (full fuel cycle);
- **Impacts from other system elements –** Construction of infrastructure and vehicles (transit, as well as highways depending upon the baseline for comparison), as well as maintenance, nonvehicle operations (e.g., station power), and disposal; and
- **Indirect effects –** Land conversion, changes in building stock, and travel impacts associated with changes in land use patterns.

The relationship between the performance categories and dimensions is illustrated in Table 3.1.

Table 3.1 Environmental Performance Categories and Dimensions

	Vehicle Operations		System Construction, Maintenance, Operations, and Disposal		Indirect Effects		
Performance Category	**Direct**	**Full Fuel Cycle**	**Facilities**	**Vehicles**	**Land Conversion**	**Buildings**	**Travel Impacts**
Energy use and greenhouse gas emissions							
Air quality and public health							
Ecology, habitat, and water quality							
Community and quality of life	(not assessed in research process)						

This research primarily focused on vehicle operations (both highway and transit) as well as indirect effects of land conversion. For energy and GHG metrics, both direct and fuel-cycle energy use and emissions were included. Energy and emissions associated with system construction were also considered to the extent that data were available, but maintenance, operations, and disposal were not considered due to lack of data. Indirect effects from travel associated with land use changes resulting from the transit project are not currently considered in comparative analysis and therefore were not considered. Effects associated with changes in building stock were deemed too speculative to consider and also outside the range of typical transportation analysis.

3.2 Development and Screening of Candidate Metrics

In Phase 1, a list of over 120 candidate metrics or variations on metrics was developed. Within each category, a variety of specific metrics were identified from various literature sources, stakeholder interviews, and the experience of the project team. Some of the metrics are direct measures of benefit or impact, while others are "proxy" measures that relate to the magnitude of benefits or impacts. For example, vehicle-miles of travel (VMT) reduced is not a direct measure of environmental benefit, but affects other metrics such as air quality and energy consumption. The strength of plans and policies directed at habitat protection also may be used as a proxy for environmental impacts, when such impacts cannot be directly measured or forecasted. Some measures are reported as total impacts, while others are normalized in different ways (e.g., per capita, per rider, or per dollar of project cost).

Each metric was described including:

- Data requirements for forecasting;
- Data sources and analysis methods;
- Advantages and disadvantages for use as a transit performance metric; and
- Current level of use or interest in the metric.

The metrics were then evaluated against three criteria as described in Table 3.2:

- Data availability and reliability;
- Ease of forecasting; and
- Environmental relevance.

Table 3.2 Description of Screening Factor Evaluation Criteria

Screening Factor	Description
Data Availability and Reliability	
Good	Widely accepted and validated data
Fair	Some existing data/research, but some knowledge gaps/uncertainties
Poor	Little or no existing research or reliable data
Ease of Forecasting	
High	Available data and models with modest additional analysis requirements
Moderate	Some new data collection and analysis required
Low	Significant new data collection and/or new analysis effort required
Environmental Relevance	
High	Direct and consistent indicator of environmental impact/benefit of project
Moderate	Indirect or inconsistent indicator of environmental impact/benefit
Low	Little relationship to environmental impact

The evaluation was performed by the project team with consultation and review by the TCRP Project Panel. The process of identifying and screening metrics in Phase 1 began in January 2010 and was completed in September 2010. The outcome was a set of recommended metrics for further testing in Phase 2. This list of metrics for further consideration was refined and finalized at an in-person meeting of the Project Panel in September 2010.

3.3 Testing of Metrics

In Phase 2, five transit agencies were recruited to support pilot-testing of the metrics. Two projects were selected at one transit agency, for a total of six projects. Also, one of these projects had two modal variations (diesel and electric), for a total of seven project alternatives. The criteria for selecting pilot projects included:

- Project sponsor was willing to cooperate in providing the necessary data;
- Projects included from small- to medium-size metropolitan areas as well as larger areas, to ensure that the metrics can be calculated by sponsors with different levels of resource availability;
- Different transit modes included;
- Projects included serving a variety of urban contexts (inner city, suburbs, exurbs/developing areas);
- Multiple projects from one project sponsor included, to take advantage of economies in data collection and also to evaluate the metrics using comparable data applied to different types of projects; and
- Appropriate timing – far enough along in the project planning phase that sufficient information is available to support the assessment.

Given the exploratory nature of the research, project sponsors were promised that their projects would remain "anonymous" in order to avoid presenting any findings that might be incorrectly reported or interpreted. The characteristics of the projects recruited for pilot-testing are shown in Table 3.3. The stage of project development – whether a draft environmental impact statement (DEIS) or New Starts application has been completed – affected the data available for the evaluation and is shown in Table 3.1.

Table 3.3 Pilot Project Characteristics

Project	Mode	Area Type/ Context	Approximate Length (Route-Miles)	DEIS Completed?	New Starts Application Completed?
Project 1	Light Rail	Suburban	10-20	N	N
Project 2	Commuter Rail – • Diesel (Alt. 1) • Electric (Alt. 2)	Suburban/ Intercommunity	>25	Y	N
Project 3	Light Rail	Urban/Suburban	5-15	Y	Y
Project 4	Commuter Rail – Electric Multiple Unit	Urban/Suburban	10-20	Y	Y
Project 5	Light Rail	Urban	5-15	Y	Y
Project 6	Bus Rapid Transit	Urban	10-20	Y	Y

A list of needed data items was then prepared for the pilot project sponsors. Project sponsors were asked to provide only data that they had in-house or could easily prepare from available data, rather than conducting additional model runs or analysis. The recruitment and data collection phase took place between November 2010 and June 2011, with data obtained on a rolling basis between January and June 2011. Appendix A of this report describes the data collection process and results in detail.

Calculation of the candidate metrics took place between February and August 2011. The project team first defined procedures for calculating each metric, including developing default data for key inputs (e.g., energy consumption per vehicle-mile) where needed. These procedures were then tested on two or three pilot projects as data became available. Metrics that were not difficult to calculate or deemed worthy of further investigation were calculated for all projects.

Once the metrics were calculated, a summary evaluation was prepared. The panel was provided with an interim briefing and early results in June 2011. The full summary evaluation was provided and discussed at a web-based panel meeting in September 2011. The results were then documented in a final report and summary document.

4.0 Assessment of Metrics

This section reports on the results of pilot-testing of the various metrics of the environmental benefits of transit projects. Following a summary of findings and presentation of computed metric values, the results for each metric are discussed in more detail. The summary for each metric contains a recommendation regarding what "tier" the metric should be considered:

- **First Tier –** Highly promising, recommend for use;
- **Second Tier –** Somewhat promising but also significant limitations, consider for use; and
- **Third Tier –** Not promising, not recommended for use for transit project evaluation.

The metrics were initially selected based on three primary evaluation criteria, including 1) data availability and reliability, 2) ease of forecasting, and 3) environmental relevance (how well the metric represents environmental impacts). These same criteria were considered in the final evaluation of metrics. The potential usefulness of the metric in distinguishing among transit projects was also considered, based on the actual evaluation results. Specific considerations included the size of the environmental impact (significant or not), transparency of the metric and understandability to decision-makers, and whether differences among projects appeared to be significant and also reliable (i.e., related to actual impacts rather than uncertainties in data or evaluation methods).

The evaluation was conducted based on somewhat limited application of the metrics across the pilot projects. Not all metrics could be computed for all projects, either because a specific data item was not available, or because resource limitations prevented doing so. In some cases, trials on two or three projects suggested the metric was unlikely to be practical, and therefore the metric was not computed for other projects, even if the necessary data were available.

4.1 Summary of Findings

Table 4.2 summarizes the ratings for each of the metrics evaluated, including its "tier" as well as an assessment of ease of calculation, reliability, and usefulness, per the criteria described in Table 4.1. All three factors are rated on a low – moderate – high scale, with high being a favorable rating. In addition to the three categories of environmental performance, Table 4.2 includes a "cross-cutting" metric that covers multiple performance categories.

Table 4.1 Description of Final Evaluation Factors

Evaluation Factor	Description
Ease of Forecasting	
High	Can be calculated with relative ease from data and models typically available from the environmental analysis and/or New Starts process. • A few hours of project sponsor staff time. • Additional (one-time) work may be required to produce standard inputs and guidance, which will minimize work for project sponsors.
Moderate	Some new data collection and analysis required. • One to two days of decision maker staff time per project.[a]
Low	Significant new data collection and/or new analysis effort required. • More than three days of decision maker staff time per project.[a]
Reliability	
Good	Modest uncertainty in key assumptions/inputs; level of uncertainty consistent with other existing factors such as ridership forecasts.
Fair	Moderate uncertainty in key assumptions/inputs.
Poor	High uncertainty in key assumptions/inputs.
Usefulness	
High	Capable of clearly distinguishing among projects or alternatives, and clear/interpretation of metric.
Moderate	Some limitations to ability to distinguish among projects or alternatives, or some lack of clarity/meaningfulness in interpretation of metric.
Low	Not capable of distinguishing among projects or alternatives, or interpretation of metric unclear/not meaningful.

[a] The level of effort required of decision makers would depend upon whether project sponsors are required to compute the metric directly, or simply to provide datasets so that others can compute the metric.

Table 4.2 Summary Evaluation of Metrics

Key	Metric Description	Tier	Ease of Calculation	Reliability	Usefulness	Benefits/Advantages	Key Drawbacks/Concerns
I. Energy and Greenhouse Gas Emissions							
IA	Operating GHG emissions per passenger-mile	1	High	Moderate/ High	High	• Rewards both efficient vehicle technology and high ridership/ load factors	• Does not consider benefits from reduced automobile travel
IB	Operating energy consumption per passenger-mile	1	High	Moderate/ High	High		
IC(i)	Change in operating GHG emissions	2	Moderate/ High	Moderate	Low/ Moderate	• Considers benefits from all modes	• Small change relative to regional emissions • Sensitive to future uncertainties in relative modal energy and emission rates
ID(i)	Change in operating energy consumption	2	Moderate/ High	Moderate	Low/ Moderate		
IC(ii)	Project cost per reduction in operating GHG emissions	3	Moderate/ High	Low/ Moderate	Low/ Moderate	• Cost-effectiveness – reports GHG benefit per dollar spent	• Unstable/not meaningful for low or negative energy and GHG benefits • May be misleading if project is compared with other air pollution reduction measures based only on cost-effectiveness
ID(ii)	Project cost per reduction in operating energy	3	Moderate/ High	Low/ Moderate	Low		
IE(i)	Construction GHG emissions	2	Low	Unknown[a]	Moderate	• Expands scope of energy and GHG emissions considered	• Data/methods still under development
IE(ii)	Construction energy consumption	2	Low	Unknown[a]	Moderate	• Rewards efficient construction practices	

Table 4.2 Summary Evaluation of Metrics (continued)

Key	Metric Description	Tier	Ease of Calculation	Reliability	Usefulness	Benefits/Advantages	Key Drawbacks/Concerns
II. Air Quality and Public Health							
IIA(i)	Change in direct operating emissions	2	Moderate	Moderate	Low/ Moderate	• Commonly used metric in air quality planning	• Small change relative to regional emissions • Previously not found useful in comparing projects in different regions
IIA(ii)	Dollar of project cost per change in direct operating emissions	3	Moderate	Low/ Moderate	Low	• Cost-effectiveness – reports pollution reduction benefit per dollar spent	• Unstable/not meaningful for low or negative emissions benefits • May be misleading if project is compared with other air pollution reduction measures based only on cost-effectiveness
IIB	Exposure Index	3	Low	Unknown[a]	Low/ Moderate	• Weights emissions by exposure to population	• Difficult to calculate • Unclear interpretation/ significance
IIC	Health Benefit Index	3	Low	Unknown[a]	Low/ Moderate	• Additional weighting of emissions by toxicity	
IID	Air Quality Index	3	High	High	Low	• Indicates severity of regional air quality problem	• Not related to benefits of project
IIE	Forecast change in daily nonmotorized access trips	2	High	Moderate	Moderate/ High	• Reasonable proxy for physical activity generated by project	• Inter-project consistency in modeling methods
	Level of Service and other measures for assessing pedestrian and bicycle access to transit	3	Low/ Moderate	Moderate/ High	Unknown[a]	• Indicates extent to which station area environments are conducive to physical activity	• Already considered qualitatively under land use/ economic development • Does not indicate actual physical activity levels

Table 4.2 Summary Evaluation of Metrics (continued)

Key	Metric Description	Tier	Ease of Calculation	Reliability	Usefulness	Benefits/Advantages	Key Drawbacks/Concerns
III. Ecology, Habitat, and Water Quality							
IIIA	Percent of corridor that is already developed	2	Moderate/ High	Moderate	Moderate	• Relates to livability principle, supporting existing communities • Proxy for potential to support infill versus greenfields development	• May not relate to actual environmental impacts
IIIB	Potentially impacted acreage of undeveloped land	3	Moderate/ High[b]	Moderate	Low/ Moderate	• Proxy for potential to induce greenfields development	• May not relate to actual environmental impacts
IIIC	Potentially impacted acreage of sensitive habitat	3	Moderate[c]	Low	Moderate	• Proxy for potential to induce development in areas of sensitive habitat	• No good, easy to obtain proxies for sensitive habitat
IIID	Potentially impacted acreage weighted by ecosystem service value		N/A – not calculated			• Weights potentially impacted land use by ecological importance	• Land use data not consistent enough to evaluate ecosystem service value
IIIE	Adequacy of state, regional, and local habitat protection plans	3	Low	Low/ Moderate	Moderate	• Assesses extent to which sensitive habitat is protected, without attempting to judge specific development impacts of project	• Inter-project consistency in assessment • Level of effort required for assessment • Very indirect connection to potential impacts of project
IV. Cross-Cutting Metrics							
	Environmental performance ratings for transit projects	2	Low	Unknown[a]	Unknown[a]	• Indicates extent to which projects sponsors are taking measures to mitigate, avoid, or offset negative impacts • Primarily useful for self-assessment and possible extra credit	• Does not indicate benefits of project, just reduction of negative impacts from construction and operation • Level of effort to assess and interproject consistency in assessment

[a] Unknown because not fully tested in this research or not enough projects tested to gauge reliability.

[b] Assuming this is calculated simply as undeveloped land in the corridor. If weighted by accessibility or another indicator of potential impact, "low" ease of calculation.

[c] Assuming this is calculated simply as agricultural and wetland land area in corridor. If weighted by indicator of development potential or using a better indicator of ecological sensitivity, "low" ease of calculation.

The only metrics that did not appear to have one or more significant weaknesses and identified as "Tier 1" metrics were IA and IB, GHG emissions per passenger-mile and energy use per passenger-mile (which are closely related, and therefore only one should be selected). Others of the original metrics which were rated as "Tier 2" and could be considered as possible candidates include:

- Change in total operating energy and GHG;
- Construction GHG emissions;
- Change in direct operating air pollutant emissions;
- Change in nonmotorized trips;
- Percent of corridor that is already developed; and
- Environmental performance ratings for transit projects.

For this list, the following additional considerations apply:

- The construction energy and GHG metrics (IE) were originally proposed as the change in total life-cycle energy and GHG emissions. However, for reasons discussed below, the project team felt it was better to keep construction emissions separate from operating emissions. The options of normalizing these per unit of project cost, track-mile, or passenger-mile should be explored.

- Change in total air pollutant emissions was previously used by FTA and determined not to be useful. However, an alternative might be to normalize emissions on a per passenger-mile project for the project alone, similar to the energy and GHG metrics.

The difficulty in identifying useful and practical metrics for air quality, energy, and GHG emissions is perhaps due less to limitations in data and methods, than to the fact that the environmental impacts of an individual transit project, when evaluated on a regional scale using existing evaluation frameworks, are small. The projects typically result in benefits of tenths or hundredths of a percentage point when compared against regional transportation emissions and energy use. Localized emissions impacts due to changes in traffic patterns and/or transit vehicle technology can be much more significant, but these are already evaluated in the NEPA documentation process and were not considered as part of the scope of this study.

The study results should not be interpreted to mean that transit projects do not have significant environmental benefits. However, the benefits may need to be measured at a system or network level in order to appear significant on a regional scale. Their significance would likely be greater if alternative plans were compared that contained transit networks and complementary transit-oriented development land use patterns, versus plans with highway expansion and associated dispersed development. However, neither network-level assessment nor the consideration of alternative land use forecasts are currently part of the New Starts evaluation framework. This suggests that an alternative evaluation framework may be required to fully measure the environmental benefits of transit.

Benefits for ecology, habitat, and water quality (aside from direct project impacts) are also difficult to measure at a project scale. Current methods are not capable of reliably forecasting the development impacts of a transit project, especially at the level of spatial detail required to assess any corresponding environmental impacts. In a narrow comparison of a project to no-project alternative, the impacts measured are most likely to be negative (i.e., more development equals more impact), unless an evaluation framework is established that accounts for alternative dispersed or "sprawl" development patterns that might have occurred without the transit project. FTA's current land use and economic development criteria already account for these issues in a qualitative sense, by evaluating the strength of land use plans and policies oriented at directing growth into transit station areas and limiting sprawl. It may not be possible to go beyond this level of assessment in terms of predicting specific environmental impacts or benefits related to land development.

4.2 Metric Values

Tables 4.3, 4.4, and 4.5 show the values computed for the various metrics for energy and GHG, air quality/health, and ecology and habitat, respectively. Table 4.3, energy use and GHG metrics, shows a range of values ("low" to "high") for some projects, representing a range of values based on sensitivity testing of uncertain parameters. The pilot projects are reported anonymously but their general characteristics are reported in Table 3.3, and the mode is shown in these tables.

The sample of projects is limited and therefore it is difficult to draw firm conclusions about whether the different metrics are strongly correlated with each other, or show different impacts. However, the data presented here do suggest that individual projects can perform very differently on different metrics. For example, Project 4 shows the second-lowest GHG and energy per passenger-mile of four projects, yet shows the highest increase in total GHG emissions and energy. Project 6 performs best on the energy and GHG per passenger-mile metrics, yet has the smallest absolute impact on air pollutant and GHG emissions. Project 2 has the highest absolute energy, GHG, and emissions savings, due to the length of the corridor and the fact that it reduces the most automobile miles of travel; but because it primarily serves suburban areas and auto access trips, it shows the highest land use impacts and lowest physical activity (walk access) impacts.

Considering these observations, this initial review does suggest that projects that are likely to perform well on some measures may perform poorly on others. This has two implications: first, it is worth looking at a variety of metrics; and second, how a project rates overall on environmental performance compared to other projects will depend upon how the individual metrics are weighted.

Each discussion in the remainder of this section includes an overview of how the metric was calculated, key assumptions that may lead to uncertainty in the metric, results from the pilot testing, pros, cons, and a summary of the usefulness of the metric for evaluating transit projects. Each metric's potential is considered for use by decision makers to evaluate individual projects and to compare projects in different regions of the country.

Table 4.3 Energy Use and GHG Emissions Metrics

Key	Metric	Project 1 – LRT	Project 2 – Commuter Rail		Project 3 – LRT	Project 4 – EMU[a]		Project 5 – LRT		Project 6 – BRT	
			Alt 1 – Diesel	Alt 2 – Electric		Low	High	Low	High	Low	High
IA	Operating GHG emissions per passenger-mile for the project (kilograms CO_2e)		0.252	0.125		0.099	0.128	0.126	0.182	0.042	0.083
IB	Operating energy consumption per passenger-mile for the project (BTU)		3,190	1,770		1,390		1,980		540	1,050
IC(i)	Change in operating GHG emissions (tonnes CO_2e per year)		-7,880	-26,280		9,020	14,680	-90	4,620	-4,630	-3,790
IC(ii)	Project cost per reduction in operating GHG emissions (dollars per tonne CO_2e)		$16,100	$5,890		N/A[b]		$949,200	N/A	$3,800	$4,640
ID(i)	Change in operating energy consumption (million BTU per year)		-165,900	-398,000		116,600		-1,300	15,100	-69,700	-58,400
ID(ii)	Project cost per reduction in operating energy consumption (dollars per million BTU)		$770	$390		N/A		$63,200	N/A	$250	$300
I(E)	Construction energy consumption and/or GHG emissions										

[a] Uncertain energy intensity values associated with this project, which is electric multiple-unit technology not currently in use in the U.S. For this analysis, an average of light rail and electric commuter rail values of energy intensity (BTU per vehicle-mile) was assumed. The project sponsor had not developed technology-specific estimates.

[b] Cost-effectiveness is not meaningful when emissions increase.

Table 4.4 Air Quality and Public Health Metrics

Key	Metric	Project 1 – LRT	Project 2 – CR[a] Alt. 1 – Diesel	Project 2 – CR[a] Alt. 2 – Electric	Project 3 – LRT	Project 4 – EMU	Project 5 – LRT	Project 6 – BRT
IIA(i)	Change in direct operating emissions (kilograms per year)							
	NO_x		(10,740)	(13,960)			(4,470)	(340)
	VOC		(14,380)	(18,100)			(2,300)	(680)
	CO		(648,400)	(841,060)			(226,020)	(18,050)
	PM_{10}		(1,280)	(1,900)			(1,120)	(240)
	$PM_{2.5}$		(210)	(510)			(780)	(100)
	Benzene[b]						(72)	(19)
IIA(i)	Change in direct operating emissions – percent of regional emissions[c]							
	NO_x		(0.15%)	(0.20%)			(0.05%)	(0.07%)
	VOC		(0.17%)	(0.21%)			(0.03%)	(0.14%)
	CO		(0.16%)	(0.21%)			(0.03%)	(0.15%)
	PM_{10}		(0.10%)	(0.15%)			(0.04%)	(0.13%)
	$PM_{2.5}$		(0.04%)	(0.09%)			(0.04%)	(0.12%)
	Benzene						(0.03%)	(0.15%)
IIA(ii)	Cost per ton of emissions reduced ($1,000s)							
	NO_x		$11,800	$11,100			$19,000	$51,200
	VOC		$8,800	$8,500			$36,800	$25,900
	CO		$200	$200			$380	$980
	PM_{10}		$99,400	$81,600			$76,100	$73,700
	$PM_{2.5}$		$609,200	$305,900			$108,400	$173,300

[a] Some discrepancies were observed between emissions estimates shown in the DEIS for this project and calculations performed on data in a spreadsheet provided by the project sponsor.

[b] Seven air toxics were computed for purposes of computing the Health Benefit Index. Sample results are shown for benzene only.

[c] For Projects 2 and 6, emissions are computed as a percentage of modeled area emissions which does not cover the entire metropolitan region.

Table 4.4 Air Quality and Public Health Metrics (continued)

Key	Metric	Project 1 – LRT	Project 2 – CR: Alt. 1 – Diesel	Project 2 – CR: Alt. 2 – Electric	Project 3 – LRT	Project 4 – EMU	Project 5 – LRT	Project 6 – BRT
IIB	Exposure Index[d]							
	CO (24-hour standard)		(5.7)	(6.3)			(2.3)	(0.3)
	PM_{10} (24-hour standard)		(9.9)	(11.5)			(12.9)	(6.9)
	$PM_{2.5}$ (24-hour standard)		(2.1)	(3.0)			(8.5)	(2.8)
	$PM_{2.5}$ (Annual Standard)						(3.9)	(2.7)
	Benzene (Annual)						(0.8)	(0.4)
IIC	Health Benefit Index							
	Non-Ozone Criteria Pollutants		(4.5)	(5.5)			(8.4)	(4.9)
	Noncancer Toxics						(17.7)	(11.5)
	Cancer Toxics						(130.9)	(47.6)
IID	Air Quality Index							
	Median	59	44	44	50	50	43	39
	Maximum	204	169	169	171	171	138	187
	Percent unhealthy days for sensitive individuals	11.1%	3.8%	3.8%	5.9%	5.9%	1.5%	3.8%
IIE	Forecast new daily nonmotorized access trips		2,600	3,600	15,400	8,100	5,300	8,300

[d] Units of the Exposure Index are (person-kilograms per square mile)/10^x, where x = 9 for CO and 6 for PM and benzene.

Table 4.5 Ecology, Habitat, and Water Quality Metrics

Key	Metric	Project 1 – LRT	Project 2 – CR Alt. 1 – Diesel	Project 2 – CR Alt. 2 – Electric	Project 3 – LRT	Project 4 – EMU	Project 5 – LRT	Project 6 – BRT
IIIA	Fraction of corridor land that is already developed	88%	36%	36%	90%	91%	96%	95%
IIIB	Potentially impacted acreage of undeveloped land	17,400	94,400	94,400	3,600	6,000	1,400	2,200
IIIC	Potentially impacted acreage of sensitive habitat (agriculture and wetlands)	13,800	91,000	91,000	3,600	5,600	280	900
IIIE	Adequacy of habitat protection plans							
	Federal issues score (out of 25)		10	10		10		
	State issues score (out of 35)		24	24		10		
	Local/regional issues score (out of 45)		29	29		32		
	Total Score (out of 100)		**63**	**63**		**52**		

4.3 Energy Use and Greenhouse Gas Emissions

The metrics are discussed in an order that presents simpler or more basic metrics first. In particular, GHG emissions are calculated from energy use, so energy use is discussed first.

Metric IB – Operating Energy Consumption (BTU per Passenger-Mile for the Proposed Project)

Calculation. This metric is calculated as the total operating energy used by the proposed transit project (considering upstream energy associated with fuel production as well as direct vehicle energy use) divided by the number of passenger-miles on the proposed project. The metric does not consider increases or decreases in energy use from other elements of the transit system (e.g., changes in feeder bus service) or from trips diverted from automobiles.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Ridership forecasts;
- Transit VMT for the proposed project; and
- Transit vehicle energy consumption rates.

Ease of Computation. The measure is fairly easy to compute from data sources typically developed for project ridership forecasting and environmental analysis of individual projects and from comparative analysis of multiple projects. Project-specific energy consumption rates are rarely known or reliably estimated, however, and national default averages by mode must generally be used. Also, analysis of operating plans for the proposed project may be required to determine changes in transit VMT.

Results. Values for this metric from pilot-testing ranged from a low of 500 to 1,000 British Thermal Units (BTU) per passenger-mile for a BRT project to a high of 3,200 BTU per passenger-mile for a diesel commuter rail project. An electrified alternative of the commuter rail project showed a significantly lower value than the diesel alternative of 1,800 BTU per passenger-mile. Estimates for two light rail projects were in the range of 1,400 to 1,800 BTU per passenger-mile.

Pros. BTU per passenger-mile has a number of advantages and seemed to be a useful metric. It is understandable and logical as a measure of the "efficiency" of travel. It clearly differentiates among projects, because it is not diluted across a system or broad area, and shows a range of values across projects. It can be compared with the efficiency of other projects and other modes (for example, the average single-occupancy vehicle on the road today uses about 4,600 BTU per passenger-mile). It rewards both efficient vehicle technology and high-ridership density. It eliminates some uncertainty factors present in other energy and GHG metrics that consider diverted automobile trips, including fuel efficiency of the future automobile fleet, forecast VMT and speed changes for highway vehicles, and choice of appropriate GHG factors. It addresses concerns from project sponsors who are improving travel conditions for a largely captive ridership base rather than shifting riders from automobiles to transit, since the value of the metric does not depend upon mode-shifting. Energy consumption as a metric may appeal to a broader set of constituents, including those interested in energy security issues, than GHG emissions.

Cons. BTU per passenger-mile is not a complete measure of the energy impacts of a project, as it does not account for nonproject operational changes (transit or highway) or the benefits of riders who shift modes from automobile to transit. It only indirectly measures environmental impacts, since different fuel sources will have different environmental impacts (including GHG emissions and air quality) per BTU. It does not indicate the *relative* benefits or cost-effectiveness of the investment, i.e., how much energy use is being reduced as a result of Federal and local spending. The use of national default vehicle energy consumption rates (BTU per vehicle-mile), while improving consistency, may not be appropriate as individual transit projects have different levels of energy consumption depending upon vehicle technology as well as operating characteristics.

Summary. The transparency of this metric, limitations on uncertainty, and ability to distinguish among projects in a way that is clearly related to environmental impacts make this a promising metric. If the metric is adopted for use in comparative project evaluation, consistent and appropriate energy consumption factors for different types of transit vehicles will be needed reflecting current and anticipated future transit vehicle technology, and/or close scrutiny of energy consumption estimates provided by the project sponsor.

Metric IA – Operating GHG Emissions per Passenger-Mile (Measured for the Proposed Project)

Calculation. This metric is calculated as the total transit operating GHG emissions from the proposed project (considering upstream fuel emissions as well as direct vehicle emissions) divided by the number of passenger-miles on the proposed project. The metric does not consider increases or decreases in GHG emissions from other elements of the transit system (e.g., changes in feeder bus service) or from trips diverted from automobiles.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Ridership forecasts;
- Transit vehicle VMT;
- Transit vehicle energy consumption rates; and
- GHG emissions per unit of energy for alternative energy sources, including electricity.

Ease of Computation. The measure is fairly easy to compute from data sources typically developed for project ridership forecasting and environmental analysis of individual projects, and from comparative analysis of multiple projects. As is also the case for the BTU-per-passenger-mile measure, project-specific energy consumption rates are rarely known or reliably estimated, however, and national default averages by mode must generally be used. GHG emission rates must also be used from national or regional sources. Analysis of operating plans for the proposed project is required to determine changes in transit VMT.

Results. Values for this metric in pilot-testing ranged from a low of 0.04 to 0.08 kilograms CO_2e per passenger-mile for a BRT project to a high of 0.25 kilograms CO_2e per passenger-mile for a diesel commuter rail project. An electrified alternative of the commuter rail project showed a significantly lower value than the diesel alternative – 0.13 kilograms per passenger-mile. Estimates for two light rail projects were in the range of 0.10 to 0.18 kilograms per passenger-mile.

Pros. The pros of this measure are largely similar to the pros of BTU per passenger-mile. This measure has an added benefit of relating directly to a particular environmental impact (GHG emissions) and considering the GHG intensity of different fuel types.

Cons. Cons are also largely similar to BTU per passenger-mile. The benefit of introducing GHG as a measure must be weighed against the challenges of fairly assessing differences in the GHG intensity of the same type of fuel among project sponsors – e.g., electricity generation by region of the country; as well as accounting for uncertainty in GHG intensity forecasts and current and future life-cycle GHGs associated with biofuels.

Summary. This metric should be considered as an alternative or supplement to BTU per passenger-mile. The transparency of this metric, limitations on uncertainty, and ability to distinguish among projects in a way that is clearly related to environmental impacts make this a promising metric for comparing projects in different regions of the country. If the metric were adopted, attention would need to be given to developing consistent and appropriate energy consumption factors for different types of transit vehicles as well as appropriate life-cycle GHG emission factors (current and future) for alternative fuels. A decision would also need to be made as to whether to use average national GHG intensity factors for electricity generation or regionally specific factors, which would reward projects in regions of the country with a "clean" electricity mix.

Metric ID(i) – Change in Total Operating Energy Consumption (BTU per Year)

Calculation. This metric was calculated as the change in total annual energy consumption from the operation of transportation vehicles, including the proposed transit project, other transit routes that changed as part of the transit project operating plan, and highway VMT. Energy consumption was calculated based on default energy consumption rates by mode and also, where available, based on energy consumption estimates provided by the project sponsor.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Transit ridership and highway VMT forecasts;
- Changes in transit VMT;

- Transit vehicle energy consumption rates (project vehicles and other services that changed); and
- Highway vehicle energy consumption rates.

Ease of Computation. The measure is fairly easy to compute from data sources typically developed for project ridership forecasting, environmental analysis, and New Starts analysis. Project-specific energy consumption rates are rarely known or reliably estimated, however, and national default averages by mode must generally be used. Also, analysis of operating plans by mode may be required to determine changes in transit VMT by mode. An alternative method of computing highway vehicle energy consumption, based on VMT by speeds and fuel consumption rates from a model such as MOVES, is potentially more accurate than using average fuel efficiency but also more computationally intensive.

Results. Some projects led to a net decrease in energy consumption, while others led to a net increase. The largest decrease was for a commuter rail project (398 billion BTU per year) while the largest increase was 117 billion BTU per year. One project showed a range from a decrease of just over 1 billion BTU to an increase of 15 billion BTU, depending upon the source of assumptions about vehicle efficiency. For comparison, 1 billion BTU is roughly equivalent to the energy expended by 18 light-duty vehicles driven an average of 12,000 miles – the average distance a car is driven annually in the U.S. Using this conversion, the pilot projects would "remove" anywhere from 18 to 7,200 cars from the road.

Pros. Total BTU is a measure of the absolute benefit of a project. It has the advantage that it captures changes in both the transit and highway systems. Compared with GHG emissions, it eliminates the need to choose appropriate GHG intensity factors for electricity generation and alternative fuels, thus addressing potential concerns about regional inequity due to differences in electricity generation mix. Energy consumption as a metric may appeal to a broader set of constituents, including those interested in energy security issues rather than GHG emissions.

Cons. The absolute value of this metric will vary with the size of the project and therefore may need to be normalized somehow for a fair comparison across projects, if evaluated against other normalized metrics. Total BTU only indirectly measures environmental impacts, since different fuel sources will have different environmental impacts per BTU. It is not a measure that is understood by most laypeople, and its magnitude must be compared to something in order to be meaningful. If it is compared to regional transportation energy consumption, the values of the metric will look small: even the project with the largest impact in this analysis reduced energy consumption by an amount equivalent to that used by less than 0.25 percent of the vehicles in the region. The value of the metric (and even whether it is positive or negative) is also sensitive to assumptions about the relative energy efficiency of transit versus highway vehicles, which may change in the future as a result of policy decisions and evolving technology.

Summary. This metric should be considered as a second-tier option for both local and national-scale evaluation, and as an alternative to IC(i), change in total GHG emissions. Primary concerns include its unfamiliarity, and its small size from a regional perspective.

If the metric were adopted for national use, attention would need to be given to developing consistent and appropriate current and future-year energy consumption factors for different types of transit vehicles as well as highway vehicles. Consideration would also be needed concerning whether to require the use of speed-based energy/emissions models (such as MOVES) for highway vehicle calculations versus use of average fuel economy. Use of speed-based factors may not be worth the extra effort given that impacts of an individual projects on model speeds are likely to be small (and possibly within the "noise" of the model). On the other hand, if Federal transportation policy should evolve to require regional GHG emissions inventories, the capability to easily perform these calculations will be developed.

Metric IC(i) – Change in Total Operating GHG Emissions (Tonnes CO_2e per Year)

Calculation. This metric was calculated as the change in total annual GHG emissions from the operation of transportation vehicles, including the proposed transit project, other transit routes that changed as part of the transit project operating plan, and highway VMT. GHG emissions were calculated in up to three ways where available: 1) based on default energy consumption rates (average fuel economy) by mode, combined with GHG intensity values by fuel type; 2) based on energy consumption rates from the project sponsor GHG estimates provided by the project sponsor, combined with GHG intensity values by fuel type; and 3) using GHG emission rates from the MOVES emission factor model (for highway vehicles). Sensitivity analysis was conducted for the use of regional versus national GHG intensity factors from electricity generation. Fuel-cycle emission factors were used that consider upstream emissions from fuel production as well as direct operating emissions.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Transit ridership and highway VMT forecasts;
- Changes in transit VMT;
- Transit vehicle energy consumption rates (project vehicles and other services that changed);
- Highway vehicle energy consumption and GHG emission rates; and
- Upstream GHG emissions per unit of energy for alternative energy sources, including electricity.

Ease of Computation. Ease of computation is similar to measure ID(i), with the minor additional step of applying GHG emission factors. Computation using the MOVES model is potentially more accurate (accounting for local traffic speeds and other factors) but also more complicated, as it involves using the MOVES model in conjunction with available travel demand model output.

Results. Some projects led to a net decrease in GHG emissions, while others led to a net increase. The largest decrease was 26,000 tonnes of CO_2e per year and the largest increase was 15,000 tonnes. One project showed a range from no change to an increase of 4,600 tonnes, depending upon methods and assumptions used. For comparison, the "carbon footprint" of a typical person in the 100 largest metropolitan areas of the U.S. averages 1.0 metric ton of carbon (or 3.7 tons CO_2) per year for passenger transportation,[8] so a change of 26,000 tonnes would represent a reduction in regional GHG transportation emissions of about 0.2 percent for a region with 4 million people.

Pros. Total GHG is a measure of the environmental benefit of a project in absolute terms that captures changes in both the transit and highway systems. In comparison with BTU, it has the advantage of reflecting the carbon intensity of fuels used in addition to total energy use.

Cons. The absolute value of this metric will vary with the size of the project and therefore must be normalized somehow for a fair comparison across projects. If it is compared to regional transportation GHG emissions, the values of the metric will look small. The value of the metric (and even whether it is positive or negative) is also sensitive to assumptions about the relative energy efficiency of transit versus highway vehicles as well as the future carbon intensity of different fuels and electricity generation. These factors are likely to change in the future as a result of policy decisions and evolving technology.

Summary. This metric should be considered as a second-tier option for both local and national-scale evaluation, and as an alternative to ID(i), change in total energy use. Primary concerns include its small size from a regional perspective, and sensitivity to a number of uncertain factors. If the metric is adopted for national use, attention must be given to developing consistent and appropriate current and future-year energy consumption and GHG intensity factors for different types of transit vehicles, highway vehicles, and fuels. Also, a decision must be made regarding the use of regional versus national electricity generation GHG factors.

Metric ID(ii) – Project Cost per Reduction in Operating Energy Consumption (Dollars per Million BTU)

Calculation. This metric was calculated as the total annualized project cost divided by the change in total annual operating energy consumption (metric ID(i)). Total annualized project cost was computed as the annualized capital cost plus the difference in annual operating cost for the build versus no-build alternatives.

Key Assumptions. Key assumptions and areas of uncertainty include all assumptions for metric ID(i) as noted above.

Ease of Computation. This metric is easy to compute from ID(i) for projects that have progressed far enough in planning to complete FTA's Standard Cost Categories (SCC) worksheets. These worksheets annualize the costs of each project component based on its expected lifetime, and therefore the annualized capital cost can be taken directly from this

[8] Brown, M.; F. Southworth and A. Sarzynski (2008). *Shrinking the Carbon Footprint of Metropolitan America.* Brookings Institution, Washington, D.C.

worksheet. Operating cost estimates are also required for FTA's cost-effectiveness calculations. For projects that have completed some environmental documentation but not the FTA New Starts process, capital cost estimates are generally available but must be annualized using gross assumptions about project lifespan. Operating cost estimates may or may not be available.

Results. Two projects showed cost-effectiveness in the range of $200 to $800 per million BTU reduced. Values for two projects with small or negative energy benefits either could not be calculated (this metric is meaningless if energy use increases) or resulted in a very large number (over $60,000 per BTU in one case).

Pros. This metric describes how much "bang for the buck" the government and project sponsor are receiving – energy reduction per dollar invested. Compared to change in total energy, it has the advantage of being a "normalized" metric that is not biased by the size of the project.

Cons. This metric cannot be calculated for projects which increase energy use, and therefore, projects that increase energy use cannot be compared based on the magnitude of this increase (small or large). For projects with small energy benefits, the metric can become unstable, increasing to very large values that fluctuate widely based on small changes from uncertainty in the energy estimates (as the denominator approaches zero).[9] Unlike dollars per ton of GHG, dollars per BTU reduced is not a unit that is widely used in planning, and therefore a frame of reference may not exist for how good a value is.

Summary. This metric should be considered a third-tier option for either local or national use due to its inability to be used for projects with small or negative energy benefits, and its lack of a general basis of comparison.

Metric IC(ii) – Project Cost per Reduction in GHG Emissions (Dollars per Tonne CO_2e)

Calculation. This metric was calculated as the total annualized project cost divided by the change in total annual GHG emissions (metric IC(i)). Total annualized project cost was computed as the annualized capital cost plus the difference in annual operating cost for the build versus no-build alternatives.

Key Assumptions. Key assumptions and areas of uncertainty include all assumptions for metric IC(i) as noted above.

[9] The problem of very large dollars per BTU values as energy savings approach zero could be solved by inverting the equation to show BTU saved per dollar. However, this would be unorthodox and therefore more difficult for many people to compare and interpret, since cost-effectiveness is usually expressed in dollars per unit of something reduced.

Ease of Computation. This metric is easy to compute from IC(i) for projects that have progressed far enough in planning to complete FTA's SCC worksheets, as discussed for metric ID(i).

Results. Two projects showed cost-effectiveness in the range of $4,000 to $16,000 per tonne GHG reduced. Values for two projects with small or negative GHG benefits either could not be calculated (this metric is meaningless if GHG emissions increase) or resulted in a very large number (over $900,000 per tonne in one case).

Pros. This metric describes how much "bang for the buck" the government and project sponsor are receiving – GHG reduction per dollar invested. Compared to change in total GHG, it has the advantage of being a "normalized" metric that is not biased by the size of the project. It also is a commonly used metric in planning and therefore has a solid basis for comparison of values in an absolute sense.

Cons. Similar to energy reduction cost-effectiveness, this metric cannot be calculated for projects which increase GHG use, and is unstable and not useful for projects with small GHG benefits. The GHG cost-effectiveness values calculated for the pilot projects are also not competitive with what is considered "cost-effective" as a GHG reduction measure ($50 per tonne is a commonly cited threshold).[10] While GHG reduction is only one of many reasons to undertake a transit project (unlike many types of nontransportation projects that are undertaken exclusively to reduce energy and GHG), the results nevertheless may be cited by project opponents as evidence that transit projects are not a worthwhile investment.

Summary. This metric should be considered a third-tier option for either local or national use due to its lack of utility for projects with small or negative GHG benefits, and its potential to be misinterpreted.

Metric IE(ii) – Reduction in Life-Cycle Energy Consumption per Dollar of Project Cost

The goal of this metric was to provide a cost-effectiveness calculation that included construction as well as operating energy use. This metric could not be calculated for individual pilot projects because of lack of data to estimate construction energy expenditures. However, some order-of-magnitude calculations of construction GHG emissions were performed, as discussed further under IE(i).

Metric IE(i) – Construction GHG Emissions

Calculation. This metric includes emissions from materials and equipment used in construction of the transit project. Due to data limitations, it was not fully tested on the pilot projects. The metric could be reported in total or normalized per route-mile, per passenger-

[10] C.f. McKinsey & Company (2007). *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?*

mile, or per dollar of project cost. It could also be annualized and combined with operating emissions for a life-cycle GHG metric.

Key Assumptions. Key assumptions and areas of uncertainty include:

- All key assumptions for change in operating GHG emissions;
- GHG emissions embodied in materials used in construction, per unit of material;
- Type and amount of materials used in construction (e.g., steel per track-mile);
- Activity of equipment used in project construction, by type of equipment;
- GHG emission factors by type of equipment;
- Other construction-related GHG emissions, including staging, lighting, and work zone traffic delays; and
- Appropriate factors for annualizing construction GHG emissions over the project lifetime.

Ease of Computation. The research team for this project developed a model of GHG emissions embodied in materials used in transit projects, based on general estimates of materials use. This model allows for calculation of embodied GHG based on parameters generally available in transit project planning, such as new track-miles, miles of overhead catenary, number and type of stations, etc. However, data were not available to permit the estimation of emissions from construction equipment activity or other nonmaterial emissions, and therefore a complete estimate of construction GHG emissions could not be developed. A research project initiated in fall 2011 by the Federal Highway Administration (FHWA) is intended to develop a model that includes all construction-related activities and can be used at a planning level for transit as well as highway projects.

Results. A sample calculation for one of the pilot projects was performed that resulted in an estimate of 268,000 tons CO_2e for a light rail project of roughly 10 miles in length. This equates to approximately 5,000 tons per year when annualized over a 50-year period, which is a common expected lifetime for many project components. This can be compared to increases in transit operating GHG emissions in the range of 5,000 to 25,000 tonnes per year, and decreases in highway vehicle operating emissions in the range of 5,000 to 40,000 tonnes per year, for the pilot rail projects. This calculation suggests that construction emissions are a nontrivial contributor to the life-cycle GHG emissions of a transit project, and will to some extent offset savings in combined highway and transit operating emissions.

Pros. Including construction emissions has the advantage of more fully presenting the impacts of a project, and also helping to differentiate projects that have more or less GHG-intensive construction practices. Furthermore, it is likely that within the next two years, a model will be publicly available that is suitable for making estimates of transit construction emissions based on data that are readily available once a project, mode, alignment, and station locations have been selected. This model is likely to allow testing of the impacts of alternative, GHG-reducing construction methods in addition to standard methods.

Cons. The use of average factors (e.g., GHG per track-mile of surface alignment) makes data collection practical at a planning level but also means that details of project construction that may have significant effects on construction GHG emissions (such as amount of cut-and-fill required, or extent to which highway traffic is affected) are ignored. Including construction GHG emissions in a life-cycle metric may paint a misleading picture of the project if the results are used in comparisons with other projects (such as highway projects) that do not include full life-cycle emissions.

Summary. This metric is promising, but needs further supporting research and development. Different ways of normalizing the metric (such as per dollar cost, per route-mile, or per passenger-mile) should be explored to allow comparison among projects of different sizes. At this point, the primary value of this metric is to compare different transit projects against each other to evaluate the GHG efficiency of their construction methods, or for evaluation of different project alternatives that include different amounts of underground versus above-ground construction, station configurations, etc. It is not recommended that construction emissions be combined with operating emissions for an overall life-cycle GHG metric, since life-cycle evaluation is not currently a standard practice in transportation project analysis.

4.4 Air Quality and Public Health

Metric IIA(i) – Change in Direct Operating Emissions (Kilograms per Year)

Calculation. This metric was originally defined as the total change in direct operating emissions from highway and transit vehicles, measured in kilograms of pollutant per year. Towards the end of the research, the research team suggested an alternative approach of taking only emissions for the new transit project and dividing by passenger-miles to get a metric similar to the proposed energy and GHG per passenger-mile metrics.

Emissions can be calculated for individual criteria pollutants or precursors, including oxides of nitrogen (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), and coarse and fine particulate matter (PM_{10} and $PM_{2.5}$). It can also be computed for a number of significant air toxics which are not currently regulated but nonetheless known to be a health concern. The U.S. EPA has identified six Mobile Source Air Toxics (MSATs) that contribute significantly to health risk estimates and are released to air mostly by transportation: acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel engine exhaust, and formaldehyde. The metric as originally calculated did not include air pollution from electricity generation facilities, primarily because of lack of data, but also because these pollutants are also likely to be generated in non-urban areas where exposure to population and consequent health effects are less than for direct emissions from vehicles. However, to make emissions per passenger-mile a meaningful metric for comparing electric rail projects (for which direct emissions are zero), electricity generation emissions should be included.

Key Assumptions. Key assumptions and areas of uncertainty for calculating total emissions changes include:

- VMT forecasts;
- Vehicle emission rates, including current and future emissions for both highway and transit vehicles reflecting local conditions (traffic flow, fuel, vehicle fleet mix, climate, etc.), and emission rates for alternative fuel vehicles not included in current emissions models; Speed changes on the roadway network due to impacts on congestion, and subsequent effects on emissions; and
- Emissions of air pollutants from electricity generating power plants (if included).

Highway vehicle data are not required if only emissions per passenger-mile for the new project are calculated.

Ease of Computation. The ease of computing changes in pollutants depends upon the region's air quality modeling requirements and capabilities. Regions in nonattainment or maintenance status are likely to have developed emission factors for the pollutants of local concern, and may have already computed changes in these pollutants for environmental documentation purposes. If emission factors and/or pollutant changes have not been calculated, they can still be calculated by an analyst skilled in the use of an emission factor model (EPA's MOVES model or CARB's EMFAC model) using default assumptions in conjunction with travel demand forecasts developed for the project. Air toxics emissions factors are unlikely to have been calculated already and would need to be developed. Existing emission factor models only include diesel and compressed natural gas options for buses, and the project sponsor, in consultation with the transit vehicle manufacturer or using literature sources, must develop appropriate emission factors for any alternative technologies or fuels. As with the energy and GHG calculations, transit operating plans must also be identified in order to calculate VMT changes for all transit services affected by the project.

Once total emissions for the project are calculated, emissions per passenger-mile can be easily calculated based on the same ridership data as used in the energy and GHG metrics.

Results. Only four projects were evaluated for total emissions (of which two were variations on the same project) due to difficulties in collecting and processing data from some projects. All four projects showed reductions in all pollutants. The maximum changes observed were a reduction of 14 tons per year of NO_x, a reduction of 18 tons per year of VOC, and a reduction of 1.9 tons per year of PM_{10}. To provide scale, pollutant changes as a percentage of regional or subregional (modeled area) emissions from highway vehicles were computed for all four projects and found to be in the range of -0.05 to -0.2 percent for most pollutants. Emissions for one project were found to be somewhat more significant when measured as a percentage of corridor emissions (TAZs within a two-mile buffer of the project alignment), where a project resulted in a 22 percent decrease in transit emissions in the corridor due to replacing bus service with electric rail. However, transit emissions were dwarfed by highway vehicle emissions in the corridor and the net effect was a reduction of less than 0.2 percent in combined highway and transit emissions. Subregional percent changes of NO_x for the BRT project differed from its percent changes for other pollutants because an increase in NO_x from the BRT service offset about half the savings from highway vehicles.

Emissions per passenger-mile were calculated for two projects, an LRT project and an electric commuter rail project, using forecast national average pollutant emissions rates identified in a private-sector study. Only forecasts of VOC, NO_x, and PM_{10} were available. (The metric was introduced for consideration after most of the research was completed, which is why it was not tested on all projects.) Coincidentally, both projects showed approximately the same emission rates per passenger-mile. For one electric commuter rail project, the transit project emissions per passenger-mile were about one-third of highway vehicle emissions (per vehicle-mile) for NO_x and one-quarter for PM_{10}. For another light rail project, emission rates were about one-half of highway-vehicles for NO_x and similar for PM_{10}. VOC emissions from electricity generation were very small relative to highway vehicle emissions and were not calculated.

Pros. Total emissions changes are a direct measure of air quality benefits. Changes in VOC, CO, NO_x, and PM emissions are familiar to air quality planners who often use them for evaluating projects for air quality program funding. Evaluating individual pollutants and examining transit and highway emissions separately can demonstrate the effects of differences in transit vehicle technology, e.g., diesel versus electric rail. This metric does not require the spatial allocation of emissions, as do the Exposure Index and Health Benefit Index metrics described below.

Emissions per passenger-mile have the benefit of showing potentially meaningful differences among projects, considering both passenger loading and vehicle technology. It rewards “clean” and highly productive projects whether they attract new riders, or improve service for existing riders. It is a “normalized” metric whose value does not depend upon the scale of the project.

Cons. Changes in kilograms or tons of pollutant emissions is not a metric that most lay-people can readily grasp the significance of, and in fact, a ton of one pollutant may be much more or less important than a ton of another pollutant depending upon the relative health effects of each pollutant. As has proven to be a problem in the past, the change in pollutant emissions for a single project tends to be small when compared with total regional emissions. Furthermore, there are multiple pollutants of interest (particularly when air toxics are considered) and they cannot easily be combined into a single metric, leading to a proliferation of different metrics that are often (but not always) correlated. While an individual region may be able to focus on two or three pollutants of particular concern to them, pollutants of local concern will vary from region to region, which poses a challenge for evaluating multiple projects consistently. The exclusion of emissions from electricity generation may be viewed as a bias in favor of electrically powered projects; these emissions could in theory be calculated, but more work would be required to identify local powerplants and corresponding emissions rates. Projects that improve conditions for existing riders, rather than generating new transit trips, will not perform well on this metric.

Emissions per passenger-mile do not consider benefits from reduced highway vehicle travel, and does not indicate the aggregate air quality benefits of the project.

Summary. This metric is proposed as a second-tier metric. Change in total emissions has been used in the past (and therefore has been proven feasible), and is often used by regional planners to evaluate projects being considered for air quality improvement purposes. However, it was not found helpful for distinguishing among projects in the context of comparative evaluation. If it is used, consideration might be given to developing a single pollutant index based on relative toxicity weightings for current criteria pollutants and precursors (VOC, NO_x, CO, PM_{10}, and $PM_{2.5}$). A determination would also need to be made whether to include air toxics. While these are of increasing concern, they are currently not regulated from transportation sources and in general will be closely correlated with VOC and PM emissions, meaning that introducing MSATs into the evaluation is unlikely to further affect decision-making.

The variation of this metric, project emissions per passenger-mile, should be considered as an alternative air quality indicator, as it will help show meaningful differences among projects, considering both transit vehicle technology/control and the efficiency of loading.

Metric IIA(ii) – Cost per Ton of Emissions Reduced

Calculation. This is computed as the total annualized project cost divided by the amount of pollutant reduced (metric IIA(i)) for each pollutant. Total annualized project cost includes the annualized capital cost and the difference in annual operating costs between the build and no-build alternative.

Key Assumptions. Key assumptions and areas of uncertainty include:

- All those identified under metric IIA(i);
- Project capital costs and changes in operating costs; and
- Appropriate annualization of costs.

Ease of Computation. Ease of computation is similar to metric IIA(i), assuming that project cost estimates are available. See the discussion of project cost data under metric IC(i).

Results. Cost per ton for two sample projects ranged from $11million to $51 million for NO_x, $9 million to $37 million for VOC, $200,000 to $980,000 for CO, and $74 million to $761 million for PM_{10}. These values are quite high compared to accepted values of "cost-effective" pollutant reduction measures as well as the damage values of these pollutants. For example, a recent review found that two regional programs, California's Carl Moyer program and the Texas Emission Reduction Program, employ a cost-effectiveness target of about $13,000 to $16,000 per ton of pollutant controlled (NO_x, VOC, and/or PM_{10}) in order to qualify for funding.[11] Delucchi (2004) reports a range of health damage values for NO_x with a midpoint of about $37,000 per ton when converted to 2010 dollars.[12]

Pros. This metric has the benefit of "normalizing" emission reductions based on the size of the project as well as showing the "bang for the buck" that the project is achieving in terms of reducing emissions.

Cons. For projects with small air quality benefits, the metric can become unstable, increasing to very large values that fluctuate widely based on small changes from uncertainty in the emissions estimates (as the denominator approaches zero). The cost-effectiveness values calculated for two pilot projects were not competitive with what is typically considered "cost-effective" for emissions control projects. While emissions reduction is only one of many reasons to undertake a transit project, the results nevertheless may be cited by project opponents as evidence that transit projects are not a worthwhile investment.

Summary. This metric should be considered a third-tier option due to its lack of utility for projects with small or negative emissions benefits, and its potential to be misinterpreted.

Metric IIB – Exposure Index

Calculation. The Exposure Index (EI) is calculated for each pollutant at a traffic analysis zone (TAZ) level as well as the region as a whole. It is a proxy for the change in population exposure to air pollutant emissions. The TAZ-level index is calculated as the change in emissions times the population of the TAZ divided by the area of the TAZ. For a given unit of emissions per unit area, the EI will be proportional to the number of people exposed to those emissions. The regional EI is simply calculated as the sum of the TAZ-level EIs. The EI can be mapped to show the spatial distribution of benefits. A negative EI is "good" because it indicates a decrease in pollutant exposure.

Key Assumptions. Key assumptions and areas of uncertainty include:

- All of those affecting emission rates (Metric IIA);
- Spatial disaggregation of link-level emissions to individual TAZs; and
- Assumption that (emissions * population/unit area) is a good proxy for exposure.

---

[11] Cambridge Systematics, Inc., and Eastern Research Group (2010). *Evaluate the Interactions between Transportation-Related Particulate Matter, Ozone, Air Toxics, Climate Change, and Other Air-Pollutant Control Strategies.* Prepared for American Association of State Highway and Transportation Officials Standing Committee on the Environment through NCHRP Project 25-25 Task 59.

[12] Delucchi, M.A. (2004) *Summary of the Nonmonetary Externalities of Motor-Vehicle Use.* ITS-Davis. Report 9 in the series: *The Annualized Social Cost of Motor Vehicle Use in the United States, Based on 1990-1991 Data.* October 2004. Publication No. UCD-ITS-RR-96-3(9) rev. 1.

Ease of Computation. Once emissions on the transportation network have been calculated as described for metric IIA using emission factors from MOVES and travel demand model data, the primary effort involved in calculating the EI is to spatially disaggregate emissions by TAZ. Since the transportation models used to develop traffic forecasts usually have spatially defined networks (i.e., in a GIS) they can in theory be spatially disaggregated. In practice, there are complications such as the need to proportionally "split" emissions from links that cross or align with TAZ boundaries. In one pilot case, misalignment between model networks and TAZ boundaries because of the use of different projection systems was not easy to correct. The project team only calculated this metric for four projects (two of which had already provided emissions disaggregated by TAZ) due to the level of effort involved.

Results. The dimensions of the EI (person-kilogram per square mile) may be difficult to interpret in absolute terms, so the EI is most useful as a measure of comparing the *relative* benefit between projects, rather than for evaluating the absolute benefits of an individual project. For ease of comparison, the regional EI for each pollutant was "normalized" (divided by a power of 10) to report the index as a number in or near the single digits (as opposed to 1,000 or 1 million plus). After this was done, the PM_{10} index varied by a factor of two across projects (-6.9 to -12.9), the $PM_{2.5}$ index by a factor of four (-2.1 to -8.5), and the CO index by a factor of 20 (-0.3 to -6.3). As expected, the electric alternative of a commuter rail project (which had lower pollutant emissions) performed better than the diesel alternative, with EI's about 20 to 30 percent lower. One interesting finding was that the diesel alternative showed negative (good) EI's despite increasing total operating emissions, suggesting that the increases in transit emissions occurred in areas of lower population exposure than the offsetting decreases in highway emissions.

Pros. The EI is an improvement over a simple metric of change in total emissions because it also accounts for the population exposure to those emissions. Emissions decreases in highly populated areas are more beneficial than decreases in sparsely populated areas. This is most significant for primary pollutants that directly affect human health, and precursors that form other pollutants on a local scale. The EI results, when mapped at a TAZ level, generally form intuitive/logical patterns and can be used to identify neighborhoods that benefit most from reduced exposure, which could be helpful in environmental justice analysis.

Cons. The EI is only a rough proxy for exposure and does not take into account factors such as meteorology or the spatial distribution of people within a TAZ compared to the sources of emissions. It assumes that exposure is proportional to where people live, which does not take into account exposure during commuting, working, or other activities, or exposure indoors versus outdoors. It may be difficult for people to interpret, and it is only valuable for comparing across projects rather than evaluating a single project. We do not have a good way of determining what level of EI may constitute a significant or meaningful change from a health perspective; however, the fact that emissions changes are relatively small means that the relative exposure and health impacts of these changes are probably also small. The EI must be evaluated for each individual pollutant, which may lead to an excessive amount of information, especially if the full range of MSATs is included. It is not useful for ozone precursors (VOC and NO_x), because the health effects of these pollutants do not depend upon their precise spatial distribution in relationship to population. Finally, it is a relatively complicated procedure to spatially disaggregate emissions; procedures can be defined to automate the calculations, but different travel demand modeling systems and databases still have unique characteristics that can complicate the task.

Summary. This metric should be considered a third-tier option due to its lack of transparency and the effort involved in calculation. It may have utility for regional/network-level analysis if a unit of comparison can be defined (e.g., a similar index of total population exposure to all anthropogenic pollutants).

Metric IIC – Health Benefits Index

Calculation. The Health Benefits Index (HBI) is based on the EI but expands upon it to include basic meteorological factors and to create a "roll-up" across multiple pollutants. The meteorological factors – average wind speed and mixing height for a metropolitan area – provide further information on the extent to which a given unit of emissions will be concentrated in a TAZ. (Faster wind speed or greater mixing height means the pollutant will disperse faster or more broadly, reducing exposure.) The roll-up is based on the relative toxicity of different pollutants. Because of different bases for measuring toxicity, three HBI's are calculated – one for non-ozone criteria pollutants (CO, PM), one for air toxics based on cancer risk, and one for air toxics based on noncancer risk. The HBI can be calculated at a TAZ level or summed across all TAZs to a regional level. A negative HBI is "good" because it indicates a decrease in pollutant exposure.

Key Assumptions. Key assumptions and areas of uncertainty include:

- All those identified under the EI;
- Assumption of average metropolitan wind speed and mixing height as proxies directly related to local air pollutant concentrations; and
- Relative health risk of different pollutants.

Ease of Computation. Calculating the HBI involves little additional effort once the EIs are calculated. Average wind speed and mixing height can easily be obtained from the National Weather Service. Toxicity weightings were developed for this project and would not need to be recalculated for individual projects.

Results. The HBI for criteria pollutants varied by a factor of two across four projects (-4.5 to -8.4 after normalization). Toxicity HBIs were only computed for two projects due to lack of data and computational intensity. They varied by a factor of two to three for these two projects. Mapping showed the greatest HBI in areas near the transit project alignment, as would be expected for an electric rail project that reduces local air pollution.

Pros. The HBI is a further improvement over the EI since it adds in meteorological data and reduces the number of metrics to be evaluated, making it easier to evaluate. The HBI results, when mapped at a TAZ level, generally form intuitive/logical patterns and can be used to identify areas that benefit most from reduced exposure, which could be helpful in environmental justice analysis.

Cons. This metric suffers from most of the same limitations as the EI.

Summary. This metric should be considered a third-tier option for individual transit project evaluation due to its lack of transparency and the effort involved in calculation. It would be interesting to further explore this metric for regional-level analysis (e.g., transportation plan alternatives), especially if a basis for determining a "significant" value of the HBI can be identified.

Metric IID – Air Quality Index

Calculation. The Air Quality Index (AQI) is defined by the U.S. EPA as a function of the measured concentration of a pollutant and various health-based benchmark parameters. The AQI is designed around a scale in which a value of 100 reflects an air pollutant concentration that is of a similar value to a health-based benchmark, typically a National Ambient Air Quality Standards (NAAQS). Values greater than 100 indicate increasingly poor air quality with greater health risk. An AQI is computed on a daily basis for each metropolitan area for each of six pollutants, and an overall daily AQI value taken as the highest of the individual pollutant values. The AQI is not a measure of the project's benefits, but rather the severity of the local air pollution problem. It is evaluated as a possible alternative to nonattainment status for national-level use.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Since the AQI is reported on a daily basis, there are multiple options for reporting AQI at a summary level over a multiday/multiyear period; and
- The transit project is assumed to have air quality benefits that help address local air pollution problems.

Ease of Computation. This measure can be easily obtained at a metropolitan area level from EPA reporting. Simple statistical analysis (which can be done in a spreadsheet) is required to determine metrics such as the 90th percentile AQI over a three-year period.

Results. The AQI was plotted for all metro areas, with selected cities with New Starts projects (including the pilot projects) sampled. The median AQI over a three-year period showed a modest variation, with most metro areas in the range of 25 to 50. The 90th percentile AQI (i.e., the value which is exceeded only 1 of every 10 days) showed somewhat more variation, ranging between 50 and 100 for most areas. The number of days considered unhealthy for sensitive individuals ranged from 0 to 25 for most areas. A handful of metro areas (less than 5 percent across the U.S.) showed extremely high AQI metrics, indicating that they are locations with unusually bad air quality problems. The choice of AQI metric matters: two pilot projects with nearly identical median AQIs had very different maximum AQIs and percent of unhealthy days, indicating that they have more extreme air quality events even though typical conditions are similar.

Pros. Compared to nonattainment status, as a simple indicator of the magnitude of the air quality problem being addressed in a region, the AQI has the possible advantage of providing a continuum across projects, rather than discrete categories, and also considering benefits to all pollutants, not just those for which an area is in nonattainment.

Cons. The AQI does not indicate the magnitude of benefit that the transit project is providing. It may be inferior to nonattainment status in that the user would need to pick a specific metric and establish potentially arbitrary thresholds to provide a project-specific rating. Also, there is a wide range of metropolitan areas without a lot of differentiation in the various AQI-based indicators.

Summary. This metric is not suitable for local use and should be considered a third-tier option for national use. While it is feasible to compute and could be used as an alternative for nonattainment status if a simple proxy metric is desired, it does not indicate anything about the actual benefits of the project. Also, it is not clear that it is preferable to non-attainment status as a metric of regional air quality needs. If it is used, "percent unhealthy days" or "percent unhealthy days for sensitive individuals" is recommended as a metric that is probably more significant from a health effects standpoint than the average AQI.

Metric IIE – Forecast Change in Daily Nonmotorized Access Trips

Calculation. This metric is calculated as the difference in nonmotorized transit access trips (usually walk trips) for the project versus no-project alternative, as determined from the travel demand forecasting model used for the project. This metric is proposed as the most direct measure of physical activity actually "generated" by the transit project. A variation of this metric, *total nonmotorized trips accessing the new project*, might be considered to alleviate concerns about projects that primarily improve conditions for existing riders.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Accuracy and resolution of the access mode choice model included in the travel demand model (e.g., trip purposes differentiated, calibrated based on local versus transferred data, bicycle versus pedestrian included);
- Lack of detailed data on the pedestrian environment/walkability, or other factors (such as parking availability) that may affect access mode choice; and
- Models do not account for spatial distribution of trip generators below a TAZ level (e.g., concentration within walking distance of the transit station versus dispersed throughout the TAZ).

Ease of Computation. This metric can usually be easily calculated from the data produced by the travel demand forecasts which are developed for ridership forecasting and traffic impact assessment.

Results. The forecast change in daily nonmotorized trips across six pilot projects ranged from 2,600 for a commuter rail project to 15,000 for an urban/suburban light rail project. An assessment of the model structures suggested that all should produce reasonable forecasts, but nonetheless some models had clear limitations compared to others. It was therefore impossible to say with confidence that a rank-ordering of projects based on modeled walk trips would be proportional to the actual benefits of the projects, versus differences in the quality of the model or its underlying data.

Pros. As a proxy for physical activity and related health benefits, this metric is preferable to measures of the built environment, which indicate how much *potential* there may be for "active" modes of transport, but not the actual use of such modes. For most projects it can be calculated from available travel forecast data.

Cons. This metric is an absolute measure and is not scaled by size of the project. (Scaled metrics such as walk trips per project-mile or per dollar invested could be developed, but would be less intuitive.) Differences in mode choice forecasting models mean that it may be difficult to reliably attribute differences in forecast nonmotorized trips to the actual benefits of the project rather than model limitations or sensitivities, when comparing across projects sponsored by different agencies. Projects that improve conditions for existing riders, rather than generating new transit trips, will not perform well on this metric.

Summary. This metric is clearly appropriate for decision makers to use to evaluate project alternatives. If used for comparative evaluation of multiple projects in different regions, it might benefit from sensitivity testing to assess how values will vary depending upon modeling methods (as opposed to project conditions). Development of standards for access mode choice models would provide more confidence that results across projects can be compared.

■ 4.5 Ecology, Habitat, and Water Quality

Metric IIIA – Fraction of Corridor Land That Is Already Developed

Calculation. This metric indicates the extent to which the project serves existing communities/developed areas versus undeveloped areas. It is computed as the ratio of land in the corridor that is already developed to total land in the corridor. For purposes of pilot-testing, the "corridor" was defined as a two-mile radius around the project alignment. A higher value for this metric is hypothesized to relate to lower environmental impact, since any project-related development pressures are more likely to occur in already developed areas rather than "greenfields" areas.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Spatial resolution of land use data to identify developed versus undeveloped land, and ambiguity over whether or not certain areas or land use classifications are considered "developed" (e.g., parks, rural residential parcels that could be subdivided);
- Presence of undeveloped land as a proxy for potential environmental impacts (depends upon environmental quality of undeveloped land, existence of land protections, and influence of the project on development); and
- Whether land use data are up-to-date.

Ease of Computation. Land use databases in geographic information systems (GIS) format are available covering most metropolitan areas, including most of the pilot project regions, at zero or minimal cost from regional or state agencies. However, the land use or land cover categories in these databases must be manually classified to identify "developed" versus "undeveloped" categories. Once that is done, the metric can be calculated relatively easily using standard GIS software.

Results. For most of the pilot projects, this metric had a value of 90 percent or higher, meaning the corridors are already highly developed. However, one suburban commuter rail project had a value of 36 percent. This appeared to be due in part to a state land use database that was based on polygons derived from satellite imagery of land cover, rather than parcel-level use data. For example, a wooded two-acre residential parcel might be identified as one acre of forest and one acre of residential, whereas in another region it would be identified as two acres of residential. Also, in one region, existing land use data could not be obtained, and existing zoning was used as a proxy, which probably inflated the value of the metric (land might be zoned for development but not actually developed).

Pros. The values reported for this metric do not depend upon making (highly uncertain) inferences about the potential impact of the project on development. Even if its relationship to direct environmental impact is questionable, it can serve as a measure consistent with "livability" goals by objectively describing the extent to which the project serves existing communities.

Cons. This metric is only a rough proxy for environmental impacts rather than a direct measure. It is not clear that the additional effort involved in computing this measure is worthwhile compared to a simple qualitative assessment of the extent to which existing communities are served (as can be done using information already reviewed in the land use assessment). Not all decision makers are likely to agree that serving existing communities is environmentally preferable to serving new, growing communities, where transit might help shape patterns of sprawl into patterns of more compact growth. Different projects are likely to have different land use-related environmental impacts depending upon growth pressures, land use policies, and other factors not captured, even if corridor land use conditions are similar.

Summary. This metric is recommended largely because of its potential utility as a quantitative measure related to livability, and because it is a relatively simple (if crude) indicator of the project's potential positive versus negative impacts on new development and associated environmental effects. While it might be used for local evaluation, it may be best suited for comparing projects in different corridors or regions since it is not likely to vary much between project alternatives in the same corridor. If it were used for national evaluation, guidance would need to be provided on which land use categories to classify as developed versus undeveloped. A categorical rating system (e.g., high, medium, low) should be considered based on quantitative benchmarks (e.g., less than 50 percent, 50 to 75 percent, more than 75 percent). As an alternative to obtaining and quantitatively analyzing land use data, a qualitative assessment could be performed based on review of land use data and aerial imagery.

Metric IIIB – Potentially Impacted Acreage of Undeveloped Land

Calculation. This metric is calculated as the acreage of undeveloped land in the project corridor (two-mile buffer) weighted by a measure of the potential impact of the project on development. The original intent was to use the percent change in transit accessibility for the project versus no-project alternative as a measure of potential impact, and weight land area by accessibility change. The idea was to use transit accessibility as a proxy for the potential impact of transit on development, and the presence of undeveloped land as a proxy for the potential for environmental impact. However, computing accessibility consistently across projects turned out to be challenging, so this metric was computed simply as the total acreage of undeveloped land in the corridor.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Identification of undeveloped land, environmental importance of this land, and existence or absence of land protections as described for Metric IIIA; and
- Presence of undeveloped land as a proxy for potential for environmental impact.

With the method that was originally intended to be used, additional assumptions include:

- Calculation of change in transit accessibility (specific accessibility measure, weighting of different travel time components, weighting of alternative access modes, etc.); and
- Assumption of transit accessibility as a proxy for the potential impact of transit on development.

Ease of Computation. This metric as computed requires only the analysis of land use data as described for Metric IIIA. Transit accessibility was more difficult to calculate, which is why it was not ultimately used in this metric. It requires transit travel time skims (TAZ-to-TAZ travel times by trip component) which may not already exist and may need to be custom-developed by modeling staff. Matrix processing is then required to sum travel times weighed by population and jobs across each TAZ pair. Different models have different ways of defining travel time components and the specific accessibility metric may vary. For one pilot project, access times could be unrealistically long (e.g., for suburban zones with no transit service nearby).

Results. For the pilot project, "potentially impacted acreage" ranged from a low of 1,300 acres in an urban corridor to a high of 94,000 acres in a suburban corridor. The project with this very high value, however, was the same one as with the low ratio of developed to total land area (36 percent) and therefore suffers from the same data consistency issues. The second highest impact was 17,000 acres for a project with 88 percent of the corridor developed.

Accessibility metrics were calculated for three projects although they were not ultimately used to develop a metric of potentially impacted land. One positive outcome of these calculations was to suggest that a two-mile radius is a reasonable influence area for the transit project. For two projects, the TAZs with significant accessibility changes were primarily inside this buffer, although the third project also influenced a fairly large area outside the buffer that was served by connecting bus service.

Pros. This metric relates to absolute environmental impact (total acreage potentially impacted), which, depending upon the evaluation framework, may be preferable to relative impact.

Cons. Without the accessibility-weighted impact calculation, this metric does not contain any more information than metric IIIA. A scaled measure of impact such as metric IIIA may be preferable to an absolute metric depending upon the evaluation framework. This metric suffers from the same limitations as metric IIIA with the additional flaw that it does not relate to livability.

Summary. This metric is recommended as a third-tier candidate. Metric IIIA is likely to be preferable.

Metric IIIC – Potentially Impacted Acreage of Sensitive Habitat

Calculation. This metric is computed similarly to IIIB, but with only the acreage of agricultural land and wetlands in the corridor calculated and used as a proxy for sensitive habitat. The original objective of this metric was to measure environmentally sensitive land uses. However, agricultural land and wetlands were the only categories of such uses that could be consistently be derived from all land use databases. The lack of consistency among land use categories also prevented the research team from testing the concept of applying ecosystem service values to weight different land use types.

Key Assumptions. Key assumptions and areas of uncertainty include:

- All those underlying Metric IIIB;
- Additional ambiguities related to inconsistencies across land use database classification systems; and
- Some "environmentally" sensitive areas such as key natural habitat that is not agricultural or wetland is not be included.

Ease of Computation. Similar to IIIB, with minor additional effort involved in distinguishing agricultural and wetland categories.

Results. Results for pilot projects ranged from under 300 acres in an urban corridor to 91,000 acres in the suburban corridor referenced in Metric IIIB. Agriculture and wetlands made up most of the undeveloped land in all but the two most urban corridors.

Pros. This metric attempts to isolate potentially environmentally sensitive land uses that might be impacted in the corridor.

Cons. It is not clear that agricultural and wetland uses are a better proxy for environmental impacts than all undeveloped land. Otherwise, this metric suffers from the same limitations as IIIB.

Summary. This metric is recommended as a third-tier candidate. Metric IIIA is likely to be preferable.

Metric IIID – Adequacy of Habitat Protection Plans and Consistency of Project with Plans

Calculation. This metric is based on a qualitative assessment of state, regional, and local wildlife and habitat protection plans and measures. The objective of the metric is to describe the extent to which any potential negative environmental impacts associated with development induced by the transit project are likely to be mitigated or avoided through conservation planning. A review procedure was developed and tested that contains a mix of objective and subjective criteria, scored on a scale to total 100 points.

Key Assumptions. Key assumptions and areas of uncertainty include:

- The extent to which the plans reviewed are actually effective at conserving habitat, i.e., how well do they address local environmental needs and how well are they implemented;
- Subjective assessment of plan strength or effectiveness that is required in some cases, and the potential for inconsistencies among reviewers;
- Arbitrary weighting of evaluation factors;
- Some factors are proxies for protections but may or may not relate to actual protections (e.g., existence of high-quality GIS data on endangered species);
- Lack of information on some evaluation factors, or excessive time requirements that do not permit a thorough review of all available information; and
- The extent to which the transit project may actually lead to development pressures in environmentally sensitive areas, and therefore where having such plans in place is important in avoiding impacts.

Ease of Computation. A review template was developed by one team member and independently applied by two others to determine its utility and ease of use. While considerable information was available on government web sites about Federal and state regulations, protected species, and other evaluation factors, a considerable amount of effort was also required to thoroughly review the documents, especially when considering corridors with multiple local jurisdictions. Limiting the review to state and regional plans and Federal designations was a more manageable task. Some of the proposed evaluation criteria were difficult to assess from documents available on the Internet (e.g., adequacy of staffing to enforce plans).

Results. Quantitative assessments were conducted for two projects. One received a score of 52 out of 100, and the other a score of 63. However, these scores were based on incomplete data. For example, one corridor contained numerous local jurisdictions and it was not possible to assess the existence or quality of habitat protection measures in all of these jurisdictions.

Pros. This metric is similar to FTA's current land use criterion in that it relies on reviewer assessment of plans and policies. (There is some overlap with the current "growth management" evaluation factor under land use plans and policies.) However, it attempts to establish greater objectivity through specific evaluation factors, defined as objectively as possible, with points assigned to each. It is designed as a proxy for likely environmental impacts related to transit-induced growth, without attempting to forecast actual growth impacts, which has proven to be a challenging if not impossible exercise. Much of the information reviewed in the assessment is not project-specific; once an assessment for an area is completed, the information could be used to evaluate the potential impacts of highway projects as well as transit projects, and systemwide plans as well as individual projects.

Cons. The key assumptions and areas of uncertainty noted above all rate as drawbacks for this metric. Transit agencies generally do not have any control over the plans and policies reviewed and some may feel it is not fair to assess them on these issues.

Summary. This metric is recommended as a third-tier candidate. The effort involved in evaluating this metric seems excessive given the questionable link between the metric and the actual environmental impacts of the transit project, as well as lack of transit agency control over this factor. It might be considered for system-level evaluation of how well a region is planning to avoid or mitigate impacts of transportation-related growth. If the metric is applied, consideration should be given to supplementing document review with interviews with experts who already have knowledge of plans and protection mechanisms and could more readily assess the effectiveness of such measures in a given area.

■ 4.6 Other Metrics

Level of Service and Other Measures for Assessing Pedestrian and Bicycle Access to Transit

Calculation. As discussed in Appendix E, there are different ways of computing these measures, including both facility-level and area-level methods that incorporate indicators of the pedestrian and/or bicycle environment. Such measures could serve as proxy measures for the physical activity and associated public health benefits of a project.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Assumption that quality of the pedestrian/bicycle environment is directly related to the number of nonmotorized trips associated with the project;
- Weighting/importance given to different factors used in the indicator systems;
- Values of these indicators, some of which may be assessed qualitatively or based on limited data.

Ease of Computation. Varies. Facility-level LOS measures require fairly detailed link-level data in GIS format. Some area-level metrics are designed to be calculated using a more limited set of quantitative and/or qualitative information.

Results. This metric was not applied to the pilot projects. However, qualitative assessments have been performed in the land use assessment process conducted by FTA.

Pros. This metric could serve as a proxy measure for the physical activity and associated public health benefits of a project, if it is determined not to use a more direct metric such as change in nonmotorized trips. It would also support livability objectives by measuring the availability/of nonmotorized travel options.

Cons. This metric does not measure physical activity directly, but rather provides an indicator of how likely the project is to support additional levels of walking and bicycling, based on the presence of a supportive local (station area or corridor) environment.

Summary. This metric is recommended as a second-tier candidate. . If it is determined to use this metric, it is probably preferable to use an area-based measure that can be assessed on somewhat limited data available via satellite imagery and basic street network files, such as presented in the research to develop quantitative metrics. If used for comparing projects in different regions, assessment of this metric would support both the land use and environmental criteria and should be coordinated between these two criteria; it may be preferable to keep it under the land use criterion.

Environmental Performance Ratings for Transit Projects

Calculation. Appendix F describes two rating systems that have been developed for highway projects and could potentially be adapted to transit projects: the Greenroads system and FHWA's Sustainable Highways Self-Evaluation Tool. Both systems are designed for self-assessment using largely qualitative methods to assign "credits" for 30 to 50 criteria. The systems are designed to evaluate steps taken in project design, construction, and operation to minimize environmental impacts.

Key Assumptions. Key assumptions and areas of uncertainty include:

- Some factors relate to process rather than outcomes – it is assumed that beneficial environmental outcomes are realized if the process is followed;
- The credits/weights are arbitrary and assumed to relate to the relative importance of each factor in terms of environmental impact; and
- The ratings are largely subjective.

Ease of Computation. The evaluation is designed to be conducted by staff familiar with the project. Assessment is largely qualitative but nonetheless there are many factors to assess. Evaluation by an independent reviewer would take more effort, likely requiring on-site interviews with project staff.

Results. This metric was not applied to the pilot projects.

Pros. This metric can indicate how well the transit agency is working to minimize the direct environmental impacts of the project construction and operation. The use of this metric could encourage transit agencies to adapt more "green" practices.

Cons. Existing systems have been designed for highways and would need to be adapted to transit. The metric only considers the impact of project construction and operation rather than the overall environmental impact or benefit of the transportation outcomes. If the credit scores were used in comparing multiple projects in different regions, project evaluations, it would be difficult to rely on self-assessments and somewhat labor-intensive independent reviews would probably need to be conducted. It is not very useful for local-level evaluation since the factors assessed are mainly agency-specific rather than alternative-specific.

Summary. This metric is recommended as a second-tier candidate for national-level evaluation under two conditions: 1) only a "yes/no" rating is conducted (whether or not the transit agency has conducted an environmental assessment, rather than the actual rating), and 2) it is used as "extra credit" rather than a significant rating factor. Development and promotion of a rating system for transit could be beneficial for transit agencies in improving their practices, but it does not appear to provide a significant basis for distinguishing among projects.

5.0 Most Promising Metrics

5.1 Summary of Most Promising Metrics

This report provides information on metrics that could be used for environmental performance evaluation of transit projects. While it does not provide recommendations, the research findings do suggest some metrics that the research team concluded might be most appropriate for use in different evaluation contexts. Table 5.1 summarizes the metrics that were rated as Tier 1 or Tier 2 and are not redundant with other metrics, and identifies the scope of how the metric is calculated. Table 5.1 also identifies additional development activities that are needed before the metric is ready for use, particularly for comparing multiple projects in different regions.

Three measures rated as Tier 2 in Section 4.0 were excluded from this list. Total energy and GHG emissions were excluded because the energy and GHG per passenger-mile metrics appear to be preferable for this category. Pedestrian and bicycle level of service measures from the "other" category were excluded because this issue is already evaluated qualitatively through the land use and economic development assessment. Environmental performance rating systems were excluded because they still need significant development to apply to transit, and because they may be more appropriate for agency self-assessment than for either local alternatives evaluation or national evaluation.

The metrics presented here represent broad environmental performance issues of interest for comparing across projects (including benefits), rather than a detailed enumeration of all the environmental impacts considered in the environmental documentation process. The list also includes only metrics that can be computed with existing data sources and modest resource requirements, and therefore is limited in its ability to fully represent some aspects of environmental performance, as discussed below.

Table 5.1 Summary of Most Promising Metrics of Environmental Performance

Performance Category	Metric	Scope	Further Development Activities
Energy and Greenhouse Gas (GHG) Emissions	Operating energy or GHG emissions per passenger-mile	Calculated for new project Include energy/GHG from fuel production as well as direct vehicle operations	• Decide whether to use energy, GHG, or both • Develop standard energy and emission factors or guidance for developing project-specific factors
	Construction energy or GHG emissions	Calculated for new project	• Research required to develop models for non-materials construction energy and GHG • Consider normalizing (per passenger-mile or route-mile) if used for New Starts evaluation
Air Quality and Public Health	Change in total project emissions	Calculated for highway and transit	• Determine pollutants of interest • Develop standard g/mi emission factors • Consider combined weighted index of all pollutants • Determine whether and how to include emissions from electricity generation
	Project air pollutant emissions per passenger-mile[a]	Calculated for transit project only	
	Change in daily nonmotorized access trips	Calculated for new project versus no-project	• Validation of consistency of results among projects/models • Consider/test total nonmotorized trips accessing new project as alternative
Ecology, Habitat, and Water Quality	Fraction of corridor land that already is developed	Project corridor (X-mile radius)	• Consider categorical rating system (e.g., high, medium, low) based on quantitative benchmarks

[a] This alternative air quality metric was considered too late in the process to fully test and compare it to other metrics. While the project team feels that project emissions per passenger-mile may be preferable to change in total emissions for informing comparative project evaluation, it will need to be more fully tested before a final judgment is made.

5.2 Limitations of the Metrics and the Current Evaluation Framework

In addition to challenges with data acquisition and consistent calculation of certain metrics, two significant challenges were encountered in attempting to develop meaningful and reliable project-level metrics of environmental performance.

First, **the impacts of any individual transit project generally look small when compared on a regional basis.** For the projects evaluated in this research, energy, GHG, and emissions changes were typically less than 0.2 percent of regional or subregional totals. The relatively small impacts were also manifested in cost-effectiveness metrics that are not favorable when compared to other air quality and GHG improvement projects on a standalone basis. This can lead to the potentially erroneous conclusion that the project is not worth doing. The small size of benefits reflects multiple factors:

- To some extent, this is the reality of the situation – most individual transit projects make a relatively small dent in regional travel patterns and associated environmental benefits.
- However, it also reflects a potentially incomplete accounting of the project's benefits due to the current evaluation framework. This framework assumes that land use patterns are the same with or without the project. Secondary, longer-term benefits associated with land use changes that the transit project may induce or support, and further changes to travel patterns because of these land use changes, are not considered.
- The individual project versus no-project approach also does not consider potential synergistic benefits of multiple coordinated transit projects, combined with supportive land use policies.
- The poor cost-effectiveness of the transit projects when measured just on air quality or GHG effects does not account for the multiple other benefits of the project, including mobility – environmental benefits are just one of multiple reasons to undertake a transit project.

The second major challenge is that **it is not possible to reliably predict the secondary benefits or impacts of a transit project for ecology, habitat, and water quality**. The factors affecting the secondary, growth-inducing impacts of transit projects (or highway projects for that matter) are complicated and include economic/as well as policy factors and physical constraints. Models to predict the effects of transportation investments on land use patterns do exist, but they are resource-intensive to apply, and a recent evaluation for FTA found that they were not yet suitable for evaluating individual projects, including transit projects.[13] Two TCRP projects currently underway are continuing to investigate methods for predicting land use and economic development impacts, using very different approaches.[14] Even if general growth patterns can be predicted, the level of detail required to assess specific environmental impacts (such as impacts to sensitive habitat or water quality) is generally not available. It may be that a qualitative assessment of supportive land use policies, such as FTA already performs in its assessment of the land use and economic development criteria, is the best that can be done with respect to this factor at the current time.

Closely related to this challenge is the difficulty of quantifying benefits from projects that serve heavily built-up areas and primarily improve conditions for existing riders, rather than diverting travelers from automobiles. The environmental benefit in this situation can be characterized as a long-term strengthening of the urban core through improved travel conditions, helping attract and retain people in these settings where the environmental impacts of travel and development can be much lower. However, most current models are not well suited to forecasting the impacts of transportation improvements on metropolitan development patterns, including retaining or increasing population and jobs in urban core areas.

These two challenges suggest that **a different evaluation framework may be required** to provide a meaningful evaluation of transit's full environmental benefits. Specifically, this framework would assess and compare the *life-cycle impacts* (construction and operation) of *all modes* (including highways and transit) on a *network or systems* level. Such an assessment would consider differences in land use patterns that support, or would be influenced by, alternative transportation networks. In fact, multimodal, systems-level assessments have already been performed in many areas of the country as part of regional scenario planning exercises. Regional scenario planning studies have found long-term air quality and energy benefits ranging from 5 to 25 percent or more for regional scenarios of compact growth and transit investment, compared to business-as-usual scenarios with highway investment.[15] These regional scenario evaluations could be further enhanced by incorporating life-cycle emissions and energy use (including construction, maintenance,

---

[13] *Deriving Economic Development Benefits of Transit Projects from Integrated Land Use Transportation Models: Review of Models Currently Used in the U.S. and Recommendations*. Prepared by Cambridge Systematics, Inc. and Dr. John Gliebe for Federal Transit Administration, April 2009.

[14] *TCRP H-39: Methodology for Determining the Economic Development Impacts of Transit Investments*, http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2364; and TCRP Project H-46, *Quantifying Transit's Impact on GHG Emissions and Energy Use: The Land Use Component* http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3092.

[15] A recent review of scenario planning studies using travel forecasting models found that land use changes, combined with supportive transit investments, were estimated to reduce metropolitan VMT by a median of 8 percent below forecast levels over a 20-year time horizon and 16 percent over a 40-year horizon. Forty-year reductions ranged from 3 to 28 percent across studies. See: Rodier, C. (2009), *Review of International Modeling Literature: Transit, Land Use, and Automobile Pricing Strategies to Reduce Vehicle Miles Traveled and Greenhouse Gas Emissions*, Transportation Research Record No. 2132.

fuel production, etc.) as better information on these factors becomes available. At a project level, evaluation could be performed by considering the consistency of the project with a regional plan that achieves substantial environmental benefits.

There are admittedly many challenges to moving towards this type of evaluation. For example, the ability to do regional scenario planning that includes land use as well as transportation will vary from region to region. Land use decisions are typically made at the local (municipal) level, whereas transit planning is part of a regional process. Even if a preferred transportation and land use scenario can be developed and "adopted" at a regional scale there may be no way to ensure that it is implemented, and therefore that the full benefits of the transit project are realized. Also, to ensure consistency in methods across projects, closer attention would need to be given to the travel demand forecasting and land use assumptions across the region, rather than just the project corridor.

""A regional-scale approach, however, may be the only way to achieve a complete accounting of transit's environmental benefits. This type of evaluation framework would also be consistent with best international practice for transportation project evaluation, as identified in the literature review for this research. In its January 2012 NPRM and proposed policy guidance, FTA is proposing to allow project sponsors the option of submitting alternative land use forecasts and associated estimates of environmental impacts, which would begin to move the process in this direction.

It would still be necessary for project sponsors to evaluate individual projects on their merits. However, this evaluation might be done considering benefits that occur when the project is implemented in conjunction with other supportive projects and policies. The relative contribution of the project to the benefits of the overall regional plan might be assessed based on some factor such as ridership or passenger-miles.

If this approach were taken , transit agencies might have concerns about the fact that their project is being evaluated based on factors beyond their control (i.e., regional transportation and land use decisions made by the MPO and local governments). On the other hand, this is already true within the current national land use and economic development evaluation criteria. Regional and local decisions also influence other benefits of the project, such as ridership, even within the current evaluation framework. A question that would need to be addressed is whether just the project would be evaluated, or whether the evaluation would also consider the broader regional planning context and the extent to which it supports the project.

6.0 Next Steps and Issues for Further Research

This research has provided an overview of the use of different metrics of environmental performance, but has left a number of issues unaddressed. These can be grouped into next steps for implementation, and issues for further research.

6.1 Next Steps for Implementation

The following issues will need to be addressed by decision makers and others who chose to apply these metrics.[16] -

- Which metrics (if any) will an individual agency use for their own project evaluation purposes? How will they be used to inform project decision-making, including weighting them in relation to other measures of performance?
- Which metrics (if any) will be used for comparative evaluation of projects, and how will they be incorporated into the evaluation and reporting framework? What weights would be set for each metric within the environmental performance category, and how would this overall category be weighted in comparison to other categories?
- If a GHG metric is selected, will GHG be calculated based on regional emission factors, or national average factors? ICLEI's protocol for development of GHG inventories by local governments specifies the use of local/factors,[17] although decision makers would not necessarily need to be consistent with this practice.
- If an air quality metric is selected, which pollutants are included? Are emissions from powerplants from electricity generation included? Again, if the metric is applied

[16] FTA's January 25, 2012 Notice of Proposed Rulemaking and accompanying Proposed New Starts/Starts Policy Guidance address some of these issues. For example, the policy guidance proposes the specific environmental metrics to be examined, how they will be combined and weighted, general methods for calculating these metrics, and the use of national rather than regional emissions, energy, and GHG factors. Details of data sources and calculation methods remain to be developed.

[17] ICLEI (2009). *International Local Government GHG Emissions Analysis Protocol (IEAP), Version 1.0.*

comparing projects in different regions of the country, are national or regional emission factors used?

6.2 Issues for Further Research

Issues that warrant further research – some shorter-term and easier to address, others longer-term in nature – include the following:

- What are the most appropriate energy and GHG emission factors, particularly for future energy use and emissions from all types of transit vehicles (including electricity generation)?

- What is the full range of energy use and GHG emissions from transit construction? (This may be addressed by research underway for FHWA).

- Can the Exposure Index and/or Health Benefits Index be further developed so that they are useful for transportation project and/or plan evaluation, considering health effects?

- How do different models of nonmotorized access mode choice affect the reliability of access mode choice forecasts? To what extent do transit projects induce nonmotorized trips in addition to those accessing the transit project (e.g., by allowing households living in transit station areas to have fewer vehicles)?

- Can systems-level forecasting methods (considering regional transportation and land use systems) provide information on the environmental benefits of projects that is significantly different than that provided by project-level methods that simply compare the project versus no-project alternative in isolation from other changes?

- To what extent are the environmental benefits of transit increased by the "trip not taken"? That is, to what extent are our current evaluation methods not capturing the benefits of more compact development and associated changes in travel patterns (including changes such as increased walking and bicycling for short trips, in addition to new transit trips)? This concept is also known as the "land use multiplier." Some research is underway to expand our understanding of this issue through TCRP H-46, *Quantifying Transit's Impact on GHG Emissions and Energy Use: The Land Use Component*, but ongoing research is likely to be required because of the complexity of the topic and the variability of the relationships in different situations.

- What are the advantages, drawbacks, and implications of evaluating the environmental benefits of a project as part of a regional plan (i.e., in comparison to a no-plan or alternative plan), rather than in isolation from other changes?

Appendix A – Data Collection for Pilot Projects

The detailed screening of environmental metrics was performed in Phase 2 using data from real-world projects that already have developed New Starts applications, or are planning to do so. While the project team did most of the data analysis, the sponsors of the pilot projects worked with the project team to provide the data needed to test the proposed metrics.

The overall pilot project recruitment and data collection process took about eight months to complete. Staff with candidate pilot projects were first contacted to determine their willingness to participate. At this time they were provided with a memorandum describing the purpose of the research and listing the data items requested. The list of data items is shown in Table A.1. (This list reflects some minor modifications that were made to the requests following a list that was originally distributed.) The list that was distributed also identifies the likely source agency for the data and the year requested, and its use in calculating metrics (not part of the list provided to project sponsors). Some data items were obtained by the project team directly from an agency besides the transit agency (MPO or national source). Project sponsors were assured that they were only expected to provide readily available data and did not need to develop data items that did not already exist. They were also asked to track the approximate amount of time it took to respond to the data request.

Table A.1 Data Items Requested

Key	Data Item	Use for Metrics	Source	Year
1 Travel Demand Model Data				
1a	Travel demand forecasting model output: network shapefile with link-level speeds and VMT for scenarios with and without transit project (by time period if available)	Emissions, energy, and GHG from highway vehicles (methods using speed-based emission factors) (IC, ID, IE, IIA, IIB, IIC)	Transit agency or MPO	Project forecast year
1b	VMT by vehicle type for region (HD versus LD; other nondefault VMT distribution)			
1c	Travel demand model – TAZ shapefiles with socio-economic data	Calculation of Exposure Index and Health Benefit Index (IIB, IIC)		
1d	Forecast change in passenger-miles by transit mode, with and without transit project	GHG and energy per passenger-mile (IA, IB)		
1e	Forecast number of nonmotorized access trips to transit, for scenarios with and without transit project	Change in daily nonmotorized access trips (IIE)		
1f	Documentation of travel demand model capabilities for modeling transit access mode choice (modes included, geographic detail of station area zones and networks, factors related to pedestrian and bicycle environment/ LOS, etc.)	Change in daily nonmotorized access trips (IIE)		
1g	Travel time skims for highway and transit for peak and off-peak	Potentially impacted acreage of undeveloped land and critical habitat (IIIB, IIIC, IIID)	MPO	

Table A.1 Data Items Requested (continued)

Key	Data Item	Use for Metrics	Source	Year
2 Emissions Data				
2a	Regional emissions outputs associated with travel demand forecasts with and without transit project (if available) – HC, CO, NO_x, PM_{10}, ($PM_{2.5}$), (CO_2)	Emissions, exposure, and health benefit metrics (IIA, IIB, IIC)	Transit agency or MPO if available; otherwise compute from 1a and 2b	Project forecast year
2b	Emission factors for roadway vehicles by speed and vehicle type (MOVES, MOBILE6, or EMFAC output) – HC, CO, NO_x, PM_{10}, ($PM_{2.5}$), (CO_2)	Emissions, exposure, and health benefit metrics (IIA, IIB, IIC)	MPO or state environmental agency; otherwise use national	Project forecast year
2c	Emission factors for any alternative-technology transit vehicles not covered in 2b	Emissions, exposure, and health benefit metrics (IIA, IIB, IIC)	Transit agency, manufacturer, or national	Year of manufacture
3 Transit System Data				
3a	Transit system: change in annual VMT by vehicle/fuel type (diesel bus, CNG bus, hybrid bus, LRT, HR, CR, DMU, other), for project versus no-project	All GHG and energy measures (IA-IE)	Transit agency	Project forecast year
3b	Transit system: energy consumption rates (fuel consumption or BTU per mile) by vehicle/fuel type, for all vehicles with VMT changes	All GHG and energy measures (IA-IE)	Transit agency if available; otherwise use national	Most recent year; project forecast year if available
3c	GIS shapefile of transit project	Exposure and health benefit indices (IIB, IIC); ecology, habitat, and water quality metrics IIIA-IIID	Transit agency	Project opening

Table A.1 Data Items Requested (continued)

Key	Data Item	Use for Metrics	Source	Year
4 Electricity Grid Data				
4a	CO_2 factors for local electricity generation	GHG metrics (IA, IC, IE)	EPA – eGRID	Most recent year
4b	Future year improvement in CO_2 emissions intensity of electricity generation	GHG metrics (IA, IC, IE)	DOE, EPRI, regional forecasts	Project forecast year
5 Transit Project Cost and Inputs Data				
5a	Standard Cost Calculation (SCC) worksheets or other capital cost estimates	GHG, energy, and air quality cost effectiveness metrics (IE, IIA(ii))	Transit agency	
5b	Project-miles and track-miles by guideway type (concrete, rail), alignment type (surface, tunnel, elevated), and propulsion type (self, catenary, third rail)	Life-cycle GHG and energy use (IE)		
5c	Material volumes required for construction: Steel, concrete, asphalt	Life-cycle GHG and energy use (IE)		
5e	Change in operating cost for build versus no-build	GHG, energy, and air quality cost effectiveness metrics (IE, IIA(ii))		
6 Land Use Data				
6a	Regional GIS land use database – existing land use	Ecology, habitat, and water quality metrics IIIA-IIID	Regional planning agency	Most recent year
6b	Local (municipal/county) GIS land use databases for municipalities in corridor – existing land use *(only if 6a not available)*		Local municipalities	

Table A.1 Data Items Requested (continued)

Key	Data Item	Use for Metrics	Source	Year
6 Land Use Data (continued)				
6c	Regional land use GIS database – land use policy, including future planned land use, protected areas, etc.		Regional planning agency	
6d	Local (municipal/county) land use GIS databases for municipalities in corridor – land use policy, including future planned land use, protected areas, etc. *(only if 6c not available)*		Local municipalities	
6e	State or regional habitat/ecology database – GIS files identifying ecologically significant areas, protection status, etc.		State environmental agency or regional planning agency	
6f	Wetlands GIS database		State environmental agency or EPA	
6g	State, regional, and/or local habitat protection plans (plan documents)	Ecology, habitat, and water quality metric IIIE	State environmental agency, regional planning agency, and/or local planning department	

The calendar time required to obtain a complete set of available data from the project sponsors ranged from about two to eight months; data collection for some projects was delayed due to high-priority project work such as the completion of an Environmental Impact Statement (EIS). For one project that was in the early stages of planning, it turned out that some critical data items that were initially thought to be available could not be obtained, and therefore most metrics could not be calculated for this project. For another project (number 4), data collection was hampered by the fact that the project had evolved by being combined with another project in the region, and therefore there were inconsistencies with some data items being available for the original project definition and others for the revised definition. Most other projects had a few missing data items meaning that not every metric could be calculated. As expected, those that had already completed New Starts submissions were able to provide the most consistent and reliable data. The estimated time requirements for project sponsors to respond to this request were as follows:

- Projects 1 and 5: unknown;
- Project 2: 15 to 20 hours;
- Projects 3 and 4: 70 hours combined; and
- Project 6: 15 hours.

The question of whether to compare the project (build) alternative to the no-project (no-build) alternative or to the baseline Transportation Systems Management (TSM) alternative required by FTA also needed to be addressed. Environmental documentation for the NEPA process requires the comparison of a project and no-project alternative, while FTA's New Starts process requires comparison with a TSM alternative (defined as "the best that can be done for mobility without constructing a new transit guideway").[1] Build and no-build data were requested from the project sponsors unless no-build data were unavailable, in which case the baseline TSM alternative was used for comparison. The distinction was not viewed as critical for the purposes of testing metrics in this research, as long as the data sources used for a given project were consistent.

Table A.2 provides an overview of the sources of data and outcomes of data collection efforts for the pilot projects.

[1] Federal Transit Administration. *New Starts Baseline Alternative Review and Approval Procedures*, http://.fta.dot.gov/planning/newstarts/planning_environment_2589.html, accessed September 12, 2011.

Table A.2 Data Collection Outcomes

Key	Data Item	Project 1 – LRT	Project 2 – Commuter Rail	Project 3 – LRT	Project 4 – EMU	Project 5 – LRT	Project 6 – BRT
1 Travel Demand Model Data							
1a	Travel demand forecasting model output: network shapefile with link-level speeds and VMT for scenarios with and without transit project	YES – Obtained from MPO or transit agency staff for all projects					
1b	VMT by vehicle type for region	Used MOVES national defaults for percentage passenger cars and trucks					
1c	Travel demand model – TAZ shapefiles with socioeconomic data	YES – Obtained from MPO or transit agency staff for all projects					
1d	Forecast change in passenger-miles by transit mode, with and without transit project	N/A	YES	YES	YES	YES	YES
1e	Forecast number of nonmotorized access trips to transit, for scenarios with and without transit project	N/A	YES	YES	YES	YES	YES
1f	Documentation of travel demand model capabilities for modeling transit access mode choice	YES – Obtained from MPO or transit agency staff for all projects					
1g	Travel time skims for highway and transit for peak and off-peak	N/A[a]	YES	YES	YES	YES	N/A[a]

Table A.2 Data Collection Outcomes (continued)

Key	Data Item	Project 1 – LRT	Project 2 – Commuter Rail	Project 3 – LRT	Project 4 – EMU	Project 5 – LRT	Project 6 – BRT
2 Emissions Data							
2a	Regional emissions outputs associated with travel demand forecasts with and without transit project – HC, CO, NO_x, PM_{10}, $PM_{2.5}$, CO_2	Obtained only for Project 2, which had already computed emissions by TAZ. Projects 5 and 6 provided aggregate emissions estimates from EIS documentation, but only for certain pollutants of local concern. For purposes of this evaluation, the project team used travel demand model output (1a) and MOVES emission factors (2b) to compute emissions changes on a spatial basis (by TAZ) for Projects 5 and 6. Project 1 had not developed a detailed transit operations plan and therefore transit emissions could not be estimated. Projects 3 and 4 used a different travel demand modeling platform that would have required significantly more resources to compute emissions changes on a spatial basis.					
2b	Emission factors for roadway vehicles by speed and vehicle type – HC, CO, NO_x, PM_{10}, $PM_{2.5}$, CO_2	Not obtained – Project team ran MOVES under generic conditions to obtain consistent emission factors for all pollutants (see Appendix C)					
2c	Emission factors for any alternative-technology transit vehicles not covered in 2b	This was only applicable for the diesel commuter rail project (2a), for which total emissions estimates were provided by the project sponsor					
3 Transit System Data							
3a	Transit system: change in annual VMT by vehicle/fuel type, for project versus no-project	N/A – Detailed operating plans not developed	YES	N/A	YES	YES	YES
3b	Transit system: energy consumption rates (fuel consumption or BTU per mile) by vehicle/fuel type, for all vehicles with VMT changes	N/A	N/A	N/A	N/A	YES, based on data in EIS	YES, based on data in EIS
3c	GIS shapefile of transit project	YES	YES	YES	YES	YES	YES

Table A.2 Data Collection Outcomes (continued)

Key	Data Item	Project 1 – LRT	Project 2 – Commuter Rail	Project 3 – LRT	Project 4 – EMU	Project 5 – LRT	Project 6 – BRT
4 Electricity Grid Data							
4a	CO_2 factors for local electricity generation	Not requested – National data from eGRID used by project team					
4b	Future year improvement in CO_2 emissions intensity of electricity generation	Not requested – National data from eGRID used by project team					
5 Transit Project Cost and Inputs Data							
5a	Standard Cost Calculation (SCC) worksheets or other capital cost estimates	YES (preliminary estimates)	YES – from DEIS	YES – SCC worksheets	YES – SCC worksheets	YES – SCC worksheets	YES – SCC worksheets
5b	Project-miles and track-miles by guideway type, alignment type, and propulsion type	YES	N/A[b]	YES – SCC worksheets	YES – SCC worksheets	YES – SCC worksheets	YES
5c	Material volumes required for construction: Steel, concrete, asphalt	N/A	N/A	N/A	N/A	N/A	N/A
5d	Number of vehicles purchased by type	N/A	N/A	YES – SCC worksheets	YES – SCC worksheets	YES – SCC worksheets	YES – SCC worksheets
5e	Change in systemwide operating cost for build versus no-build	YES (preliminary estimates)	YES – from DEIS	YES	YES	YES	YES – from EIS

Table A.2 Data Collection Outcomes (continued)

Key	Data Item	Project 1 – LRT	Project 2 – Commuter Rail	Project 3 – LRT	Project 4 – EMU	Project 5 – LRT	Project 6 – BRT
6 Land Use Data[c]							
6a	Regional GIS land use database – existing land use	From MPO/COG	From State	From MPO/COG		From MPO/COG	From State
6c	Regional land use GIS database – land use policy, including future planned land use, protected areas, etc.	N/A	N/A	N/A		From MPO/COG	N/A
6b, 6d	Local (municipal/county) GIS land use databases for municipalities in corridor – existing and planned land use	Not obtained					
6e	State or regional habitat/ecology database – GIS files identifying ecologically significant areas, protection status, etc.	From MPO/COG	N/A	N/A		Available from state (not obtained due to cost)	N/A
6f	Wetlands GIS database	From U.S. Fish and Wildlife Service					
6g	State, regional, and/or local habitat protection plans (plan documents)	Not reviewed	Various web sources	Various web sources	Not reviewed	Not reviewed	Not reviewed

[a] Travel time skims were requested for the purpose of computing transit accessibility changes to support metrics IIIC and IIID. For two projects, they were not readily available. They could have been generated but were not requested due to a significant amount of work required (two to three days of staff time) and the fact that preliminary testing on three projects led to the decision not to further explore the accessibility measures (see Appendix D).

[b] This project involved a combination of new track construction, conversion of existing single-track to double-track, and reconstruction/upgrade of existing trackage.

[c] Additional information on land use data sources is provided in Appendix D.

Appendix B – Calculation of Energy and GHG Metrics

This appendix describes the data sources and methods used in this project to estimate metrics of the energy and greenhouse gas benefits of transit projects. The methods rely on existing data sources on energy consumption and emissions for highway and transit vehicles, including the National Transit Database, the U.S. Environmental Protection Agency's MOVES emission factor model, the Department of Energy's Annual Energy Outlook and GREET model, and other published literature. Data from these sources are combined with project-specific data (such as changes in highway and transit vehicle-miles) for the pilot projects evaluated in this research, to estimate changes in energy use and GHG emissions expected to result from each project.

The appendix describes the data sources and procedures for calculating the metrics. The appendix also discusses the results of sensitivity testing of the metrics in greater detail than presented in the main body of the final report. For ease of description, the metrics are discussed in the following order:

- Total energy consumption;
- Energy cost-effectiveness;
- Energy per passenger-mile;
- Total GHG emissions;
- GHG cost-effectiveness;
- GHG per passenger-mile; and
- Life-cycle emissions (including construction).

B.1 Procedure for Calculating Metrics

ID(i) Change in Total Annual Operating Energy Consumption

This metric was calculated as the change in total annual energy consumption from the operation of transportation vehicles, including the proposed transit project, other transit routes that changed as part of the transit project operating plan, and highway VMT. The equation is:

*Change in energy = Σ [Energy consumption (BTU per vehicle-mile) * Change in annual vehicle-miles * Fuel-cycle energy factor] by vehicle type*

Energy Consumption Rates – Transit Vehicles

For transit vehicles, national default energy consumption rates were first developed for the current year (most recent historical data) based on National Transit Database (NTD) average energy consumption by transit mode (Table B.1). The quantity of fuel consumed from the Energy Consumption table and the vehicle-miles (or train-miles, for rail modes) from the Service table were used to calculate fuel per vehicle-mile or train-mile for each mode, which was converted to British thermal units (BTU) per vehicle-mile or train mile using standard BTU values for various fuels.[1] These energy consumption rates varied significantly in some cases (see discussion below) and care should be taken when applying these national averages to specific transit projects. Default rates were projected to the project evaluation year (2030 or 2035, depending upon the pilot project) using average fuel efficiencies for heavy-duty vehicles from the U.S. Department of Energy (DOE), Energy Information Administration (EIA) Annual Energy Outlook (AEO), as discussed in more detail below.

One project (Project 5) provided data from the project environmental impact statement (EIS) on the assumed energy intensity of light rail transit vehicles and buses. These numbers, which were derived from a national source,[2] showed considerably higher energy intensity (61 percent for light rail and 23 percent for bus) than those derived from the NTD as the defaults found in Table B.1. Another project (Project 6) provided data from the project EIS on the assumed energy intensity of two different bus rapid transit vehicle technologies: one with diesel buses and one with hybrid diesel-electric buses. The diesel bus energy intensity assumptions from the project EIS were 12 percent lower than those found in Table B.1 and were based on current transit fleet information for articulated buses adjusted to the future year using estimates from the California Air Resources Board's EMFAC model of the decrease in urban bus CO_2 emission factors between 2015 and 2035. The diesel electric hybrid bus energy intensity assumptions from the project EIS were 40 percent lower than those found in Table B.1 and were based on a national source.[3] Due to these differences between project-reported transit vehicle energy intensity rates and the defaults developed in Table B.1, the project team performed sensitivity testing to assess how alternative assumptions about future transit vehicle efficiency (within a plausible range of 25 percent) affect the energy and GHG benefits of transit relative to highway vehicles. See the sensitivity testing section at the end of this appendix.

---

1 U.S. Department of Energy, Energy Information Administration. *Fuel Emission Factors Worksheet*, from Appendix H of the instructions to Form EIA-1605, http://www.eia.doe.gov/oiaf/1605/emission_factors.html.

2 Sinha, K.C. and S. Labi. *Transportation Decision-Making, Principles of Project Evaluation and Programming*, Hoboken, New Jersey: John Wiley & Sons, Inc., 2007. See Table 15.4, Direct Energy Consumption of Passenger Transportation.

3 U.S. Department of Transportation. *Fuel Cell Bus Life-Cycle Cost Model*, http://.hydrogen.dot.gov/projects_across_dot/publications/fuel_cell_bus_life_cycle_cost_model/presentation/html/text.html.

Table B.1 Default Energy Consumption Rates by Mode
BTU per Vehicle-Mile or Train-Mile[a]

Mode/Technology	2009	2030	2035
Diesel Bus	36,239	33,946	33,392
CNG Bus	36,239	33,946	33,392
Hybrid Bus (Diesel-Electric)	28,991	27,157	26,714
Light Rail (Electric)	51,495	48,237	47,449
Heavy Rail (Electric)	138,509	129,745	127,627
Commuter Rail (Electric)[b]	134,653	126,133	124,074
Commuter Rail (Diesel)[b]	409,143	383,255	377,000
Highway Vehicles (Light-Duty Car/Truck)	6,016	4,638	4,493

[a] Diesel bus, light rail, heavy rail, and commuter rail for 2009 from Federal Transit Administration, 2009 National Transit Database, Table 17 Energy Consumption and Table 19 Transit Operating Statistics: Service Supplied and Consumed. Calculated by dividing fuel used for each mode (gallons of kWh) by vehicle-miles (for buses) or train-miles (for rail modes). Fuel usage is converted to energy usage using BTU factors from the EIA Fuel Emission Factors Worksheet found in Appendix H of the instructions to Form EIA-1605 (see: http://www.eia.doe.gov// /_factors.html, calculated from Table 2, Carbon Dioxide Emission Factors for Transportation Fuels). CNG bus is assumed to be the same energy efficiency as diesel bus. Hybrid bus is assumed to be 20 percent more efficient than diesel bus. Transit Cooperative Research Program Report 132 (Clark, N., et al, *Assessment of Hybrid-Electric Transit Bus Technology,* 2009) develops equations predicting hybrids are 14 to 25 percent more efficient than diesel depending upon average speed; 20 percent is taken as typical for a 13 mph average speed. Energy consumption rates for 2030 and 2035 are the 2009 rates adjusted by the ratio of average 2035 to 2009 efficiency for the most similar mode from AEO 2011 Early Release, Table 7. Heavy-duty vehicles were used to represent buses; rail (all types) to represent light, heavy, and commuter rail; and light-duty vehicles to represent highway vehicles.

[b] The NTD data report energy use separately for electric and diesel commuter rail but not vehicle revenue-miles, so an average energy rate including both propulsion modes had to be used.

Project 3 was an electric multiple unit (EMU) project, a new technology for which energy estimates could not be obtained from the NTD or from the project sponsor. Like light rail vehicles, EMU vehicles are self-propelled vehicles, powered by overhead catenary. However, they are larger and heavier than light rail vehicles because they are designed to meet standards for operation on freight rail tracks and to provide service similar to commuter rail. As a result, their energy intensity per vehicle-mile would be expected to fall somewhere between a light rail and electric commuter rail vehicle. For this research, and average of light rail and electric commuter rail energy intensity was assumed (87,185 BTU/ vehicle-mile in 2030).

Variance in Transit Vehicle Energy Consumption Rates

Data from the 2009 National Transit Database was used to produce current transit vehicle energy consumption rates by mode and fuel type, which are reported as a weighted average since they sum all energy used by all vehicle-miles. Energy consumption can also be reported for individual transit systems within each mode/fuel type. This was done to explore the variability of the energy consumption within each mode/fuel type. Table B.2 shows the number of transit systems and the minimum and maximum energy consumption found for an individual transit system in that group. The weighted average energy consumption is also shown to illustrate where it falls relative to the minimum and maximum.

Table B.2 Transit System Energy Consumption Data from the 2009 National Transit Database

Mode and Fuel Type	Number of Transit Systems	Weighted Average Energy Consumption (BTU per Vehicle-Mile or Train-Mile)	Minimum Energy Consumption (BTU per Vehicle-Mile or Train-Mile)	Maximum Energy Consumption (BTU per Vehicle-Mile or Train-Mile)
Diesel Bus	284	36,239	4,901	151,979
CNG Bus	11	50,576	21,020	58,433
Biodiesel Bus	39	32,447	6,810	40,431
Electric Heavy Rail	15	138,509	75,141	219,122
Electric Light Rail	29	51,495	14,614	98,310
Diesel Commuter Rail	14	409,143	265,337	882,481
Electric Commuter Rail	4	134,653	3,070	247,814

Graphs of all of the individual transit systems; energy consumption rates were also created. Figure B.1 provides an example of such a graph for commuter rail. In the case of electric commuter rail, there was a very small sample size with high variability. Since several of the largest commuter rail systems in the country are found in the mixed (diesel and electric) fuel category and do not have vehicle-miles separated out by fuel type, much of the valuable data is lost in that category.

A similar graph for motor buses shows the large sample size and how the minimum and maximum could be considered outliers in some cases (Figure B.2). CNG buses appear to have a higher energy consumption rates than diesel buses according to this data, but due to the small CNG sample size diesel energy consumption rates are applied for CNG buses in Table B.1. There is no inherent reason that CNG buses should be less energy-efficient than diesel buses, and differences may be due to other factors such as differences in fleet mix (e.g., 60-foot articulated versus 40-foot buses) or local operating conditions.

Figure B.1 Commuter Rail Energy Consumption from the 2009 National Transit Database

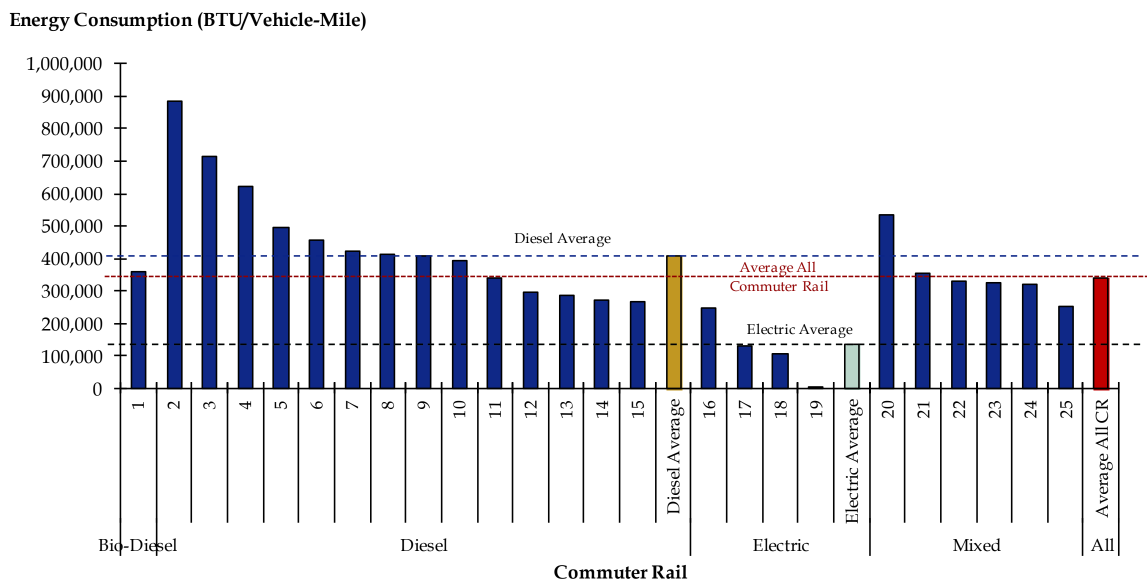
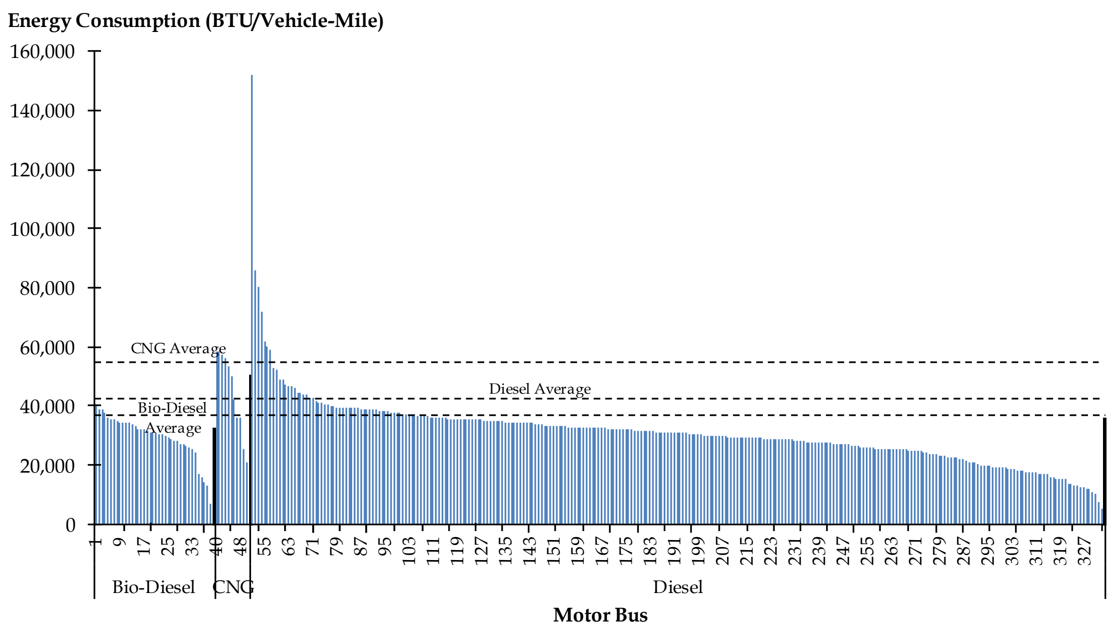


Figure B.2 Motor Bus Energy Consumption from the 2009 National Transit Database



Future Transit Vehicle Efficiency Improvements

Assumptions regarding future improvements in transit vehicle efficiency will have an important effect on the relative energy and GHG benefits of transit projects. Light-duty vehicles are improving substantially due to Federal fuel efficiency regulations, and if transit vehicles do not improve at a similar rate, they will be relatively less beneficial for energy and GHG in the future than they are today.

An attempt to determine whether past trends could be used to predict future technological efficiency improvements was unsuccessful. Analysis of data from the American Public Transportation Association (APTA) 2010 Public Transportation Fact Book shows no discernible change in efficiency (per vehicle-mile) for diesel buses over the 1984 to 2008 period and for heavy rail over the 1996 to 2008 period. Light rail is about 5 percent more efficient for the 2003 to 2008 period than for 1996 to 2002, although it is not clear whether that is due to new systems coming on-line with different operating characteristics versus technology improvements. Commuter rail is more difficult to analyze because of the need to account for electric versus diesel power use (many systems use both power sources, but vehicle-miles are not reported separately by power source).

Current efficiency levels may be obtained using national averages from NTD/APTA data, or estimates provided by the project sponsor if these are believed to be more reliable (i.e., applicable to the specific vehicles and system operating conditions). Options for future efficiency assumptions include:

- **Annual Energy Outlook** forecasts of heavy-duty vehicle (trucks) and rail fuel efficiency – Forecast changes in efficiency could be assumed to apply to buses and to rail vehicles. This results in an 8 percent improvement for 2035 versus 2009, probably conservative.

- The ***Moving Cooler*** report[4] was a national study of the GHG benefits of various transportation strategies. The study included more aggressive assumptions about improvements in transit energy efficiency. For buses, fuel economy improvements of 1.27 percent per year were assumed from implementing advanced propulsion technologies such as hybridization, resulting in a 34 percent improvement for 2030 versus 2008 (page B-43). The study assumed a 20 percent improvement for diesel and electric rail (page B-46), which is from BritRail study on regenerative braking benefits and assumes that intercity rail benefits are transferable to commuter, heavy, and light rail.

[4] Cambridge Systematics, Inc. (2009). *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions*. Urban Land Institute, Washington, D.C.

- **TCRP Report 132**[5] studied the fuel efficiency of hybrid diesel-electric buses. The report includes equations that predict a 14 percent benefit for an average operating speed of 20 mph, increasing to 18 percent at 15 mph and 25 percent at 10 mph for hybrid versus standard diesel. A 20 percent improvement might be considered as an estimate for hybrid buses in 2009. The average 2030/2035 bus fleet could be assumed to include a much greater proportion of hybrid buses. Complete hybridization of the fleet, in addition to the 8 percent AEO improvement for heavy-duty vehicles, would therefore result in a 26 percent improvement for 2035 versus 2009 bus efficiency.

- The **Center for Neighborhood Technology** (CNT) issued a report in 2011 entitled *The Route to Carbon and Energy Savings for Transit Systems*. This report evaluated strategies that included transit vehicle technology. For the hybrid bus strategy, the report projects an overall fuel efficiency of diesel-electric hybrid and biodiesel electric hybrids of 4.3 to 8.6 mpg in 2030. It does not provide the current fuel efficiency of hybrid buses, but instead compares these efficiencies to the existing efficiency of regular diesel buses of 3.6 mpg in 2010, yielding a 19 to 139 percent improvement. The high-efficiency rail strategies examine efficiency improvements in diesel commuter rail, electric commuter rail, electric light rail, and electric heavy rail. For electric rail, the report anticipates reductions in CO_2e per vehicle-mile that reflect both improved vehicle efficiency and reduced GHG intensity from electricity generation, but does not present the assumed contribution of each factor. All of the electric rail modes show a 43 to 55 percent improvement in GHG emissions, while diesel commuter rail shows a 35 to 45 percent improvement in GHG emissions between 2010 and 2030.

A related variable that affects the relative GHG benefits of transit, but not energy benefits, is the carbon content of fuel. Biofuels have the potential to reduce the GHG intensity of both gasoline (by blending with ethanol) and diesel (biodiesel blend). The default values used in this research are 7 percent ethanol in gasoline and 2 percent biodiesel, which are the current levels for average national gasoline blend and for diesel fuel at transit agencies, respectively. Reasonably conservative future scenarios might include up to a 10 percent ethanol blend in gasoline and up to a 20 percent biodiesel blend, which are the blend limits that are currently used in gasoline and diesel vehicles without special adaptations.

[5] Clark, N., et al (2009). *Assessment of Hybrid-Electric Transit Bus Technology.* Transit Cooperative Research Program Report 132, Transportation Research Board, Washington, D.C.

Energy Consumption Rates – Highway Vehicles

For highway vehicles (light-duty), three different sources of vehicle energy efficiency were tested:

- **Method 1**, *value from project sponsor* (provided by Projects 5 and 6 only).
- **Method 2**, *national average efficiency* (all projects). This was calculated for the evaluation year using AEO light-duty stock average miles per gallon gasoline equivalent (mpgge)[6] and BTU value of gasoline[7] (see Table B.5). Note that the AEO data used here incorporated the adopted MY 2012-2016 fuel economy and GHG standards, but not proposed 2017-2025 standards.
- **Method 3**, *MOVES model* (calculated for Project 5). Speed and road type-based MOVES total energy consumption factors (million BTU per mile) were applied. A weighted average energy consumption rate was calculated using VMT distributions by speed bin and MOVES road type from the project sponsor's travel demand model output, or from MOVES defaults of the VMT distribution for the county used in MOVES runs if travel demand model results were not available. The county used in MOVES runs was required to have all four MOVES road types available and to have at least part of the transit project traveling through it. MOVES runs to provide total energy consumption factors assumed national defaults (no county data manager), and were run with a time aggregation level of year for gasoline and diesel passenger cars and passenger trucks. Only running emissions were included; however, nonrunning emissions that are proportional to VMT (such as starts) could be added in the future. Using output from MOVES it is estimated that energy consumption from starting the vehicle only represents about 0.2 to 7 percent of the energy it takes to run the vehicle depending on the speed, time of day, and month of year.

Table B.3 compares the highway vehicle energy and GHG emission rates from the three sources for Project 5. The large variations in rates between the highway vehicle methods (as much as 40 percent) show that the method chosen could determine whether or not a transit project shows an overall energy/GHG savings or gain, especially if the transit emissions are close to the emissions savings from lower highway vehicle VMT. If this metric is advanced for consideration, consideration will need to be given to specifying the most appropriate highway vehicle method.

---

[6] AEO 2011 Early Release Reference Case. Table 7. Transportation Sector Key Indicators. Light Duty Stock Energy Efficiency (mpg) Combined car and light truck "on-the-road" estimate for 2008-2035.

[7] Energy Information Administration. Fuel Emission Factors Worksheet. (From Appendix H of the instructions to Form EIA-1605). http://www.eia.doe.gov/oiaf/1605/emission_factors.html Calculated from Table 2. Carbon Dioxide Emission Factors for Transportation Fuels.

Table B.3 Highway Vehicle Energy and GHG Emission Rates
Project 5

	Energy Intensity (BTU per mile)	GHG Rate (Kilograms CO_2e per Mile)	Equivalent MPG
Method 1 – Project Sponsor Value	6,233	0.54	17.42
Method 2 – AEO	4,638	0.40	23.42
Method 3 – MOVES + TDM	3,805	0.33	28.54

Change in Annual Vehicle-Miles

For transit vehicles, transit operating data was provided by the project sponsor.

For highway vehicles, two methods were evaluated:

- The first was to use VMT data from the travel demand model for the base and build alternatives, as provided by project sponsor.
- The second was an alternative approach using a “mode shift factor” instead of travel demand model output. In this method, the change in transit passenger-miles by mode was multiplied by an estimate of the prior single-occupancy vehicle mode share of passengers on the transit project. Project sponsors were asked subsequent to the original data request whether they could provide an estimate of the prior mode of transit riders. In general this would have required some work analyzing travel demand model data, so instead a value of 50 percent was used, which was an average or typical value identified in a recent report for the Florida DOT.[8] Given the substantial uncertainties in applying a generic factor to a particular project, the research team determined that the travel model-based results probably provided a more reliable estimate of VMT changes. Since all project sponsors were able to easily provide these estimates, the research team chose not to further pursue or test this alternative approach.

[8] Tindale-Oliver Associates. *Conserve by Transit: Analysis of the Energy Consumption, Climate Change, and Health Benefits of Transit*, prepared for Florida Department of Transportation, Central Transit Office. The “mode shift factor” is interpreted as the fraction of riders who would have a) driven alone, b) taken taxi, or c) carpooled (divided by average carpool occupancy).

Fuel-Cycle Energy Factor

The fuel-cycle energy factor accounts for the additional energy consumption resulting from extracting, producing, and transporting the fuel to the point of use. The factor is defined as the ratio of "well-to-wheel" to "pump-to-wheel" energy use (BTU per mile). Well-to-wheel includes five stages – feedstock recovery, feedstock transportation, fuel production, fuel distribution, and fuel utilization (on-vehicle). Pump-to-wheel includes the fifth stage only. This is illustrated in Figure B.3. The factor is calculated using U.S. DOE's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model. GREET is only set up for light-duty vehicles, but life-cycle factors are assumed to be the same for heavy-duty vehicles (transit) using the same fuel. Table B.4 shows the fuel-cycle energy factors by fuel type used in this study, as well as GHG factors (discussed later) which represent the same issue. While these factors reflect typical current conditions for fuel production and distribution in the U.S., actual upstream emissions may vary temporally and geographically depending upon the specific fuel production method and transport requirements. A complete analysis would examine differences in upstream emissions by region of the country. Fuel-cycle factors should also be revisited over time in case energy sources and production methods shift (e.g., greater reliance on tar sands for oil extraction).

Figure B.3 Five Stages of the Fuel Cycle

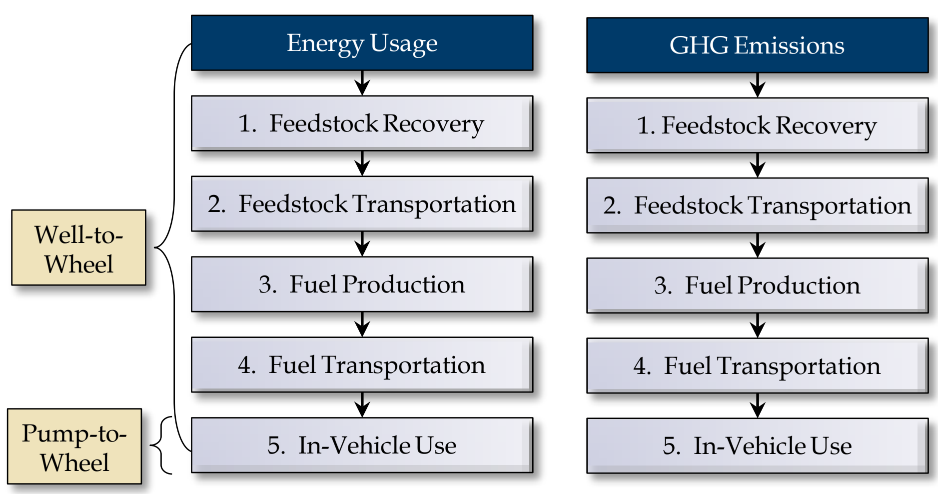


Table B.4 Default Fuel-Cycle Factors
Ratio of "Well-to-Wheel" to "Pump-to-Wheel" Energy or GHG Emissions

Fuel Type	Fuel-Cycle Energy	Fuel-Cycle GHG
Gasoline	1.24	1.25
Gasoline with 10% Corn Ethanol	1.27	1.23
Diesel Fuel	1.19	1.25
CNG	1.15	1.28
Electric	2.43	1.03[a]

Source: Cambridge Systematics, Inc. analysis using GREET Model Version 1.8d.

[a] This value is the ratio of all steps including feedstock recovery (1-5) to fuel production and transport (steps 3-4) since GHG emissions from the vehicle itself (step 5) are zero.

ID(ii) – Project Cost per Reduction in Operating Energy Consumption

This metric is represents the cost-effectiveness of reducing energy consumption. It is calculated as:

Cost/BTU = annualized project cost/change in total operating energy (ID(i)

The annualized project cost is calculated as:

(Total annualized project capital cost) + (change in annual operating cost for project versus no-project alternatives)

where:

- Total annualized project capital cost (in 2007 dollars for one project and 2010 for the other projects), is taken from the Standard Cost Calculation worksheets submitted to FTA, "Subtotal – 10-90" line on the "Annualized Cost – Build Alternative" worksheet, for four projects where the SCC was available. For projects that had not completed SCC worksheets, the project capital cost was annualized assuming the same ratio of annualized to total cost as the other four projects (6.7 percent, with a range of 6.0 to 7.0 percent).

- Change in annual operating cost was reported by the project sponsor.

IB – Operating Energy Consumption per Passenger-Mile

This metric was calculated as:

Total project operating energy =
*Energy consumption (BTU per vehicle-mile) * Annual vehicle-miles for new project*

Operating energy consumption per passenger-mile =
Total project operating energy/Passenger-miles on new project

IC(i) – Change in Operating GHG Emissions

This metric was calculated as the change in total annual GHG emissions from the operation of transportation vehicles, including the proposed transit project, other transit routes that changed as part of the transit project operating plan, and highway VMT. The equation is:

Change in operating GHG emissions =
*Σ [Energy consumption (BTU/vehicle-mile) * Change in annual vehicle-miles **
GHG intensity factor (GHG/BTU)] by vehicle type (all modes with changes)

Energy consumption rates and change in annual vehicle-miles are computed as described for calculation ID(i), change in total energy use.

The GHG intensity factor (GHG/BTU) was calculated for highway vehicles and internal combustion engine transit vehicles as follows:

GHG/BTU = CO_2 *intensity of fuel * GHG scale factor * Fuel-cycle GHG factor*

where:

- CO_2 intensity of fuel = kilograms CO_2/million BTU, by fuel type (Table B.5).

- GHG scale factor is the ratio of CO_2e/CO_2 (including the global warming potential of N_2O, CH_4, and refrigerant emissions) (Table B.6).

- Fuel-cycle GHG factor is the ratio of “well-to-wheel” to “pump-to-wheel” GHG emissions (grams per mile), where well-to-wheel includes feedstock recovery, feedstock transportation, fuel production, fuel distribution, and fuel utilization (on-vehicle). It is calculated using U.S. DOE’s GREET model. GREET is only set up for light-duty vehicles, but life-cycle factors are assumed to be the same for heavy-duty vehicles using the same fuel. Table B.3 shows the GHG fuel-cycle factors used by fuel type. While these factors reflect typical current conditions for fuel production and distribution in the U.S., actual upstream emissions may vary temporally and geographically depending upon the specific fuel production method and transport requirements. A complete analysis would examine differences in upstream emissions by region of the country. Fuel-cycle factors should also be revisited over time in case energy sources and production methods shift (e.g., greater reliance on tar sands for oil extraction).

Table B.5 Fuel Energy and Carbon Content

Fuel Type	CO_2 Emission Factor (Kilograms per Gallon)	Energy Content BTU per gallon	Kilograms CO_2 per Million BTU
Gasoline	8.86	125,024	70.87
Gasoline with 10% Ethanol[a]	7.98	120,979	65.96
Diesel Fuel[b]	10.15	138,689	73.19
Biodiesel (B20)	8.11	136,497	59.42
Compressed Natural Gas (CNG)	6.89[c]	121,500[d]	53.06
Electricity	N/A	N/A	166.03[e]

Source: Energy Information Administration. *Fuel Emission Factors*. Downloaded from http://.eia.doe.gov///_factors.html, April 14, 2011.

[a] A 10 percent ethanol blend is assumed for future year (2030/2035) analysis in this report. The current nationwide average ethanol content of gasoline is already over 7 percent (see California Air Resources Board, *Frequently Asked Questions about the California Reformulated Gasoline Program*, http://www.arb.ca.gov/fuels/gasoline/faq.htm) and Federal renewable fuels requirements will increase this to at least 10 percent – the current limit for use in general transportation fuels – in the future.

[b] Since biodiesel is not yet in widespread use among transit agencies, diesel fuel is used as the default assumption in this analysis. A sensitivity test may be conducted that assumes the use of biodiesel at a 20 percent blend in future years.

[c] Carbon emissions per gallon of gasoline equivalent for CNG, from GREET model.

[d] BTU per gallon diesel equivalent.

[e] National average for 2030. National average for 2035 is 165.11 kilograms CO_2 per million BTU. Also developed and tested alternative method to use regional averages.

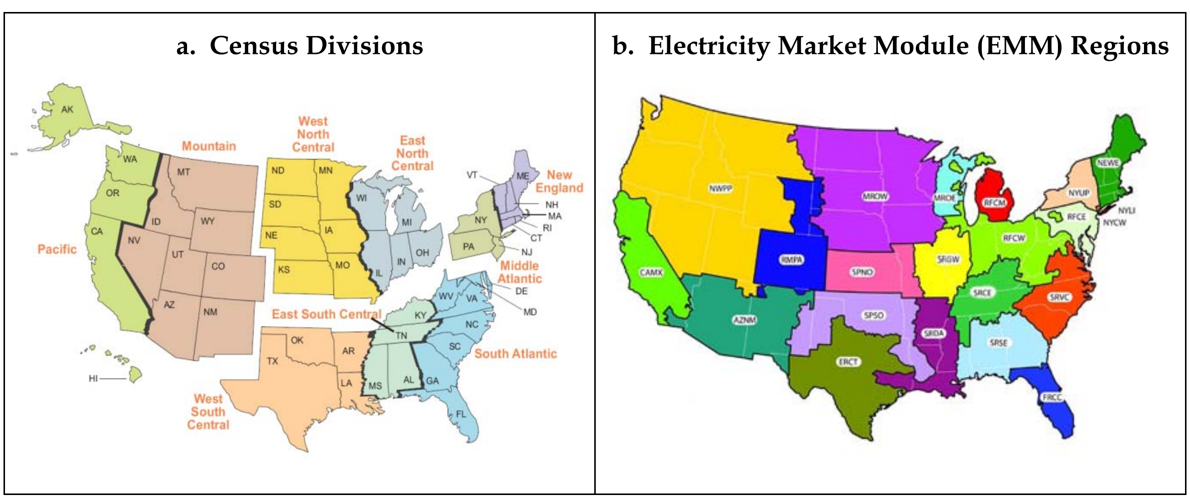
Table B.6 Default GHG Scale Factors
Ratio of CO_2e to CO_2

Vehicle Type	Scale Factor
Passenger Cars	1.058
Diesel-Powered Transit Vehicles	1.026
Electric-Powered Transit Vehicles	1.005

Source: Cambridge Systematics, Inc. analysis based U.S. DOE Annual Energy Outlook data.

The GHG intensity factor for electrically powered transit vehicles was taken from the AEO 2011 Reference Case. This provided forecasts of CO_2 emissions from electricity production by region and electric sales (billion kilowatt-hours) by region for years 2008 to 2035. A simple analysis used these two variables to calculate the GHG intensity of electricity (in kilograms CO_2 per million BTU) for each region and year. The analysis was conducted for two sets of regions that were available from AEO: one that uses the 9 U.S. Census divisions shown in Figure B.4a, and another that uses the 22 electricity market module (EMM) regions shown in Figure B.4b. This analysis produced the results shown in Figure B.5a for the Census Divisions and Figure B.5b for the EMM regions. For the pilot project calculations, the set of 22 EMM regions was chosen over the Census divisions since these regions were specifically constructed to model electricity markets for different power plants that have different CO_2 emissions characteristics. Pilot project calculations also used the national average intensities in some scenarios. A policy decision would have to be made about whether to use national or regional intensities in the calculation of this metric.

Figure B.4 Regions Used for Electricity GHG Intensity



Source: U.S. Energy Information Administration.

Figure B.5a Electricity GHG Intensities by Census Division

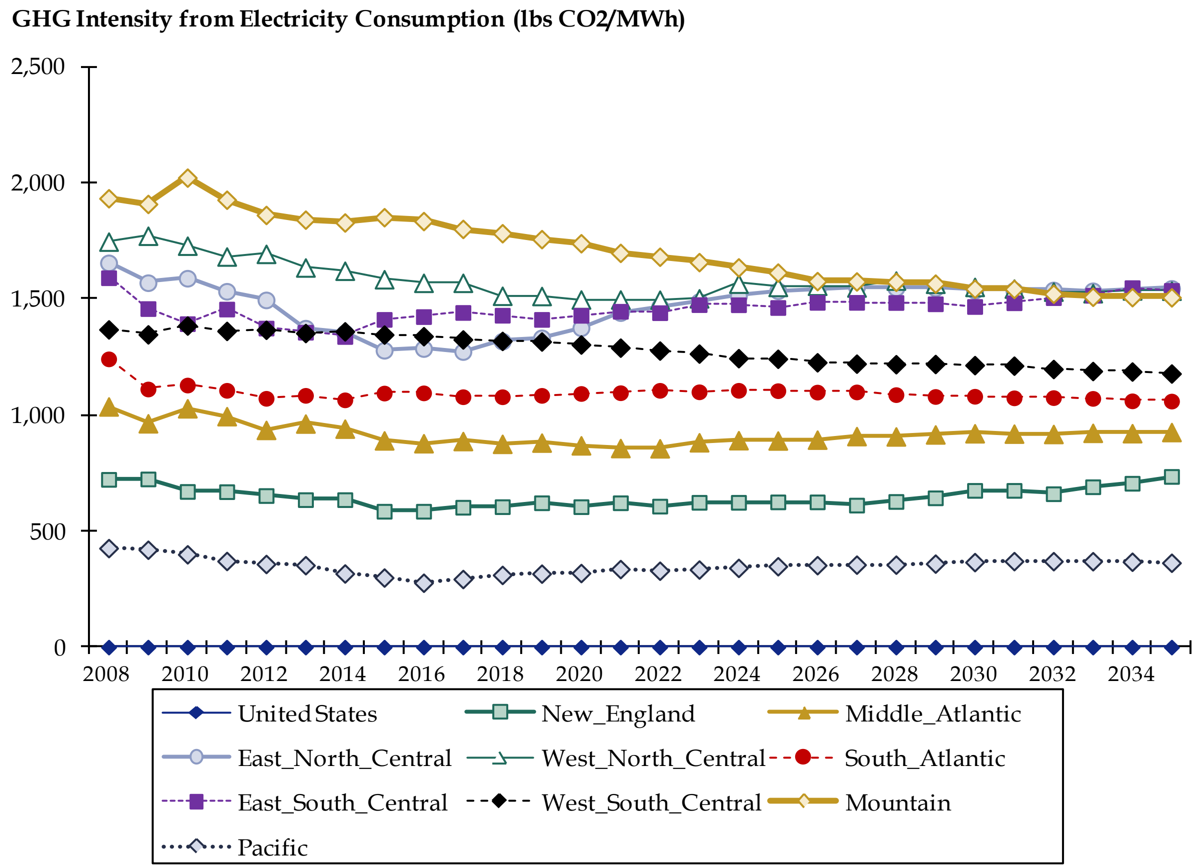
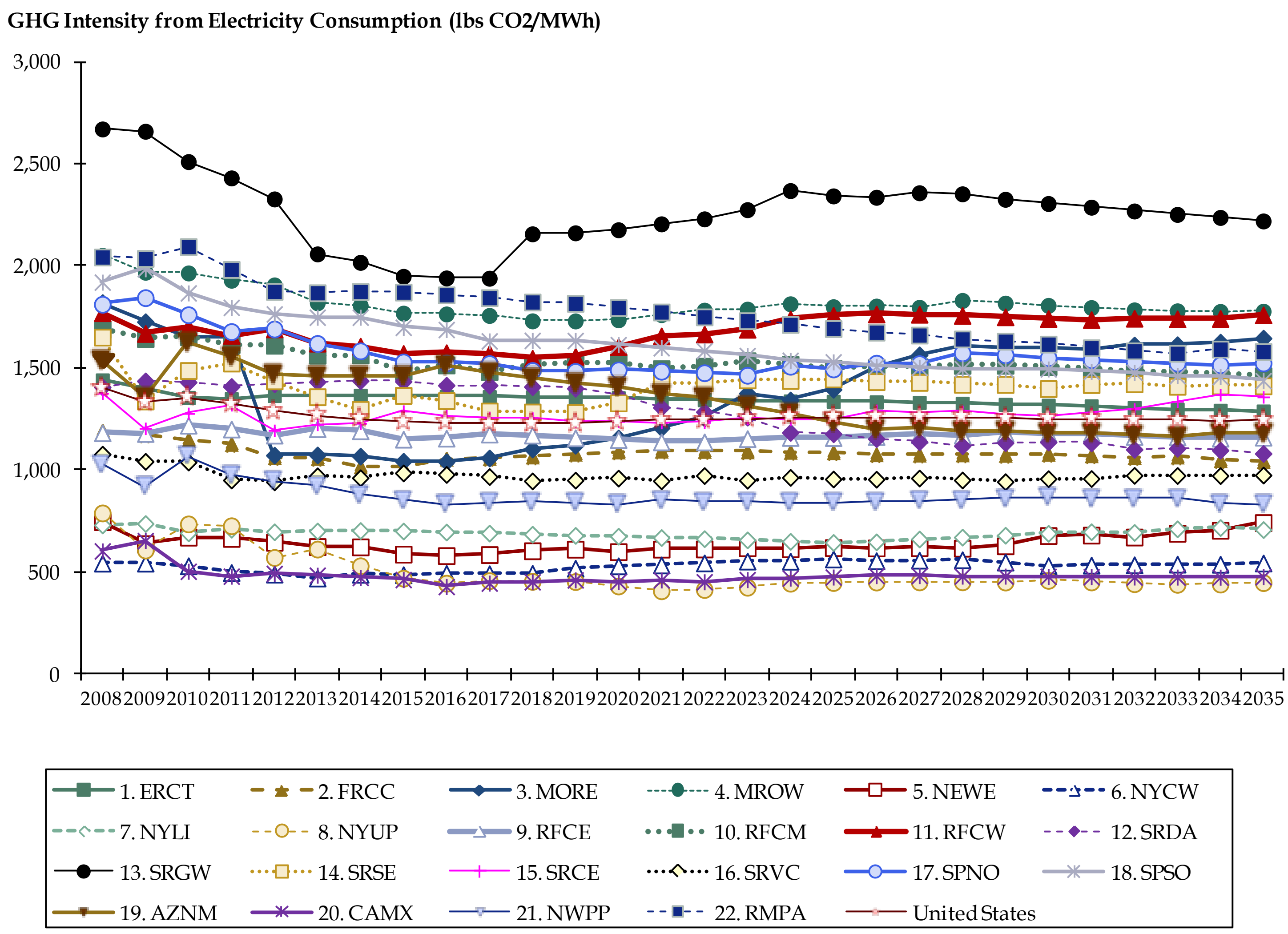


Figure B.5b Electricity GHG Intensities by EMM Region



IC(ii) – Project Cost per Reduction in Operating GHG Emissions

This metric was calculated as the annualized project cost divided by the change in total operating GHG emissions (metric IC(i)). Calculation of the annualized project cost is described under metric ID(ii) above.

IA – Operating GHG Emissions per Passenger-Mile

This metric was calculated as:

Total operating GHG emissions from new project =
*Energy consumption (BTU/vehicle-mile) * Annual vehicle-miles for new project **
GHG/BTU factor (see metric IC(i)) for the new project mode and fuel type

GHG emissions per passenger-mile **=**
Total project operating GHG/Passenger-miles on new project

IE(ii) – Construction Energy per Dollar or Passenger Mile

The goal of this metric was to provide a cost-effectiveness calculation that included construction as well as operating energy use. This metric could not be calculated for individual pilot projects because of lack of data to estimate construction energy expenditures. However, some order-of-magnitude calculations of construction GHG emissions were performed, as discussed further under IE(i).

IE(i) – Construction GHG Emissions

The goal of this metric was to include a measure of life-cycle project impact that included construction as well as operating GHG emissions. This metric could not be calculated for individual pilot projects because of lack of complete data to estimate construction GHG emissions. However, some order-of-magnitude calculations of construction GHG emissions were performed, including an estimate for one pilot project.

The project team performed research to develop a model of GHG emissions embodied in materials used in transit projects, based on general estimates of materials use. This model allows for calculation of embodied GHG based on parameters generally available in transit project planning, such as new track-miles, miles of overhead catenary, number and type of stations, etc. Data were not available to permit the estimation of construction equipment activity or other GHG-producing emissions, and therefore a complete estimate of construction GHG emissions could not be developed. The data and procedures for developing the construction GHG model, as well as the example application to one pilot project and sensitivity analysis on typical data, are described in more detail in Appendix G.

B.2 Sensitivity Testing of Energy and GHG Metrics

Table B.7 shows the complete results of the energy and GHG scenarios evaluated for the pilot projects. Key assumptions are shown first, followed by the calculated metric values. The evaluation year was consistent with project data provided by the project sponsor. The other factors that vary in this table include the use of national default (average) versus project sponsor-provided energy consumption rates, how highway vehicle emissions are calculated, and whether national or regional electricity CO_2 intensity factors are used. Project 6 was a diesel project (BRT) so this issue was not applicable.

For Project 5, the use of MOVES energy and emission rates provided estimates that were about 20 percent lower than using AEO average fuel economy values. For Project 6, use of project sponsor estimates provided values that were in close agreement with AEO rates (about 6 percent higher). For the same project, the project sponsor provided estimates of energy and GHG emissions for transit that were nearly 50 percent lower than the default rates used by the study team. The project sponsor made more aggressive assumptions about future transit vehicle energy efficiency, including the use of hybrid electric buses. The sponsor of Project 5 also provided project-specific energy consumption values for both highway and transit vehicles, but these were general values taken from a literature source and were not felt to represent either current or project-specific information in any way, so they were not included in the sensitivity testing.

A significant effect was also seen from the use of regional versus national electricity GHG intensity rates. The magnitude of the effect varied depending upon the regional generation mix, and in particular whether it was more or less GHG intensive than the national average.

Table B.8 shows how changes in assumptions about future vehicle energy efficiency or GHG intensity affect the relative outcomes. Table B.8 shows total GHG emissions by mode assuming a) default intensities, b) a 25 percent decrease in transit vehicle GHG intensity, c) a 25 percent decrease in highway vehicle GHG intensity, and d) a 25 percent decrease in GHG intensity for all modes. It can be seen in (b) that decreasing transit GHG intensity by 25 percent causes one of the 11 project scenarios (Project 5, scenario 3N) to switch from an overall increase in GHGs to an overall decrease due to less transit GHG from the same amount of transit service. It can be seen in (c) that decreasing highway vehicle GHG intensity causes one of the 11 project scenarios (project 5, scenario 1N) to switch from an overall decrease in GHGs to an overall increase due to less benefit from removing the same amount of highway vehicles. It can be seen in (d) that decreasing both transit and highway vehicle GHG intensity by 25 percent has somewhat of a canceling out effect since none of the project scenarios switches its overall effect; however, the GHG savings becomes larger or the GHG increase becomes smaller in all cases. These results illustrate the importance of choosing consistent data sources and calculation methods for all projects since allowing inputs to vary on the scale of 25 percent can predict different outcomes for the same project. Some of the alternative methods and data sources discussed earlier in this appendix vary more than 25 percent. Therefore it is important for agencies employing energy and GHG metrics to use consistent data sources and methods.

Table B.7 Sensitivity Testing of Energy and GHG Metrics

Metric or Assumption		Project 2 – Commuter Rail			Project 3 – Electric Multi. Unit[a]		Project 5 – Light Rail Transit				Project 6 – Bus Rapid Transit	
		Diesel	Electric									
		Scenario 1	Scenario 1N	Scenario 1R	Scenario 1N	Scenario 1R	Scenario 1N	Scenario 3N	Scenario 1R	Scenario 3R	Scenario 1	Scenario 3
Assumptions												
	Evaluation Year	2030	2030	2030	2030	2030	2030	2030	2030	2030	2035	2035
	Use National Default Transit Energy Consumption Rates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	Highway Vehicle Energy Consumption Method (1 = Project Sponsor, 2 = AEO, 3 = MOVES)	2	2	2	2	2	2	3	2	3	2	1
	Electricity CO_2 Intensity Method (R = Regional Factors; N = National Factor)	N/A	N	R	N	R	N	N	R	R	N/A	N/A
Metrics												
IA	Operating GHG Emissions (Kilograms CO_2e) per Passenger-Mile	0.252	0.125	0.068	0.099	0.128	0.126	0.126	0.182	0.182	0.083	0.042
IB	Operating Energy Consumption (BTU) per Passenger-Mile	3,189	1,767	1,767	1,393	1,393	1,775	1,775	1,775	1,775	1,048	535
IC(i)	Change in Operating GHG Emissions (Metric Tons CO_2e)	(7,885)	(26,275)	(32,671)	9,015	14,684	(89)	1,025	3,501	4,615	(3,793)	(4,632)
	Transit	23,249	14,010	7,613	21,188	26,856	5,553	5,553	9,144	9,144	1,087	555
	Highway	(31,134)	(40,284)	(40,284)	(12,172)	(12,172)	(5,643)	(4,529)	(5,643)	(4,529)	(4,880)	(5,187)
IC(ii)	Project Cost per Change in Operating GHG Emissions (Dollars per Metric Ton GHG)	(16,115)	(5,889)	(4,736)	11,075	6,799	(949,237)	82,782	24,227	18,379	(4,640)	(3,800)
ID(i)	Change in Operating Energy Consumption (Million BTUs)	(165,907)	(397,953)	(397,953)	116,613	116,613	(1,341)	15,142	(1,341)	15,142	(58,422)	(69,705)
	Transit	294,739	198,078	198,078	296,708	296,708	82,145	82,145	82,145	82,145	13,786	7,041
	Highway	(460,646)	(596,031)	(596,031)	(180,095)	(180,095)	(83,486)	(67,003)	(83,486)	(67,003)	(72,208)	(76,746)
ID(ii)	Project Cost per Change in Operating Energy Consumption (Dollars per Million BTU)	(766)	(389)	(389)	856	856	(63,248)	5,602	(63,248)	5,602	(301)	(252)

Table B.8 Sensitivity of Change in Operating GHG Emissions to Modal GHG Intensity Assumptions

Change in Operating GHG Emissions (Tonnes CO_2e)

	Project 2 – Commuter Rail			Project 3 – Electric Multiple Unit		Project 5 – Light Rail Transit				Project 6 – Bus Rapid Transit	
	Diesel	Electric									
Metric or Assumption	**Scenario 1**	**Scenario 1N**	**Scenario 1R**	**Scenario 1N**	**Scenario 1R**	**Scenario 1N**	**Scenario 3N**	**Scenario 1R**	**Scenario 3R**	**Scenario 1**	**Scenario 3**
a) Default Intensities											
Total	**(7,885)**	**(26,275)**	**(32,671)**	**9,015**	**14,684**	**(89)**	**1,025**	**3,501**	**4,615**	**(3,793)**	**(4,632)**
Transit	23,249	14,010	7,613	21,188	26,856	5,553	5,553	9,144	9,144	1,087	555
Highway	(31,134)	(40,284)	(40,284)	(12,172)	(12,172)	(5,643)	(4,529)	(5,643)	(4,529)	(4,880)	(5,187)
b) 25% Decrease in Transit Vehicle Intensity											
Total	**(13,697)**	**(29,777)**	**(34,575)**	**3,718**	**7,970**	**(1,478)**	**(364)**	**1,215**	**2,329**	**(4,065)**	**(4,771)**
Transit	17,437	10,507	5,710	15,891	20,142	4,165	4,165	6,858	6,858	816	417
Highway	(31,134)	(40,284)	(40,284)	(12,172)	(12,172)	(5,643)	(4,529)	(5,643)	(4,529)	(4,880)	(5,187)
c) 25% Decrease in Highway Vehicle Intensity											
Total	**(102)**	**(16,204)**	**(22,600)**	**12,058**	**17,727**	**1,321**	**2,157**	**4,912**	**5,747**	**(2,573)**	**(3,335)**
Transit	23,249	14,010	7,613	21,188	26,856	5,553	5,553	9,144	9,144	1,087	555
Highway	(23,351)	(30,213)	(30,213)	(9,129)	(9,129)	(4,232)	(3,396)	(4,232)	(3,396)	(3,660)	(3,890)
d) 25% Decrease in Transit and Highway Vehicle Intensity											
Total	**(5,914)**	**(19,706)**	**(24,504)**	**6,762**	**11,013**	**(67)**	**769**	**2,626**	**3,461**	**(2,845)**	**(3,474)**
Transit	17,437	10,507	5,710	15,891	20,142	4,165	4,165	6,858	6,858	816	417
Highway	(23,351)	(30,213)	(30,213)	(9,129)	(9,129)	(4,232)	(3,396)	(4,232)	(3,396)	(3,660)	(3,890)

[a] As a new technology, energy intensity data were not available for the Project 3, so intensity per vehicle-mile was assumed to be the average of light rail and electric commuter rail (see discussion under metric ID(i). This introduces an additional element of uncertainty not reflected in the results shown in Table B.8.

Appendix C – Calculation of Air Quality and Public Health Metrics

This appendix describes the data sources and methods used in this project to estimate metrics of the air quality and public health benefits of transit projects. The methods rely on existing data sources on emission rates for highway and transit vehicles, particularly the U.S. Environmental Protection Agency's MOVES emission factor model. Emissions data are combined with project-specific data (such as changes in highway and transit vehicle-miles, and local population density) for the pilot projects evaluated in this research, to create air quality and public health-related metrics of impact for each project. Project-specific forecasts of walk trip access are also evaluated as a public health indicator related to increased physical activity.

This appendix is provided in three sections:

- **Section C.1 –** An overview of the calculation of the emissions and air quality metrics (IIA, IIB, IIC, and IID);
- **Section C.2 –** A detailed description of the procedures for calculating the emissions and air quality metrics; and
- **Section C.3 –** A discussion of the physical activity/health indicator of nonmotorized trips (metric IIE).

C.1 Overview of Calculation of Emissions and Air Quality Metrics

IIA(i): Change in Direct Operating Emissions

This metric describes the change in criteria pollutant and air toxics emissions as a result of the transit project, including reductions in highway vehicle emissions and increases in on-road transit vehicle emissions. Emissions changes were calculated for oxides of nitrogen (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), coarse and fine particulate matter (PM_{10} and $PM_{2.5}$), and seven mobile source air toxics (MSAT). MSATs analyzed included benzene, naphthalene, 1,3 butadiene, formaldehyde, acetaldehyde, acrolein, and diesel particulate matter.

The change in emissions is expressed in kilograms per year for each pollutant, as well as percent of regional and corridor emissions. One project (Project 2) provided this metric for a limited number of pollutants. For three other projects, emissions of each pollutant were calculated by summing the change in highway vehicle emissions and the change in transit vehicle emissions based on highway vehicle travel demand model data and transit VMT provided by the project sponsor, combined with emission factors calculated by the project team. Calculations were performed for year 2030 or 2035 depending on the year of pilot project data.

Change in Highway Vehicle Emissions

The basic steps were as follows. The calculation procedures are described in more detail in Section C.2.

- Speed-based emission factors from the U.S. Environmental Protection Agency's MOVES model were applied to link-level travel model output for both the no-project and project alternatives;
- Emissions with the project were subtracted from no-project emissions to get the change in daily emissions by link;
- Emissions for all links were summed and annualized based on an annualization factor of 341.98, which is based on MOVES national defaults for weekend versus weekday VMT; and
- The change in emissions was compared to no-project emissions to get the percent change in regional emissions.

The exposure and health benefit indices require emissions spatially disaggregated by traffic analysis zone (TAZ). If these indices were not calculated, this procedure can be simplified to eliminate calculations at the link level and just provide summaries of VMT by speed for the entire model area.

To calculate the change in emissions as a percent of transit corridor emissions, GIS was used to identify TAZs with centroids within two miles of the transit project alignment. No-project emissions were summed for these TAZs and the percent change computed relative to this baseline.

Changes in Transit Vehicle Emissions

Bus emission factors were calculated using EPA's MOVES model and multiplied by annual bus VMT changes as provided by the project sponsor. Although sources of emission factors for other modes were considered, emissions only needed to be calculated for buses. The diesel commuter rail project evaluated in this research had emissions reported by the project sponsor. If emissions were not reported by the project sponsor for diesel commuter rail vehicles, EPA Tier 4 emissions standards for locomotives could be used. As an alternative, EPA's NONROAD model could be run to get a complete set of emission factors.

Air pollution from electric rail was initially not calculated in this study, due to lack of ready, locality-specific data on pollution from electricity generation sources that could be related to power drawn by the transit vehicle; as well as the fact that emissions are likely to be generated in areas of lower population density and, therefore, lower health risk compared to direct emissions from vehicles. However, to test a variation on the air quality metric of project emissions expressed in grams per passenger-mile, national emission rates using current data and available forecasts of NO_x and PM_{10} emissions were used.

To estimate 2030 emissions, projections of total national electricity generation and total annual NO_x and PM_{10} emissions were taken from the a 2007 study of plug-in hybrid electric vehicles by the Electric Power Research Institute (EPRI).[1] These projections and the resulting average national emission rates are shown in Table C.1. VOC and CO emissions rates from electricity generation are very low and are not considered here.

Table C.1 Electricity Generation Emissions Projections

Pollutant	Annual Emissions, 2030 (Tons)	Electricity Generation (gwh)	Emission Rate (g/kwh)	Emission Rate (kg/MMBTU)
NO_x	2,035,075	5,875,149	0.3233	0.0948
PM_{10}	492,015		0.0782	0.0229

Source: EPRI (2007).

For illustrative purposes, emissions per passenger-mile were calculated for Project 2 (electric commuter rail) and Project 5 (light rail) and compared to highway vehicles based on single occupancy, as shown in Table C.2. Transit NO_x emissions are about one-third of the highway value for Project 2 and one-half for Project 5, while transit PM_{10} emissions are about one-quarter of the highway value for Project 2 and nearly the same for Project 5. If compared with occupancy of about 1.6 persons per vehicle, NO_x and PM_{10} would still be lower for transit per passenger-mile, except for PM_{10} for Project 5. For this particular example, emissions per passenger-mile also are nearly identical for Projects 2 and 5, although this will not always be the case.

[1] Electric Power Research Institute (2007). E*nvironmental Assessment of Plug-In Hybrid Electric Vehicles. Volume 2: United States Air Quality Analysis.* Report no. 1015326.

Table C.2 Electric Rail Emissions per Passenger-Mile

	Project 2		Project 5	
Source	NO_x	PM_{10}	NO_x	PM_{10}
Transit electricity emissions	0.0692	0.0167	0.0689	0.0167
Emissions from private highway vehicles (single-occupancy)	0.2114	0.0675	0.1379	0.0187

Source: Transit emissions based on EPRI (2007) per Table C.1 and passenger-mile data provided by project sponsors. Highway vehicle emissions based on VMT data from project sponsors and MOVES emission rates.

IIA(ii): Cost per Ton of Emissions of Emissions Reduced

The cost-effectiveness (cost per ton) of emission reductions was computed for each pollutant considering both capital and operating costs, as follows:

$$\text{Cost/ton} = \frac{(\textit{Annualized Capital Cost} + \textit{Change in Annual Operating Costs})}{\textit{Change in Emissions}}$$

Where:

- Total annualized project capital cost (in 2007 dollars for one project and 2010 for the other projects), is taken from the Standard Cost Calculation worksheets submitted to FTA, “Subtotal – 10-90” line on the “Annualized Cost – Build Alternative” worksheet, for four projects where the SCC was available. For projects that had not completed SCC worksheets, the project capital cost was annualized assuming the same ratio of annualized to total cost as the other four projects (6.7 percent, with a range of 6.0 to 7.0 percent).

- Change in annual operating cost is reported by the project sponsor.

Cost-effectiveness was not calculated for projects with increases in emissions.

IID. Air Quality Index

The Air Quality Index (AQI) is defined by the U.S. EPA as a function of the measured concentration of a pollutant and various health-based benchmark parameters. The AQI is designed around a scale on which a value of 100 reflects an air pollutant concentration that is of a similar value to a health-based benchmark, typically a National Ambient Air Quality Standard (NAAQS). Values greater than 100 indicate increasingly poor air quality with greater health risk. An AQI is computed on a daily basis for each metropolitan area for each of six pollutants, and an overall daily AQI value taken as the highest of the individual pollutant values. This measure can be easily obtained at a metropolitan area level from EPA reporting with a small amount of simple statistical analysis (which can be done in a spreadsheet) to report items such as median, maximum, and any percentile AQI over a selected time period. For this research, values of median, maximum, and percent of days with unhealthy air quality for sensitive populations was reported based on data from a three-year period, 2006-2008.

The AQI is driven by ozone and $PM_{2.5}$ in most areas. Section C.2 provides more detail on the data for the AQI.

IIB. Exposure Index

The Exposure Index (EI) is calculated for each pollutant at a TAZ level as well as the region as a whole. It is a proxy for the change in population exposure to air pollutant emissions. The TAZ-level index is calculated as the change in emissions times the population of the TAZ divided by the area of the TAZ. For a given unit of emissions per unit area, the EI will be proportional to the number of people exposed to those emissions. The regional EI is simply calculated as the sum of the TAZ-level EIs.

The changes in emissions by TAZ were calculated as described in Section C.2. The changes in highway emissions and transit emissions were summed by TAZ. The following equation for exposure index was the applied for each individual TAZ and pollutant:

$$EI_{TAZ_n} = \frac{\Delta E}{A} P$$

Where:

- EI_{TAZ_n} is the exposure index for each TAZ;
- ΔE is the estimated *change* in pollutant emissions for each TAZ;
- A is the area of the TAZ; and
- P is the number of permanent residents in the TAZ.

The exposure index was then summed for all TAZs in the region to get one exposure index per pollutant, as shown in the following equation:

$$EI_{region} = \sum_{n=1}^{N} EI_{TAZ_n}$$

Where:

- EI is the exposure index for the region;
- EI_{TAZ_n} is the exposure index for an individual TAZ; and
- N is the number of TAZs in the region.

Emission reductions are represented by a negative ΔE and increases are represented by a positive ΔE. Therefore, the project with the most pollutant exposure reduction will be the one with the lowest or most negative regional exposure index. Separate regional exposure indices must be calculated for each pollutant since no toxicity weightings are included. However, toxicity weightings could be added, as was done in the health benefit index, to calculate a single regional exposure index for all pollutants.

IIC. Health Benefit Index

The Health Benefit Index (HBI) is based on the EI but expands upon it to include basic meteorological factors and to create a "roll-up" across multiple pollutants. The meteorological factors – average wind speed and mixing height for a metropolitan area – provide further information on the extent to which a given unit of emissions will be concentrated in a TAZ. (Faster wind speed or greater mixing height means the pollutant will disperse faster or more broadly, reducing exposure.) The roll-up is based on the relative toxicity of different pollutants. Details on meteorological and toxicity data are provided in Section C.2. The inclusion of meteorological data is not critical to this index, and it could be simplified by omitting it. In essence the overall HBI would then simply be the EI of all pollutants combined and weighted by toxicity.

The following equation was used to compute the health benefit index for each individual TAZ and each pollutant, except for ozone precursors NO_x and VOC, which were used to create a separate ozone index (see Section C.2):

$$HBI_{pollutant_m,TAZ_n} = \frac{\Delta E}{UAM_H}P = \frac{EI}{UM_H}$$

Where:

- $HBI_{pollutant_m,TAZ_n}$ is the health benefit index for each pollutant in each TAZ;
- ΔE is the estimated *change* in pollutant emissions for each TAZ;
- A is the area of the TAZ;
- P is the number of permanent residents in the TAZ;
- U is the average wind speed;
- M_H is the mixing height; and
- EI is the exposure index for each TAZ.

The health benefit index was computed for three groups of pollutants: non-ozone criteria pollutants (CO, $PM_{2.5}$, and PM_{10}), noncancer air toxics, and cancer air toxics. These three groups must remain separate because they have different sets of toxicity weightings that cannot be combined. HBIs also were summed across TAZs to get a regional HBI for each pollutant group. These two steps are done through the following equation:

$$HBI_{region,pollutantgroup} = \sum_{n=1}^{N} \sum_{m=1}^{M} \left(HBI_{pollutant_m,TAZ_n} * TW_m \right)$$

Where:

- $HBI_{region,pollutantgroup}$ is the health benefit index for a group of pollutants in the region;
- $HBI_{pollutant_m,TAZ_n}$ is the health benefit index for each pollutant in each TAZ;
- TW_m is the toxicity weighting for each pollutant;
- M is the number of pollutants in each pollutant group (three for criteria pollutants, five for noncancer air toxics, and five for cancer air-toxics); and
- N is the number of TAZs in the region.

Since $PM_{2.5}$ was calculated for both short-term (24-hour) and long-term (annual) levels, the maximum of the HBI*TW for these two time periods was used to represent $PM_{2.5}$ in the overall HBI.

The end result is three health benefit indices for each region: one for criteria pollutants, one for noncancer air toxics, and one for cancer air toxics. These can be compared across regions. Similar to the regional exposure index, the project with the greatest health benefit is the one with the lowest or most negative regional health benefit index.

C.2 Detailed Description of Procedures for Calculating Emissions and Air Quality Metrics

This section provides more detail on the following topics:

- The Air Quality Index data and metrics;
- Calculation of emission factors using MOVES and post-processing steps;
- Calculation of changes in emissions by network link;
- Assignment of link-level emissions to traffic analysis zones (TAZ);
- Meteorological data for wind speed and mixing height;
- Toxicity weightings for different pollutants; and
- A proposed Ozone Index.

Air Quality Index

An analysis of Air Quality Index (AQI) data from 2006-2008 for 306 MSAs was completed to identify statistical variables that could be used to describe the current state of air quality in areas with proposed transit projects. The following five indicators were investigated:

1. The median AQI value;
2. The maximum AQI value;
3. The 90^{th} percentile AQI value;
4. The percent of days the AQI was unhealthy for sensitive populations; and
5. The percent of days the AQI was unhealthy for all people.

Distributions of these indicators for all 306 MSAs were graphed to understand how much each indicator varies among MSAs. The graphs were marked to indicate the location of the MSAs containing selected New Starts projects. These graphs were used to determine if a particular indicator varied enough among projects to provide a meaningful indicator of current air quality. Figures C.1, C.2, and C.3 provide examples of these graphs and Table C.3 provides the values of three of the indicators for the cities of the pilot projects. Different AQI indicators are somewhat closely correlated, but not completely. For example, as shown in Table C.1, Minneapolis has a much lower maximum AQI and percent of unhealthy days despite having a similar median to the other cities. If an AQI indicator is used, "percent unhealthy days" or "percent unhealthy days for sensitive individuals" is recommended as a meaningful metric, probably more significant from a health effects standpoint than the median AQI.

Figure C.1 Median Air Quality Index for U.S. Metropolitan Statistical Areas

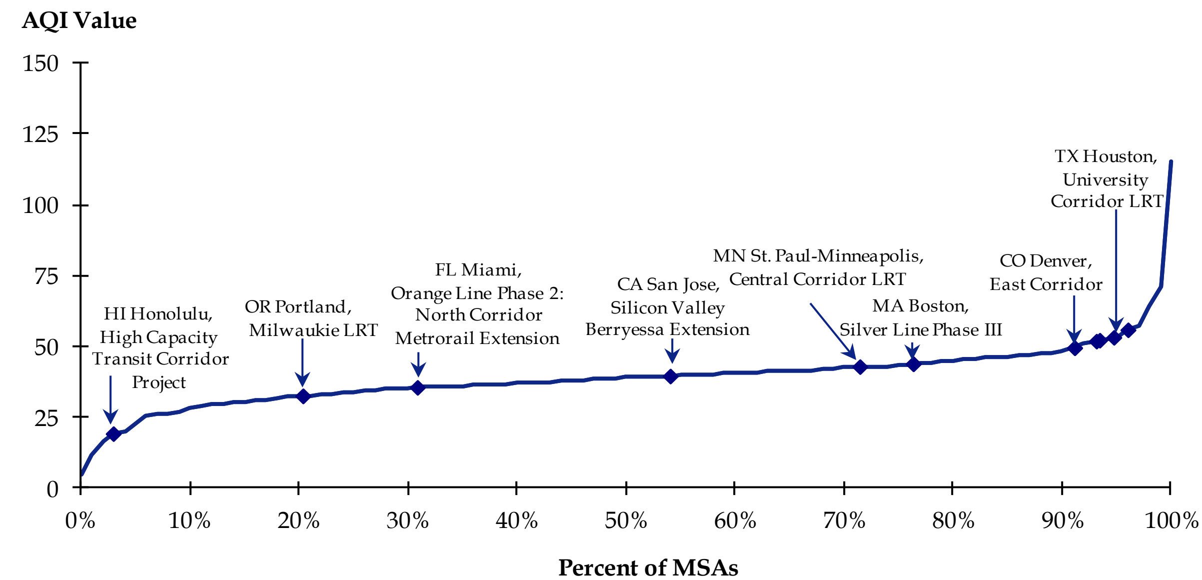


Figure C.2 90th Percentile Air Quality Index for U.S. Metropolitan Statistical Areas

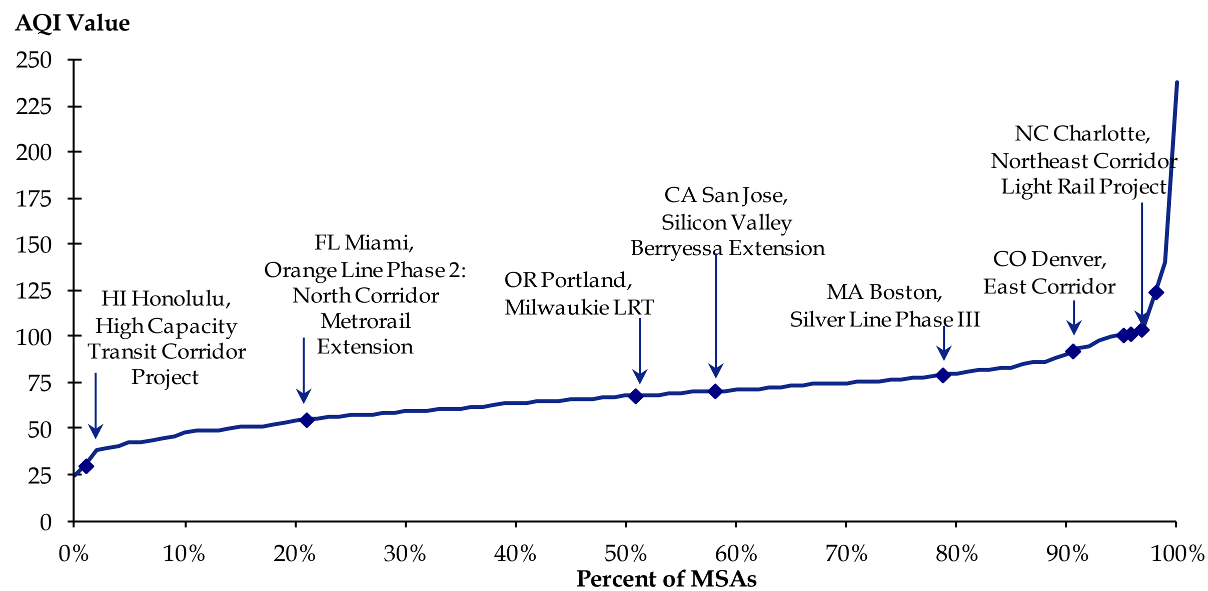


Figure C.3 Number of Days per Year Unhealthy for Sensitive Individuals in U.S. Metropolitan Statistical Areas

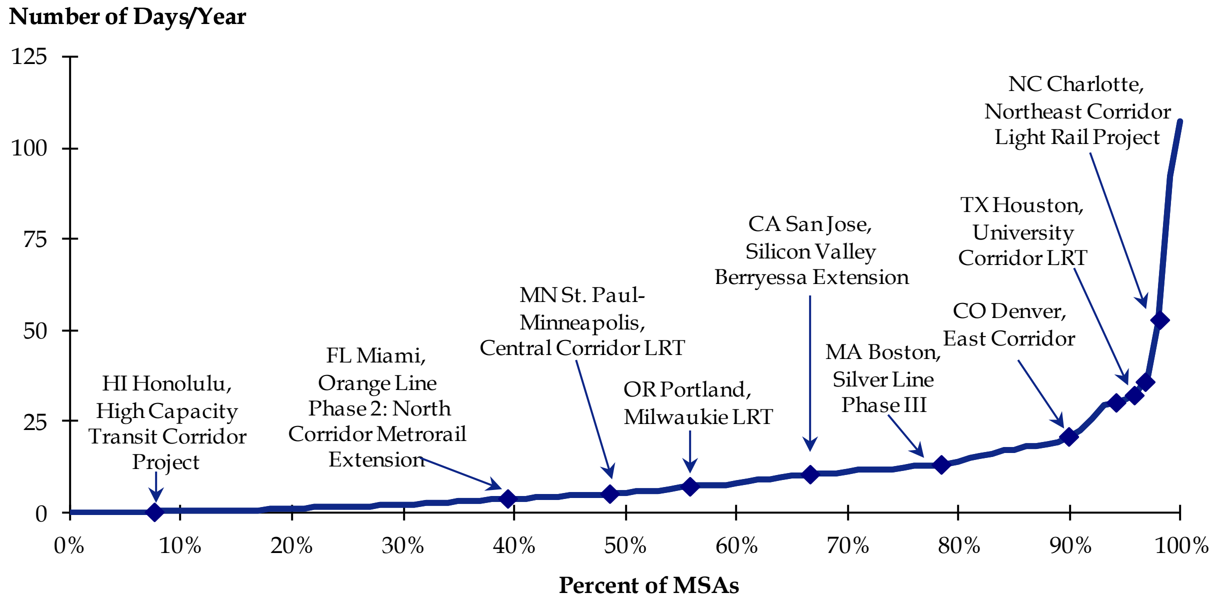


Table C.3 Daily AQI Indicators for Pilot Projects

Region	Median	Maximum	Percent Unhealthy Days for Sensitive Populations
Project 1	59	204	11.1%
Project 2	44	169	3.8%
Projects 3 and 4	50	171	5.9%
Project 5	43	138	1.5%
Project 6	39	187	3.8%
Range, FY 2011 New Starts MSAs[a]	33-56	129-206	0.5%-10.1%

[a] Excluding lowest and highest.

Calculation of Emission Factors Using MOVES and Post-Processing Steps

The U.S. EPA's MOVES emission factor model, version 2010a, was used to calculate emission factors by speed for light-duty vehicles (passenger cars and passenger trucks) and for transit buses.

MOVES Runs

A series of MOVES runs was designed to calculate emission factors for a number of criteria pollutants and MSATs. The criteria pollutant runs were designed around the averaging times of several national ambient air quality standards (NAAQS) associated with most of the current nonattainment and maintenance areas across the country that are affected by transportation sources. The five standards selected are the annual $PM_{2.5}$ standard, 24-hour $PM_{2.5}$ standard, 24-hour PM_{10} standard, 8-hour CO standard, and the 8-hour ozone standard.

In addition to the criteria pollutant standards, seven air toxics of "particular concern," which are modeled by MOVES, are included. Since there are no air quality standards for air toxics and since the health effects are believed to be long term in nature, an annual time period was assumed. The seven air toxics included were: benzene; naphthalene; 1,3 butadiene; formaldehyde; acetaldehyde; acrolein; and diesel exhaust (modeled using diesel particulate matter).

Seven MOVES runs were conducted to provide emission rates for these pollutants. This is the result of conducting one run for each of the five criteria pollutant standards, one run combining six of the air toxics, and another run for diesel particulate matter (the last air toxic), which must be run separately from the other toxics. Whenever possible, MOVES was run using a coarse level of time aggregation (year or month) to reduce run times and simplify the post-processing required. All runs were for the weekday only to be consistent with the VMT estimates from the travel demand models. The time spans selected for each run instruct MOVES to use default meteorological conditions stored within MOVES for that time of year for each county in the United States. The following bullets describe the time-based input assumptions for each of these seven runs.

- **Ozone –** Since the one-hour ozone standard has been revoked, all calculations are based on the eight-hour standard. In transportation conformity, the ozone standard is generally modeled using a typical summer day (July or average of June, July, and August), which is the worst-case meteorological conditions for ozone. However, since minimum average monthly mixing heights typically occur in late summer or fall, MOVES was run for an August weekday. Since the ozone run contains VOCs, which are calculated based on hourly changes in temperature, MOVES requires the time aggregation level to be set to hour.

- **Carbon Monoxide –** In transportation conformity, the CO standard is generally modeled using a typical winter day (January), which is the worst-case meteorological conditions for CO. MOVES was run for a January weekday. Since MOVES allows a coarse time aggregation level for CO, the time aggregation is set to month.

- **Twenty-Four-Hour PM_{10} Standard –** In transportation conformity, the 24-hour PM_{10} standard is generally modeled using a typical winter day (January), which in many areas (and in the MOVES model) is the worst-case meteorological condition for PM_{10}. MOVES was run for a January weekday. Since MOVES allows a coarse time aggregation level for PM_{10}, the time aggregation is set to month.

- **Twenty-four-hour $PM_{2.5}$ Standard –** The 24-hour $PM_{2.5}$ standard is generally modeled using a typical winter day (January), which in many areas is the worst-case meteorological conditions for $PM_{2.5}$. MOVES was run for a January weekday. Since MOVES allows a coarse time aggregation level for $PM_{2.5}$, the time aggregation is set to month.

- **Annual $PM_{2.5}$ Standard –** In transportation conformity, the annual $PM_{2.5}$ standard is generally modeled using an annual average day to represent long-term exposure to $PM_{2.5}$. MOVES was run for an average annual weekday. Since MOVES allows a coarse time aggregation level for $PM_{2.5}$, the time aggregation is set to year, which automatically includes all months of the year.

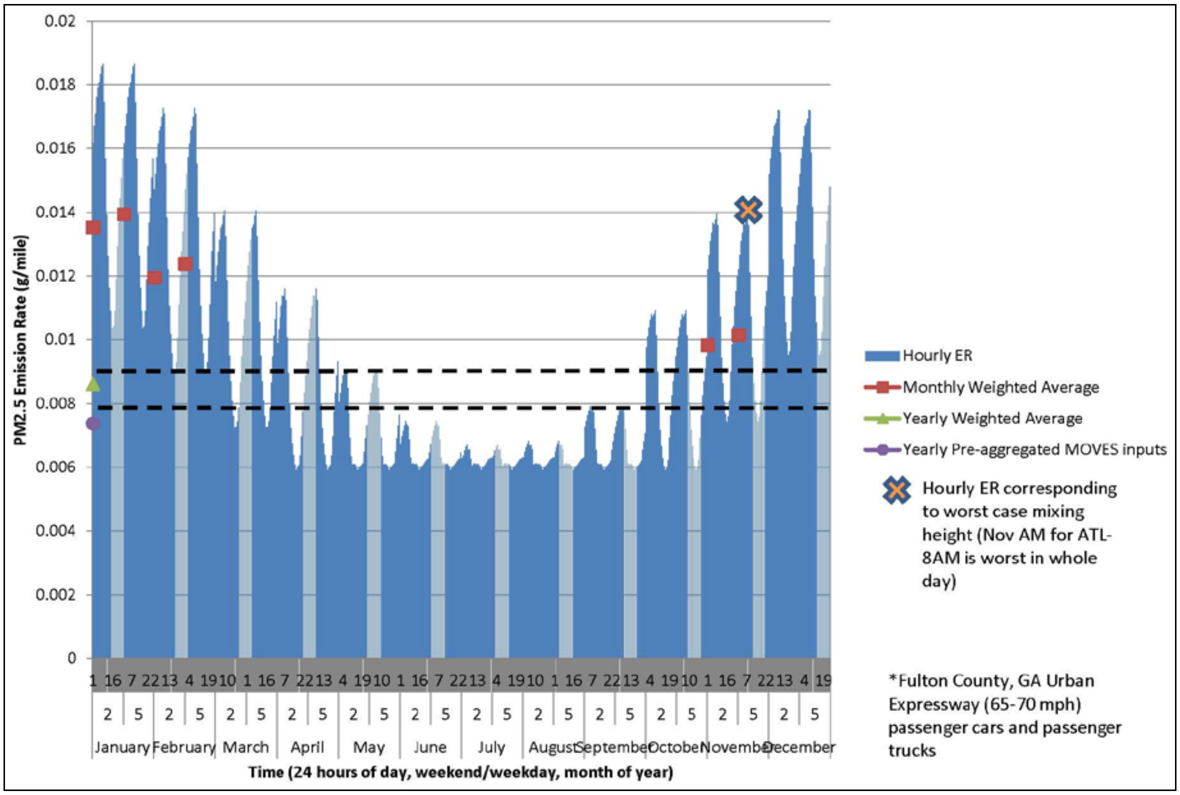
- **Toxics –** Since there are no air quality standards for air toxics and since the health effects are believed to be long term in nature, an annual time period was assumed. MOVES was run for January and July to represent the two meteorological extremes in a year. The emission rate results for these two months were averaged together to represent the entire year. Since the toxics runs include VOCs as a supporting pollutant for the calculations, and since VOCs are calculated based on hourly changes in temperature, MOVES requires the time aggregation level to be set at hour.

- **Diesel exhaust** was represented by diesel particulate matter from MOVES ($PM_{2.5}$ and PM_{10} from tailpipes of diesel fueled vehicles).[2] As an air toxic with no air quality standards and since the health effects are believed to be long term in nature, an annual time period was assumed. Since MOVES allows a coarse time aggregation level for $PM_{2.5}$ and PM_{10}, the time aggregation was set to year, which automatically includes all months of the year.

It is apparent in constructing the metrics that close attention is required to the most appropriate time scale for measuring and averaging pollutant emissions. Figure C.4 illustrates the variation in $PM_{2.5}$ depending upon the time period and time scale over which emissions are averaged.

[2] Pollutants and processes to include in the MOVES run were derived from: U.S. EPA (2000). *Technical Support Document: Control of Emissions of Hazardous Air Pollutants from Motor Vehicles and Motor Vehicle Fuels.* EPA420-R-00-023, pages 95-96.

Figure C.4 Comparison of $PM_{2.5}$ Emission Rates at Different Time Scales



Preparation of MOVES Output Files

An air quality postprocessor developed by the project team was used to work with MOVES output. When MOVES is run, it produces three output tables of emission factors, entitled rate per distance, rate per profile, and rate per vehicle. Each of these represents different emissions processes (ways that vehicles produce emissions) and is, therefore, handled differently by the air quality post processor as described below.

- **Rate per Distance –** Represents all of the running emissions from a vehicle, which occur when a vehicle is traveling. These emission factors have units of grams/mile and are provided for different roadway types and speed bins.

- **Rate per Profile –** Represents some of the nonrunning emissions from a vehicle, which occur when a vehicle is stopped. Specifically, it includes the evaporative fuel vapor venting process (process 12), which depends on hourly temperature profiles. Since this process has no relationship with the amount of vehicle travel, this table is ignored by the post-processor.

- **Rate per Vehicle –** Represents all of the other nonrunning emissions from a vehicle that are not included in the rate per profile table. It includes the following start and evaporative processes: start exhaust (process 2), crankcase start exhaust (process 16), evaporative permeation (process 11), and evaporative fuel leaks (process 13). The two evaporative processes are excluded from the post-processor since they have no relationship to vehicle travel, while the two start processes are included since they can be related to the running emissions by the amount a vehicle travels per year.

Preparing Rate Per Distance (Running) MOVES Output Files

To prepare the rate per distance table, the appropriate pollutants and processes were selected and combined, and aggregation was performed for emission factors that were output for multiple time periods. The following steps were performed.

- **Sum Processes –** All processes included in the rate per distance table are relevant and were summed together. No processes were excluded.

- **Select Relevant Pollutants and Sum when Appropriate –** There are many pollutants included in the MOVES output tables that are part of the internal MOVES calculation processes, but are not needed. Out of the remaining pollutants that are relevant some needed to be summed, such as brakewear and tirewear particulates, which were added to total $PM_{2.5}$ and total PM_{10}.

- **Aggregate Hourly Emission Factors –** Ozone and toxics were output for each of the 24 hours of the day and needed to be aggregated using a weighted average based on MOVES default VMT fractions for the 24 hours of the day.

- **Aggregate Monthly Emission Factors –** Toxics were output for January and July and needed to be aggregated by averaging the two months together.

Preparing Rate per Vehicle (Nonrunning) MOVES Output Files

To prepare the rate per vehicle table, the appropriate pollutants and processes were selected and combined, and aggregation was performed for emission factors that were output for multiple time periods. The following steps were performed.

- **Sum Processes –** Only start exhaust (process 2) and crankcase start exhaust (process 16) were included and summed together. Evaporative permeation (process 11) and evaporative fuel leaks (process 13) were excluded.

- **Select Relevant Pollutants and Sum when Appropriate –** As indicated in the rate per distance section above, there are many pollutants included in the MOVES output tables that are part of the internal MOVES calculation processes, but are not needed.

- **Aggregate Hourly Emission Factors –** Ozone and toxics were output for each of the 24 hours of the day and needed to be aggregated by summing them together since they are reported in units of grams per vehicle per hour. Summing a set of 24 hours for a day effectively converts the units to grams per vehicle per day.

- **Aggregate Monthly Emission Factors –** Toxics were output for January and July and needed to be aggregated by averaging the two months together.

Incorporation of Nonrunning Emissions into Running Emissions Rates

After preparing the rate per vehicle table, these emission rates were converted to units of grams/mile and combined with the rate per distance table. The following steps were taken.

- For 2030 divide by the MOVES national default 13,379 miles/vehicle (composite of passenger cars and passenger trucks) to get grams/mile.
- For 2035 divide by the MOVES national default 14,131 miles/vehicle (composite of passenger cars and passenger trucks) to get grams/mile.

Since nonrunning emissions are not categorized by road type or speed bin, the same converted nonrunning (gram/mile) emission factor was added to every running emission factor (gram/mile) for each road type and speed bin. This provided a lookup table of combined running and nonrunning emission factors.

Calculation of Change in Emissions by Link

After a set of emission factors that considers running and nonrunning emissions were formed into a lookup table by road type and speed bin, these were applied to links in the travel demand model network. The following steps were used.

- A grams/mile emission factor for each link was selected based on the road type and speed on that link. This was done for both the base and build scenario since the speeds on each link may differ by scenario.
- Base VMT for light-duty vehicles was calculated. Since most travel demand models do not separate VMT into vehicle types, MOVES national default percentages of passenger cars and passenger trucks were applied to the base VMT on each link. Passenger car and truck percentages from Table C.4 were used for all pollutants except diesel particulate matter, for which the diesel passenger car and truck percentages shown in this table were used.

Table C.4 Percent of Total VMT Made up of Passenger Cars and Passenger Trucks and Diesel Vehicles

MOVES Road Type	Road Type Description	Passenger Cars and Trucks		Diesel Passenger Cars and Trucks	
		2030	2035	2030	2035
2	Rural Restricted Access	72.62%	73.14%	0.63%	0.62%
3	Rural Unrestricted Access	82.05%	82.33%	0.72%	0.71%
4	Urban Restricted Access	84.44%	84.81%	0.72%	0.71%
5	Urban Unrestricted Access	87.09%	87.40%	0.74%	0.73%

Source: MOVES model national defaults.

- Build scenario VMT for light-duty vehicles was calculated. Base VMT for nonlight-duty vehicles was first calculated, by subtracting the base VMT for light vehicles from the total base VMT. Since changes in the transit network do not change nonlight-duty VMT, this also was the build scenario nonlight-duty VMT. This was subtracted from the build scenario total VMT to get build scenario light-duty vehicle VMT. This calculation is summarized in the following equation:

- $VMT_{build,light} = VMT_{build,total} - (VMT_{base,total} - VMT_{base,light})$

- The selected base scenario emission factor (for light vehicles) was multiplied by base scenario VMT (for light vehicles) for that link to get total light vehicle emissions for the base scenario. This was repeated for the build scenario.

- The base scenario light vehicle emissions were subtracted from the build scenario light vehicle emissions to get the change in emissions from light vehicles.

This procedure was repeated for each pollutant.

Assignment of Link-Level Emissions to TAZs

To calculate the Exposure and Health Benefit Indices, emissions calculated for network links (based on travel demand model data and MOVES emission factors) had to be assigned to TAZs, which are spatial units with a corresponding population and land area.

Highway Emissions

After emissions from each roadway link were calculated, several steps were completed using GIS to calculate emissions for each TAZ:

- Links were exported into GIS with the change in emissions by link already calculated.

- The TAZ GIS layer was overlaid.

- Links were associated with one or more TAZs using GIS functions. While this could require manual checking to correct for TAZ layers not “snapped” to link layers, it was performed without this checking to get a quick result. Association rules were as follows:

  – Links completely inside of a TAZ were associated with only that TAZ;

  – Links that cross TAZ boundaries were associated with more than one TAZ and an estimate of the fraction of the link within each TAZ was created; and

  – Links that form TAZ boundaries were associated with both TAZs and assigned a fraction of one-half to each TAZ.

- Allocation percentages from Step 3 were used to allocate changes in emissions from links to TAZs.

- The change in roadway emissions was summed for all links associated with each TAZ.

Transit Emissions

The change in transit emissions by TAZ for bus modes was calculated and added to the change in roadway emissions. The TAZ-level emissions were only calculated for transit buses because they emit tailpipe emissions within each TAZ through which they travel. The project sponsor for Project 2 provided emissions estimates that included diesel commuter rail emissions. TAZ-level emissions are not calculated for electric rail transit modes since their emissions are located at the power plant where the electricity is generated. The following steps were taken:

- The change in transit VMT by mode (provided by the project sponsor) was allocated to TAZs. Since GIS data were not available to identify the spatial nature of changes in transit service aside from the project itself (e.g., reductions in corridor bus service or revisions to connecting/feeder bus service), this was done based on the ratio of the length of the proposed transit project alignment through a TAZ as a percentage of the total project length. This approach assumes that bus service changes are allocated spatially in proportion to increases in rail service.

- Transit emission rates for the appropriate vehicle technology were multiplied by the change in transit VMT for that technology/mode. In this project, MOVES emission rates were used for diesel transit buses.

Meteorological Data for Wind Speed and Mixing Height

Meteorological data were used for calculating the Health Benefit Index. Meteorological data are available in various forms for most areas of the United States. Comparable surface observations, collected according to largely uniform procedures at most major airports, are available for major metropolitan areas. Upper air measurements, which are taken at fewer locations, provide mixing height estimates. These two types of data are typically used in air quality modeling studies undertaken pursuant to the U.S. EPA's Clean Air Act regulations. As such, the U.S. EPA's readily accessible on-line Support Center for Regulatory Air Modeling (SCRAM) was used as the primary data source. The most convenient forms of SCRAM data were developed for applications of the Industrial Source Complex Short-Term (ISCST3) dispersion model, and date from the late 1980s and early 1990s; although more recent data are generally available, the older SCRAM data also are adequate, as meteorological data patterns are similar over time. A more important factor is the consideration of a multiyear period to account for short-term, year-to-year fluctuations, which led to the adoption of a baseline data period from 1987 to 1991. Tables C.5, C.6, and C.7 provide annual and monthly averages of wind speed, morning (a.m.) mixing height, and evening (p.m.) mixing height for the five pilot project cities. The particular time period chosen depends on the pollutant as shown in the Table C.8, which assumes that a.m. and p.m. mixing heights are averaged to represent an entire weekday.

Table C.5 Average Wind Speeds (m/s)

Period	City 1	City 2	City 3/4	City 5	City 6
Annual	3.99	5.85	3.56	4.73	3.48
January	4.06	6.18	3.6	4.79	2.74
February	4.66	6.32	3.29	4.72	3.83
March	4.48	6.17	4.06	5.3	3.78
April	4.39	6.11	4.07	5.14	4.16
May	3.99	5.74	4.14	4.76	4.17
June	3.9	5.55	3.78	4.63	3.93
July	3.64	5.12	3.48	4.22	3.75
August	3.22	5.36	3.31	4.35	3.41
September	3.65	5.36	3.23	4.55	3.17
October	3.7	5.83	3.14	4.79	3.11
November	3.98	6.17	3.48	4.91	3.05
December	4.28	6.35	3.17	4.67	2.65

Table C.6 Average A.M. Mixing Heights (m)

Period	City 1	City 2	City 3/4	City 5	City 6
Annual	392	611	365	370	570
January	354	568	317	364	485
February	425	678	372	370	529
March	426	674	506	529	765
April	366	712	486	390	671
May	415	563	492	378	710
June	428	569	413	299	611
July	510	543	310	281	524
August	446	577	308	258	614
September	374	583	294	332	499
October	291	529	259	391	459
November	287	641	348	441	490
December	386	691	285	406	489

Table C.7 Average P.M. Mixing Heights (m)

Period	City 1	City 2	City 3/4	City 5	City 6
Annual	1241	1012	2180	1084	754
January	680	653	1273	458	611
February	1013	822	1383	663	777
March	1160	1035	2233	886	958
April	1536	1067	2580	1621	973
May	1405	1073	2772	1695	943
June	1681	1409	3084	1611	779
July	1623	1290	3148	1563	632
August	1586	1239	2821	1373	737
September	1423	1086	2500	1072	668
October	1200	925	2013	1114	688
November	930	824	1427	551	735
December	688	689	961	403	561

Table C.8 Example Meteorological Data Chosen for City 2

Pollutant	Final Time Period	Wind Speed (m/s)	Mixing Height (m)
NO_x	Aug Weekday	5.36	908
VOC	Aug Weekday	5.36	908
CO	Jan Weekday	6.18	610.5
PM_{10}	Jan Weekday	6.18	610.5
PM_{25}	Jan Weekday	6.18	610.5
PM_{25}AN	Annual Average Weekday	5.85	811.5
BENZ	Annual Average Weekday	5.85	811.5
NAPT	Annual Average Weekday	5.85	811.5
BUTA	Annual Average Weekday	5.85	811.5
FORM	Annual Average Weekday	5.85	811.5
ACET	Annual Average Weekday	5.85	811.5
ACRO	Annual Average Weekday	5.85	811.5
DPM	Annual Average Weekday	5.85	811.5

Toxicity Weightings

Different toxicity weighting factors were constructed for different groups of pollutants based on standard EPA benchmarks: health-based (primary) NAAQS, reference concentrations (RfC) for noncancer health endpoints, and inhalation unit risks (IUR) for cancer potency. Ozone is separated from the remaining criteria pollutants since it is regional instead of local in nature. This results in three groups of pollutants with three corresponding sets of toxicity weightings: non-ozone criteria pollutants, non cancer-toxics, and cancer toxics.

The toxicity weighting function for non-ozone criteria pollutants could be calculated in several ways, but the following method includes not only a measure of absolute toxicity, but also some measure of the existing air quality with respect to toxicological benchmarks. To do so, the pollutant-specific *AQI* is divided by the *NAAQS* for each criteria pollutant, *m*, other than ozone. This is shown in the following equation.

$$TW_m = \frac{AQI_m}{NAAQS_m}$$

Use of the *AQI* in the numerator provides higher weighting to the pollutants that are of greatest importance to local air quality, and use of the *NAAQS* in the denominator provides a scaling that puts pollutants on similar relative basis.

This method assigns different toxicity weightings to projects in different areas based on local air quality. It also would be possible to develop generic default factors based on typical air quality, and this may be necessary for some pollutants and areas based on the availability of AQI data. Summary AQI data are available for 302 MSAs and 1,031 counties from the EPA's AirData web site.[3] For areas not covered by either an MSA or county in the database, a national average set of AQI data was developed which was used instead of site-specific data. AQI values were calculated daily for each pollutant based on the concentration of the pollutant as measured at EPA monitoring sites and the short-term NAAQS for the pollutant. On each day, the maximum AQI among the pollutants was used as the overall AQI for the day. In general, but not always, an AQI of 100 indicates that one pollutant was measured or estimated to be at the short-term NAAQS concentration on that day.

The EPA's AQI database lists the overall AQI for each day at each location, the pollutant responsible for the overall AQI, and the AQIs for the pollutants with the second and third highest values. To calculate long-term pollutant indices the average of a pollutant's daily AQI values over a three-year period was used, and to calculate short-term pollutant indices, the 98th percentile of a pollutant's AQI values over the three-year period was used. Detailed instructions were developed for extracting the AQI information from the EPA database, and a computer program developed to process the AQI data files and

[3] http://www.epa.gov/air/data/geosel.html.

perform the averaging and 98th percentile calculations. Table C.9 gives the assessment periods, NAAQS values, and AQI values used in the criteria pollutant index calculations.

Table C.9 AQI Parameters for Criteria Pollutant Index Calculations

Pollutant	Emission Rate/ Assessment Period	NAAQS (µg/m³)	AQI
$PM_{2.5}$	Annual average	15	Annual average
SO_2	Annual average	80	Annual average
CO	8 hours	10,000	98th percentile for year
$PM_{2.5}$	24 hours	35	98th percentile for year
PM_{10}	24 hours	150	98th percentile for year
SO_2	24 hours	365	98th percentile for year

An initial evaluation was performed of weighting factors for the five cities of focus, as shown in Table C.10. The factors generally vary by less than a factor of two within each pollutant, but vary substantially across pollutants. For the two pollutants that have both short- and long-term weighting factors, the maximum of the two values in each case was taken (after the weighting factors were multiplied by the emission term, which can be different for the short- and long-term periods).

Table C.10 Weighting Factors

	Short-Term				Long-Term (Annual)	
City	**CO**	**$PM_{2.5}$**	**PM_{10}**	**SO_2**	**$PM_{2.5}$**	**SO_2**
City 1	0.0022	3.28	0.32	0.077	3.87	0.15
City 2	0.0015	2.66	0.28	0.058	3.00	0.12
City 3/4	0.0034	2.26	0.41	0.033	2.15	0.15
City 5	0.0027	2.38	0.32	0.125	2.74	0.19
City 6	0.0017	2.69	0.38	0.036	2.34	0.084

Some weighting factors for PM_{10} and SO_2 were based on limited AQI information – particularly for SO_2, which infrequently dominates daily AQI calculations. Since SO_2 is not typically important in transportation projects, the lack of AQI data will not likely be of importance. For City 3/4, in which PM_{10} is a more frequent contributor to the AQI, the statistics bear out its relative importance (compared with other pollutants).

Toxicity weighting factors for mobile source air toxics (MSAT) are consistent with standard risk assessment practice as shown in Tables C.11 and C.12.

Table C.11 Noncancer Health Benefits of Emissions Avoided

MSAT	RfC[a]	Relative Toxicity
Acetaldehyde	9×10^{-3} mg/m^3	3.3
Acrolein	2×10^{-5} mg/m^3	1,500
Benzene	3×10^{-2} mg/m^3	1
1,3-Butadiene	2×10^{-3} mg/m^3	15
Diesel Particulate Matter	5×10^{-3} mg/m^3	6
Naphthalene	3×10^{-3} mg/m^3	10

[a] RfCs are taken from EPA's IRIS program (www.epa.gov/iris). An RfC is applicable to long-term exposure.

Table C.12 Cancer Risk Benefit of Emissions Avoided

MSAT	IUR[a]	Relative Cancer Risk
Acetaldehyde	2.2×10^{-6} m^3/µg	1
Benzene	2.2×10^{-6} to 7.8×10^{-6} m^3/µg	1 to 3.5
1,3-Butadiene	3×10^{-5} m^3/µg	14
Diesel Exhaust Particulate	3×10^{-4} m^3/µg	140
Formaldehyde	1.3×10^{-5} m^3/µg	6
Naphthalene	3.4×10^{-5} m^3/µg	15

[a] IURs are taken from EPA's IRIS program except for diesel engine exhaust and naphthalene, which are taken from California EPA's Office of Environmental Health Hazard Assessment (http://www.oehha.ca.gov/air/hot_spots/tsd052909.html).

Ozone Index

The criteria pollutant ozone (O_3) is different than the other criteria pollutants in that it is not emitted directly from pollution sources, but is formed (and also destroyed) through a complex set of atmospheric chemical reactions. Therefore, the emission-to-concentration relationship implied in the indices for the other criteria pollutants is not valid for ozone. Also, because there are no appreciable direct sources, and because there is typically a delay between precursor emissions and incremental ozone concentrations, ozone is a pollutant that almost entirely assessed on a regional scale through State Implementation Plans.

It also is the case that ozone is an important criteria pollutant in many areas. An attempt was, therefore, made to establish a separate toxicity-based index for ozone. The initial approach for the ozone index was to calculate it using regional emissions, normalized by area, on a countywide basis (which simplifies the gathering of information). In some cases, regional considerations dictate inclusion of multiple counties. NO_x and VOC emissions were treated equally; but, if appropriate, more realistic and site-specific apportioning methods could be developed to properly account for the different sensitivities of ozone levels to changes in NO_x and VOC emissions. The ozone index is calculated as:

$$\text{Ozone Index} = AQI_{O3}\left(\frac{\Delta E_{NOx}}{OWF_{NOx}} + \frac{\Delta E_{VOC}}{OWF_{VOC}}\right)$$

where the ozone weighting factors (OWF) are estimated as regional (countywide) emissions divided (normalized) by area. Use of the *AQI* is maintained for ozone to reflect the importance of local air quality (thus weighting higher those areas with higher existing ozone levels). Since the current *NAAQS* for ozone is based on short-term (eight-hour) health impacts, daily maximum emissions and an upper-percentile (98th) AQI were used. The data used in calculating the ozone index and resulting values are shown in Table C.13. The values suggest that a given unit of NO_x or VOC emissions will have the greatest impact on ozone in Project 1 and 6 areas (due to the low OWFs and high AQI), and the least impact in Project 5 area (due to the high OWFs and low AQI).

Table C.13 Data Used for Calculation of Ozone Index

Project Area[a]	AQI (98th Percentile)	Regional 2005 (Countywide) Emissions (tpy)		County Area (km^2)	Ozone Weighting Factor (OWF)		Ozone AQI	Ozone Impact Index
		NO_x	VOCs		NO_x	VOCs		
Project 1	169	47,102	50,568	1,369	34.4	36.9	169	30.6
Project 2	110	70,469	82,326	2,284	30.8	36.0	110	22.2
Project 3/4	116	27,570	26,648	397	69.4	67.1	116	10.5
Project 5	77	111,667	77,842	1,845	60.5	42.2	77	8.1
Project 6	106	48,065	36,994	1,910	25.2	19.4	106	26.8

[a] Data is shown for the corresponding primary county for each project.

If a data-based approach were developed to combine the ozone impact index with the indices for the other criteria pollutants, then this may allow for a single overall criteria pollutant index to be calculated. However, due to the differing nature of ozone relative to the other pollutants, this may not be possible or even advisable.

C.3 Forecast New Daily Nonmotorized Access Trips (Metric IIE)

The metric selected to measure the amount of nonmotorized activity is the difference in the forecast number of nonmotorized access trips for the project versus the no-project alternative. Forecast nonmotorized trips is an output of the travel demand model used for ridership forecasting for each project and was, therefore, obtained directly from the project sponsor. In addition to presentation of this metric, the research for this project included a general overview of mode choice models, discussion of the variables that affect nonmotorized access to transit, and a review of the travel models used to develop the travel forecasts for the six pilot projects. A summary of this review and implications for the nonmotorized trips metric is provided below.

Nonmotorized Travel in Travel Forecasting Models

The ability to reliably forecast nonmotorized access to transit depends upon a number of attributes of the travel forecasting model, including the form and structure of the mode choice model, level of detail in transportation networks and zones, and representation of the pedestrian environment.

Model Form. Nonmotorized access to transit is typically represented as walk access in most mode choice models used to forecast travel in urban areas. Few, if any urban travel models separately forecast walk and bicycle (or other nonmotorized modes) access to transit. Most urban mode choice models forecast auto access and “non-auto” access to transit with all nonmotorized access being lumped together in a generic “walk access” mode.

Mode choice models are used to forecast travelers’ choices of travel mode and are commonly specified using discrete choice models based on the logit formulation. This model form estimates the probability of a traveler choosing a specific mode from a fixed number of alternative modes. With logit models, there are three main factors that determine choices among travel modes. They are:

1. Attributes of the modes of travel available to the trip-maker (e.g., travel times, cost of travel);
2. Attributes of the trip-maker (e.g., income, household size, auto availability); and
3. The values travelers place on the different attributes listed above for the specific type of trip (e.g., work or shop) being made.

Travel is typically segmented into different groups or market segments that define travelers or trips with similar characteristics. For example, trip purpose is perhaps the most common market segmentation used in the modeling process. For mode choice, the same types of travelers may value travel time or travel cost for work trips differently from those attributes for shopping trips.

The probability of a traveler selecting a mode is a function of the “utility” of that mode versus the aggregate utility of all available modes. While the concept of utility is borrowed from economics and is a measure of relative satisfaction when one consumes a certain good or service, it also can be applied to the decision of selecting a mode of transportation. A utility function for each mode can be defined by variables describing the attributes of travel of the mode and attributes of the trip-makers, coupled with parameters that provide the relative importance of each of the attributes. For example, the utility of traveling by bus may be described as:

$$U_{Bus} = a * \textit{Access Time} + b * \textit{In-Vehicle Time} + c * \textit{Cost} + d * \textit{Income} + e$$

Where:

- Access Time, In-vehicle Time, and Cost = Variables that describe the characteristics of the bus mode such as the amount of time and cost of traveling from an origin to a destination.
- Income = A socioeconomic variable, descriptor of the traveler.
- *a, b, c* and *d* = Coefficients that determine the relative weights or importance of each variable.
- *e* = A term in the utility expression commonly referred to as a mode-specific constant. It captures factors that affect choice for an alternative but cannot be measured. Examples of nonmeasured attributes include comfort, reliability, and aesthetics.

Model Structure. The model structure is dependent on a number of factors. Several of the most important are the complexity of the transit system being modeled, the data available for model development, and the alternatives that need to be evaluated.

Transit access is an important consideration in mode choice. In some areas, walk (or nonmotorized) access to transit is the primary access mode. In other areas, drive access to transit may be the access mode for a large segment of transit riders. Different modeling approaches may be used where multiple access modes are available. Figure C.5 shows a multinomial mode choice structure where walk to transit and drive to transit "compete" with auto modes. In such a mode choice structure, an increase in the share for one mode resulting from an improvement in the utility of that mode draws proportionately from the other modes.

Figure C.5 Multinomial Mode Choice Structure

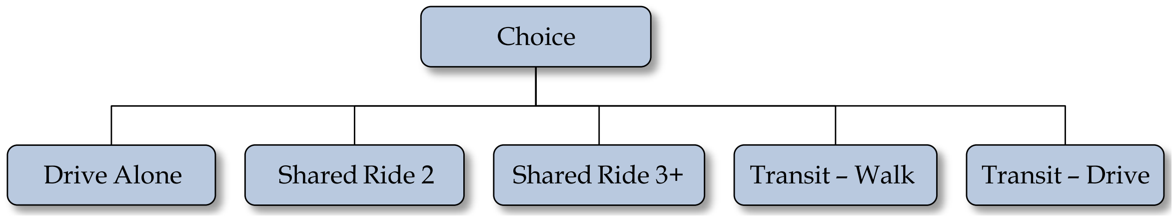
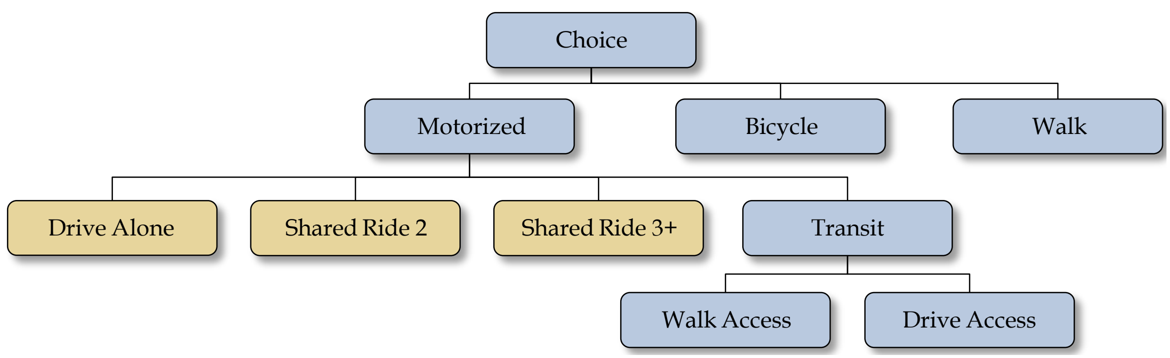


Figure C.6 shows a nested mode choice where the walk and drive access options "compete" with each other but, at the same time, both contribute to the overall utility of "transit." Under the nested mode choice structure shown in Figure C.6, an improvement in the walk access to transit submode (e.g., through increased transit coverage) would draw most new walk access to transit users from the drive to transit submode. However, since both contribute to the transit mode, some new riders also would be drawn from the auto modes.

Figure C.6 Sample Mode Choice Structure



There are a variety of mode choice model forms in use today. The level of detail provided for transit access modes varies greatly based on the transit service levels found in the region and the data available for model development. These differences may lead to differences in the quality and outcomes of nonmotorized access trip forecasts.

Transportation Networks. The networks used in the travel demand model also affect the ability to produce reliable forecasts of nonmotorized access. Mode choice models require a representation of the transportation network in order to make forecasts of the modes used for travel. Specifically, they require detailed information on the travel choices available to travelers between two areas (time, cost, etc.) This data can be found in a physical representation of the region, which includes:

- The traffic analysis zone is a unit of geography used in travel demand models. The size of TAZs vary greatly depending on their location in the region. For example, TAZs located in the central business district (CBD) tend to be smaller while those located in suburban or exurban areas are much larger. Each TAZ contains socioeconomic information that is used by the travel demand models. Data on population, households, auto availability, and employment are some of the variables used to estimate the number of trips that are produced or attracted to a TAZ. TAZs are connected by transportation network links (highway and transit) with capacity, travel speed, and cost attributes.

- Centroids are considered the main activity centers of a traffic zone and used to mark the relative location of a TAZ. Centroid connectors link the activity from a zone to the transportation network throughout the region. These connectors represent the minor streets within an area that provide a local circulation/distribution function. While some models allow travelers to traverse a centroid connector to access/egress a transit line, a more common method of providing a link between a traffic zone and the outside network is by walk access links.

- Walk access links are usually coded from a centroid to several transit stops in the vicinity of the zone. Research indicates that most transit users will walk up to one-third mile for a bus stop and one-half mile for a rail station. As distance to transit line increases, the likelihood that a rider will walk to a transit stop decreases. Walk access links also are coded with speeds of 2.5 to 3.0 miles per hour which represents the average walk speed of a pedestrian.

Pedestrian Environments. The networks and transit station areas zones found in most travel models are coarse since the modeling area normally covers the entire region. In more detailed transit corridor studies, traffic zones are often split into smaller geographic units along with more detailed road network data.

Transit accessibility is an important input for access mode choice models. The concept is related to the maximum distance that most transit riders will walk to board a bus route or train. In estimating the percentage of a TAZ within walk access or egress, a buffer may be applied using GIS to a route or stop and calculating the percentage of that zone that is within walk distance of the route. The regional model for Project 5, for example, uses transit accessibility to segment transit trips by access mode for mode choice. Each TAZ has information on the percentage of the zone with one-third mile of transit and the share of the zone between one-third mile and one mile of transit.

Many model networks also do not directly differentiate between pedestrian-friendly environments such as the CBD with an ideal mix of density, land use mix, and street grid patterns, as compared to suburban or rural areas that have less walkable environments. A higher number of walk access trip to transit may still be expected in pedestrian-friendly environments as these areas are often more urban and better served by the transit providers.

Some agencies, however, have addressed the influence of pedestrian environments on transit access mode choice. The model used for Projects 3 and 4, for example, uses different area types to change perceived walk time to reflect the quality of the pedestrian environment. This concept is very similar to "walk scores" used by some real estate companies. There are five area types that each have their own weight that is used to calculate the perceived walk time, which is calculated by multiplying the walk time by the weight. This information is captured in the transit skimming process where the most competitive paths between every origin and destination zone using transit are built. The mode choice model then uses the transit skims to calculate the probability of a traveler using the available modes.

Some mode choice models use population density as one socioeconomic variable that impacts the number of walk access trips to transit. The model used for Project 2, for example, uses people per acre in the traffic zone. Population density has been found to be positively correlated to walk access to transit; travelers are more likely to walk to transit service in areas with greater density. Area with higher population densities also tend to be located in urban areas that have more transit opportunities.

Pilot Project Models

Project 1. The MPO's trip-based regional travel demand model was used to evaluate the project. The nested logit mode choice model estimates travel for three trip purposes – Home-Based Work (HBW), Home-Based Nonwork (HNW), and Nonhome-Based (NHB). Drive access and walk access transit trips are estimated for the following modes: local, express, BRT, heavy/light rail, and commuter rail.

Project 2. The MPO's trip-based regional travel demand model was used for this project. The mode choice model uses a nested logit choice structure and estimates person trips for three trip purposes: HBW, Home-Based Other (HBO), and NHB. The modes included in the HBW mode choice model are drive alone, 2-person high-occupancy vehicle (HOV), 3+ person HOV, walk, and transit. In the transit nest, there are two submodes: 1) walk to transit; and 2) drive to transit. The HBO mode choice model has the same modes as HBW model, except there is only one HOV mode – 2+ person HOV. Finally, the NHB mode choice model splits work and nonwork trips using a work dummy variable in the two auto modes. Trips are estimated for the same modes as the HBO mode choice model.

Projects 3 and 4. The MPO's trip-based regional travel demand model was used for both projects. The model uses a multinomial logit mode choice structure that estimates trips for three trip purposes: HBW, Home-Based Nonwork (HBNW), and NHB. The modes included in the HBW model are drive alone, two-person high-occupancy vehicle (HOV), 3+ person HOV, drive to transit, and walk to transit. The modes included in the HBNW model are auto, drive to transit, and walk to transit. Finally, the modes included in NHB trips are auto and walk to transit.

Project 5. The MPO's trip-based regional travel demand model was used to develop forecasts for the project. The nested logit mode choice model forecasts trips for the following trip purposes: HBW, HBNW, Home-Based School (HBSch), Nonhome-Based Work (NHBW), and Nonhome-Based Other (NHBO). The modes included in all the mode choice models are drive alone, shared ride, nonmotorized, transit, and school bus. Under the transit mode, there is local bus, express bus, LRT, premium bus, and commuter rail. Three access submodes are estimated for each of the five transit modes. The mode choice model estimates walk-access, park-and-ride access, and kiss-and-ride access for each of the main transit modes.

Project 6. A county-level model was used to develop forecasts for the project. The model estimates travel for the following trip purposes: HBW, home-based school/university, home-based shop/other, home-based social/recreation, and NHB. The mode choice model uses a nested logit mode choice model structure for home-based work trips. There are four modes at the top of the nest, including drive alone, 2-person HOV, 3+ person HOV, and transit. In the transit nest, there are five submodes: 1) walk to local bus; 2) walk to express bus; 3) walk to rail transit; 4) park-and-ride; and 5) kiss-and-ride. For all other purposes, a binary logit mode choice model structure is used with two modes: 1) auto; and 2) transit.

Results and Discussion

Table C.14 shows the forecasted nonmotorized access trips for each pilot project, for the no-project and project alternatives, as well as the difference and the change expressed as a percentage of total model area nonmotorized trips.

The pilot projects showed a wide range in values for walk access trips to transit when the major transit investment is added. Project 2, for example, is forecast to have an increase of 0.21 to 0.28 percent of new walk access trips to transit (based on subregional totals). Project 6 is forecast to have an increase of 2.90 percent (based on subregional totals). Project 5 is expected to have a 1.96 percent increase (based on regional totals). Finally, the Projects 3 and 4 are forecast to have 2.91 percent and 5.24 percent increases, respectively (based on regional totals).

There are several reasons for the range in values. Some are due to characteristics of the project and its environment. In corridors where existing transit ridership is high, one might expect the addition of a new fixed guideway project to attract fewer new transit riders. Another important factor is the markets the project will be serving – urban neighborhoods

Table C.14 Nonmotorized Access Trip Forecasts

Project	Area Type	Walk Access Transit Trips		Difference	Percent Change
		Without Project	With Project		
Project 1	Suburban	N/A	N/A	N/A	N/A
Project 2	Suburban/Intercity	1,273,456	1,276,092[a]	2,636	0.21%
			1,277,079[b]	3,623	0.28%
Project 3	Urban/Suburban	298,513	314,147	15,364	5.24%
Project 4	Urban/Suburban	277,393	285,457	8,064	2.91%
Project 5	Urban Core	271,056	276,375	5,319	1.96%
Project 6	Urban Core	286,224	294,512	8,289	2.90%

[a]Diesel; [b]Electric.

with high pedestrian accessibility, versus suburban neighborhoods that will rely more on automobile access. In this evaluation, project serving more densely populated urban environments did show higher numbers of nonmotorized trips than projects serving more suburban environments.

Other differences, however, may be due to characteristics of the model. As described above, model structures vary in terms of how nonmotorized access to transit is considered for different trip purposes. Some mode choice models may overestimate the number of walk access trips to transit. For example, the mode choice model for nonwork trip purposes in the Project 6 model used a binary structure – auto or transit. In this case, it was assumed that many of these transit trips could be classified as nonmotorized access since the proposed service operates in a very urban environment. This simplifying assumption, however, is probably overstating the number of walk-access trips that are forecast when the project opens. Similarly, the Project 5 model included informal park-and-ride in the walk access category.

Models also vary in how pedestrian networks and conditions are represented. TAZs that are too large may have unreasonable walk access links distances if generated automatically by the transportation planning software. When zonal walk access/egress percentages are calculated, only a small percentage of the population/employment residing in the zone may have access to transit. On the other hand, when walk access/egress percentages are calculated for smaller zones, the GIS programs that are often used to calculate this variable may overestimate the percentage of the zone with transit access which would affect the estimate of walk access trips to transit. Some pilot project models included factors related to the quality of the pedestrian environment, while others did not.

A more detailed evaluation, for example, by applying different model structures and variables to develop forecasts for the same project, would be required to determine the importance of the effect of different model configurations on forecast levels of nonmotorized travel.

Appendix D – Calculation of Ecology, Habitat, and Water Quality Metrics

This appendix describes the data sources and methods used in this project to estimate metrics of the ecology, habitat, and water quality impacts of transit projects. The metrics that were proposed for testing in Phase 2 of this research are shown in Table D.1. Metrics IIIA-IIID use corridor-level land use data as the basis for assessing a project's potential impacts. Metric IIIE is based on a qualitative review of existing plans and other documents related to habitat protection. This appendix also describes how measures of a transit project's accessibility impacts were evaluated as potential indicators of development and associated ecological impacts.

Table D.1 Ecology, Habitat, and Water Quality Metrics

Key	Original Metric Description	Revised Metric Description
IIIA	Ratio of already-developed land to undeveloped land (greenfields).	Percent of corridor that already is developed.
IIIB	Potentially impacted acreage of undeveloped land.	Potentially impacted acreage of undeveloped land.
IIIC	Potentially impacted acreage of 1) wetlands; 2) critical habitat; and/or 3) other land with high resource value.	Potentially impacted acreage of wetlands and agricultural land.
IIID	Potentially impacted acreage weighted by ecosystem service value.	Not computed.
IIIE	Adequacy of state or regional habitat protection plans and consistency of project with plans.	Adequacy of state, regional, and local habitat protection plans.

To inform the development of these metrics, the project team first prepared a white paper on indicators of ecological impact (included as Appendix J of this report). This paper reviewed key impact measures (e.g., loss of habitat, loss of native plants), data requirements, and specific metrics in detail. Detailed data on ecological impacts is only likely to be available if the specific details of a project are known, such as is the case for the project footprint (construction and operation) itself. Because of the broader focus of this exercise on a project's impacts on development patterns, the paper also discussed the relative ecological impacts of different land use patterns. It further provides an overview of common types of ecosystem protection plans at different scales of planning.

D.1 Metrics IIIA-IIID – Land Use-Based

Metric IIIA indicates the extent to which the project serves existing communities/ developed areas versus undeveloped areas. Metrics IIIB-IIID are three variations on the same theme, with increasing complexity. Each of these metrics looks at **potentially** impacted acreage in the project corridor (i.e., acreage that is likely to experience development pressures as a result of the transit project). The easiest is to simply look at undeveloped land in the corridor. A second level of complexity is to look at undeveloped land by type, focusing on lands with significant resource/ecological value. A third level involves weighting these potentially impacted acres by the ecosystem service value. All of these metrics are proxies for actual environmental impacts, rather than direct measures of impact. Specifically, they represent potential impacts related to development induced by the project.

Land Use Data

All of these metrics required acquiring land use data from state or regional agencies. (Acquiring data from local municipalities was deemed to be impractical because of the number of municipalities in some corridors and the level of effort involved in combining data sets with potentially different land use categories, projection systems, etc.). Metrics IIIA and IIIB simply require land use data that identify developed and undeveloped land types. Metrics IIIC and IIID require additional information that relates to the ecological/ resource value of the land. For each pilot project, attempts were made to obtain the following data sources:

- State or regional GIS database of existing land use (year of most recent update may vary);
- State or regional GIS database of future planned land use;
- State or regional habitat/ecology database – GIS files identifying ecologically significant areas, protection status, etc.; and
- Wetlands GIS database.

Table D.2 shows the sources (state or MPO/regional agency), dates, and specifics of the data obtained.

State and metropolitan agencies (including MPOs and councils of government) have made great strides within the past decade in developing integrated regional or state-level land use databases in GIS format. Existing land use was generally available; although for one area only existing zoning could be obtained from a regional source. Future land use was only available in some areas. Wetlands data was generally available from state and sometimes regional sources. However, data on areas of critical habitat (protected or otherwise) was not consistently available or categorized among states or regions.

Table D.2 Land Use Data Collected for Pilot Projects

Data Type	Project 1	Project 2	Projects 3 and 4	Project 5	Project 6
Existing Land Use	Regional (2008)	State (2005)	Regional Zoning (2005) [a]	Regional (2005)	State (2004)
Future Land Use	N/A	N/A	Regional (2025)[b]	Regional (2005)	Regional (2010) [b]
Habitat/Ecology/ Critical Areas	MPO – species habitat	N/A	Regional (2009) (watersheds, open space)	State[c]	N/A
Wetlands	State (1999)	State (2006)	Regional Zoning (2005) [a]	Regional (2005)	State (2004)

[a] Existing regional land use was not available.

[b] A regional dataset comprised of merged municipal data was obtained but was unusable for the purposes of this research.

[c] Not obtained due to cost.

[d] State or regional sources were available, but USFWS wetlands data was ultimately used for consistency.

The next step was to develop a consistent classification system across all data sets to identify 1) at a minimum, developed versus undeveloped land; and 2) land of high ecological value. An attempt also was made to distinguish transit-supportive from nontransit-supportive developed land uses, to improve the relevance of metric IIIA. The first distinction was relatively straightforward, but the second was more challenging because of a lack of consistent definition for high ecological value. It was possible to identify a number of categories that were generally consistent, including developed, agricultural, forest, park/recreation, wetlands, and water.[1] Some data sets included "other open space" while one included "vacant." Ecological identifiers or indicators of protected areas were not consistent, and there was no other information to identify the relative ecological value of the land. Because of this, Metric IIID, "potentially impacted acreage weighted by ecosystem service value," was not calculated, and Metric IIIC could be calculated only as the acreage of agricultural land and wetlands in the corridor rather than as land with ecological value. (It could be argued that agricultural land has primarily economic rather than ecological value, but preservation of agricultural land is commonly viewed as a desirable growth management objective and therefore it was included in the definition of sensitive or valuable land.)

Table D.3 shows how land uses were reclassified by the project team for consistency and grouped into land use types.

[1] There were still some ambiguities such as whether cranberry bogs are agricultural or wetland.

Table D.3 Land Use Reclassification

Land Use	Project 1	Project 2	Projects 3 and 4	Project 5	Project 6
Agricultural	Agriculture	Cropland, Nursery, Orchard, Pasture	Agriculture	Agricultural, Farmstead	Agricultural
Developed, Not Transit-Supportive	Cemeteries, Industrial, Ltd_Access, Res_Low, TCU	Cemetery, Junkyard, Low-Density Residential, Marina, Powerline/, Transportation, Very Low-Density Residential	General Industrial, Heavy Industrial, Industrial, Industrial Light, Light Industrial, Low-Density Office, Low-Density Residential, Semi Urban Residential, Semi_Rural Residential, Semi-Rural Residential, Semi-Urban Residential, Transportation/, Utilities	Industrial and Utility, Seasonal/, Single Family Detached, Major Highway, Railway	Industrial, Low-density commercial, Low-density residential, Very low-density residential
Forest	Forest	Brushland/, Forest			
Other Open Space	Transitional, Urban_Other	Open Land	Open Space, Regional Open Space		
Other Water	Reservoirs, Rivers		Water	Water	Water
Park/Recreation	Park_Lands/, Park_Lands/, Park_Lands/_Rock, Park_Lands/, Golf_Courses, Parks, Park_Lands/, Inst_Extensive/, Park_Lands/, Inst_Extensive/_Other, Park_Lands/_Other, Park_Lands/	Golf Course, Participation Recreation	Parks	Golf Course, Park, Recreational, or Preserve	Other – Not Determined, Open space and public lands

Table D.3 Land Use Reclassification (continued)

Land Use	Project 1	Project 2	Projects 3 and 4	Project 5	Project 6
Potentially Transit-Supportive	Inst_Extensive/, Commercial, Inst_Extensive/, Ind/, Inst_Intensive, Res_High, Res_Med, Res_Mobile, Res_Multi, Inst_Extensive/, Inst_Extensive/, Inst_Extensive/	Commercial, High-Density Residential, Industrial, Medium-Density Residential, Multifamily Residential, Spectator Recreation, Transitional, Urban Public/	Airport Influence, Airport Influence, Civic, Commercial, Commercial – Retail/Office, Commercial Mixed Use, Commercial PUD, General Commercial, General Commercial, General Mixed Use, General Mixed Use PUD, High-Density Office, High-Density Residential, Incorporated Areas, Medium-Density Residential, Residential Mixed Use, Residential PUD, Retail Commercial, Retail Commercial, School and Campus, Schools and Campus, Unincorporated Areas, Very High-Density Residential	Airport, Institutional, Manufactured Housing Parks, Mixed Use Commercial and Other, Mixed Use Industrial, Mixed Use Residential, Multifamily, Office, Retail and Other Commercial, Single Family Attached	High-density commercial, High-density residential, Medium-density residential, Mixed use Res. Com., Planned development, Urban reserve
Undevelopable	Exposed_Rock, Quarries	Mining, Waste Disposal	Extraction/Utilities	Extractive, Undeveloped	
Wetlands	Wetlands	Cranberry Bog, Forested Wetland, Non-Forested Wetland, Saltwater Sandy Beach, Saltwater Wetland, Water, Water-Based Recreation	Flood Plain, Floodplain		Water

It also turned out to be impossible to consistently identify transit-supportive versus nontransit-supportive land uses. For example, residential is commonly grouped into different density categories (e.g., high, medium, low) and types (e.g., single or multifamily), but the specific categories and definitions (e.g., what constitutes high density) are not consistent across datasets. Datasets may or may not identify "mixed use" as a separate category. Commercial land is often not distinguished by density, meaning that it could include anything from high-rise office buildings to single-story suburban office parks.

Another problem with developing consistent land use comparisons among projects is the basis for the data – parcel-based from tax assessment data or polygon-based as identified from image processing. Most of the data were based on parcel records, but in one case, a state data set was based on polygons on the order of one-acre in size as identified from processing of satellite data. (This type of data also may be referred to as "land cover" rather than "land use.") This difference in data sources would lead to discrepancies where, for example, a two-acre residential lot might be classified as "low-density residential" in one region but only partly residential and partly "forest" in another. In this test case, this difference appeared to greatly affect the calculation of developed versus undeveloped land area for one of the pilot projects.

Indicators of Potential Development Impact

The initial thinking for the land use-related metrics was to use land use data in conjunction with an indicator of transit's potential development impacts in order to identify a measure that weights sensitive land by the likelihood that it will be impacted. The *change in accessibility to population and jobs resulting from the transit investment* was selected as the indicator of potential development impact. The hypothesis is that the higher the change in accessibility resulting from the transit project, the greater the likelihood of development occurring in a particular location, and therefore the greater the likelihood of environmental impacts.

Accessibility measures describe the number or amount of activities that can be reached within a given travel time. Population and jobs are often used to represent activities. For this analysis, the sum of population and jobs by traffic analysis zone (TAZ) was used as the accessibility indicator. Accessibility from a given location (e.g., a TAZ) can be measured in different ways. Two common methods include:

- A "threshold" accessibility measure, i.e., the total number of activities (population + jobs) reachable from the TAZ within an X-minute travel time; and
- A distance-weighted accessibility measure, where population and jobs are given greater weight the closer they are to the location.

The accessibility from each TAZ can be compared for both the no-build and build project scenarios, and the *change* in accessibility expressed in absolute or percentage terms. Accessibility can be measured for individual modes, or summed across modes. For this research, only transit accessibility is evaluated, as changes in transit accessibility are hypothesized to lead to changes in development patterns in the transit corridor. Changes in automobile accessibility also may result from reduced congestion on the highway network, but these effects are likely to be dispersed and may not be perceived by developers as directly attributable to the transit project. An empirical analysis of the relationship between accessibility changes and development impacts would be desirable, but beyond the scope of this project.

Data Sources and Calculation Methods

Accessibility is computed using two data sets:

- Socioeconomic data (population and jobs) by TAZ.
- Travel-time "skim" matrices, which provide the travel time between each origin-destination pair of TAZs. Travel-time skims are generally available for both peak and off-peak periods, and for individual modes. Skim matrices can be developed from the travel demand forecasting model used for the project.

The research team found that travel-time skim matrices are not always easy to obtain or work with. They may take 20 to 30 hours of work to prepare if they have not already been produced. Furthermore, transit travel-time skims are much more complicated than highway skims, as they involve multiple modes of travel. There are typically separate skim files provided for walk and drive access, wait time, in-vehicle travel time, and transfer time, at a minimum. These times may be given different weights in the mode choice model (e.g., wait time is typically viewed as more onerous than in-vehicle travel time). It may not be clear how to weight walk versus drive access time when using these skims for a simple accessibility calculation, and unreasonable results may be obtained by using very long walk-access times defined in suburban areas with large TAZs, even if they are unrealistic and are not likely to represent a typical trip.

Skim matrices were obtained for three of the pilot projects (including two in the same region). Transit accessibility was computed using two different methods for comparison:

1. Threshold (population + jobs within 60-minute travel time):

$$A_i = \sum_j O_j$$, where t_y<60 min

Accessibility A_i = Accessibility for zone i
O_j = Population + jobs in zone j (sum across all zones in region)
t_y = Travel time between i and j. Travel Time = Initial Wait Time + In-Vehicle Time + Transfer Wait Time + Transfer Penalty Time (Denver only). Walk

Time was not included due to a number of zones with very long walk access times in the Denver skims.

2. Distance-weighted:

$$A_i i = \Sigma_j j \equiv O_j j/(t\ (/y)$$

where α is a coefficient (using 1.0, a linear decrease in weighting with distance), and all other variables are as described above.

Findings

Figures D.1 through D.6 show changes in transit accessibility by TAZ for the peak period for the evaluated projects. There are distinct differences between the patterns computed by the two measures, particularly for Projects A and B. These projects show very small changes in 60-minute threshold accessibility, less than 0.5 percent, for nearly all zones (Figures D.1 and D.3). However, the distance-weighted measure shows much more meaningful differences, over 10 percent in many zones (Figures D.2 and D.4). The small results for threshold accessibility be an artifact of the strong concentration of employment in the CBD and at the airport, which means that most zones remain within or outside the 60-minute radius of these centers, but a few may shift from outside to inside this radius, leading to much larger effects.[2] Project C also shows a pattern of some zones gaining significantly in 60-minute accessibility and other zones losing accessibility (Figure D.5). The distance-weighted measure (Figure D.6) shows much more uniform but generally lower-magnitude results for Project C (less than a 5 percent change for most TAZs).

Based on this analysis, the distance-weighted measures appear to show more spatially uniform and intuitive results for both projects. However, these measures should be evaluated and compared with data from other projects if they are to be used further. The patterns shown in Figures D.1 through D.6 can be considered to be a rudimentary indicator of where the transit project is most likely to create development impacts and related environmental impacts, with the areas of greatest accessibility change representing the areas of greatest potential impact.

[2] Project B with the 60-minute threshold was modeled assuming a full-build transit network. Therefore, accessibility benefits also are seen for areas served by other transit corridors in the proposed system.

Figure D.1 Transit Accessibility Change – Project A
Peak-Period, 60-Minute Threshold

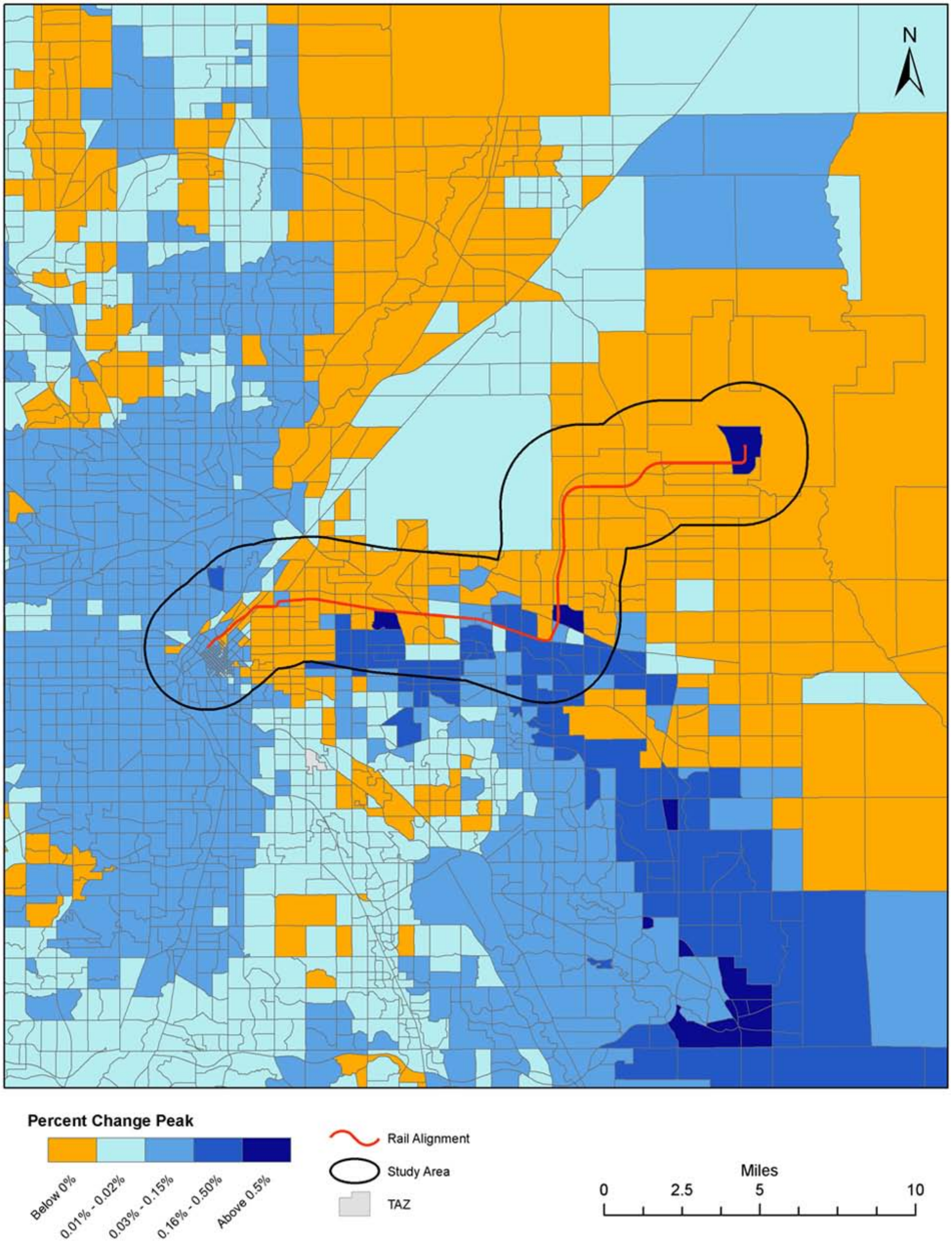


Figure D.2 Transit Accessibility Change – Project A
Peak-Period, Gravity-Weighted

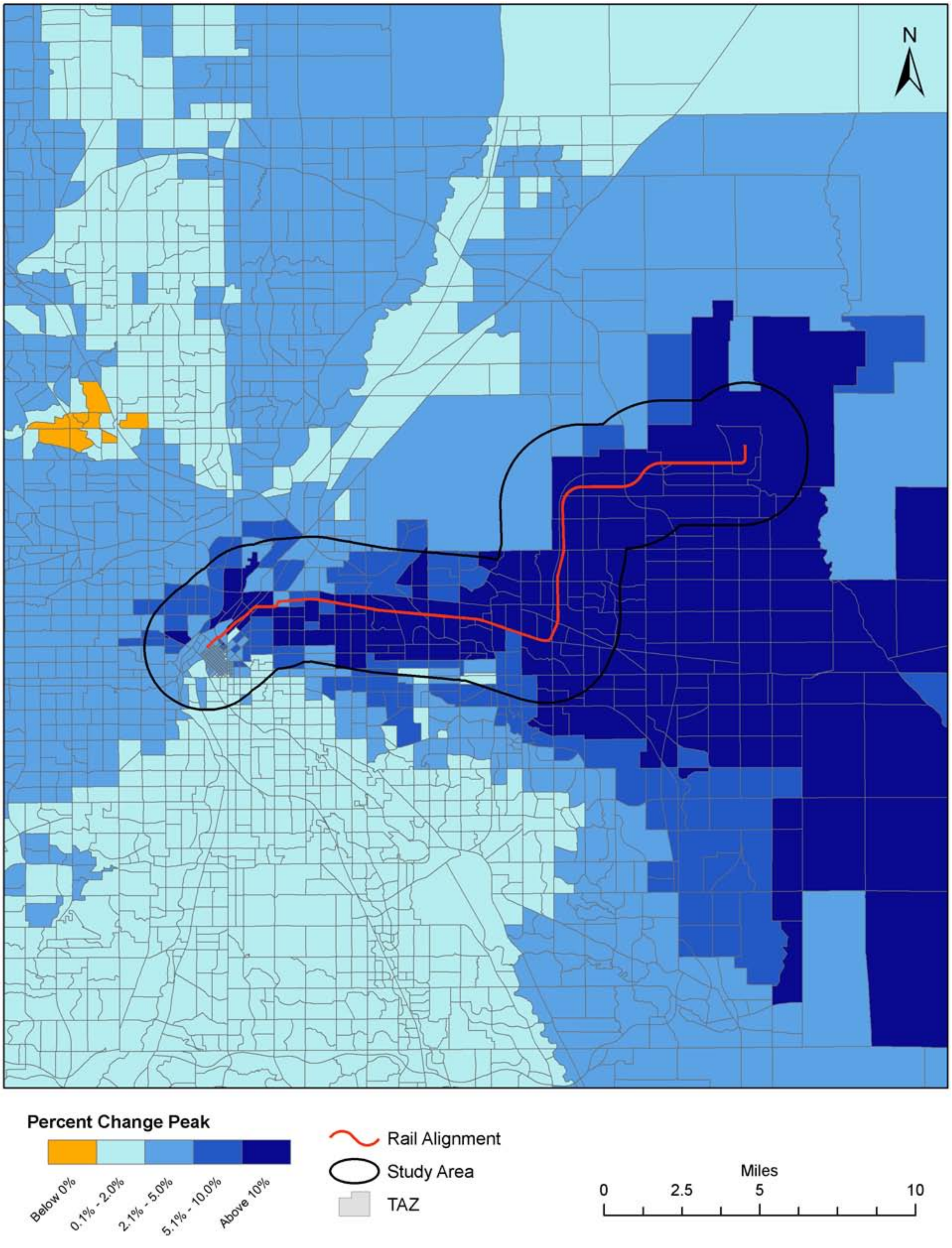


Figure D.3 Transit Accessibility Change – Project B
Peak-Period, 60-Minute Threshold

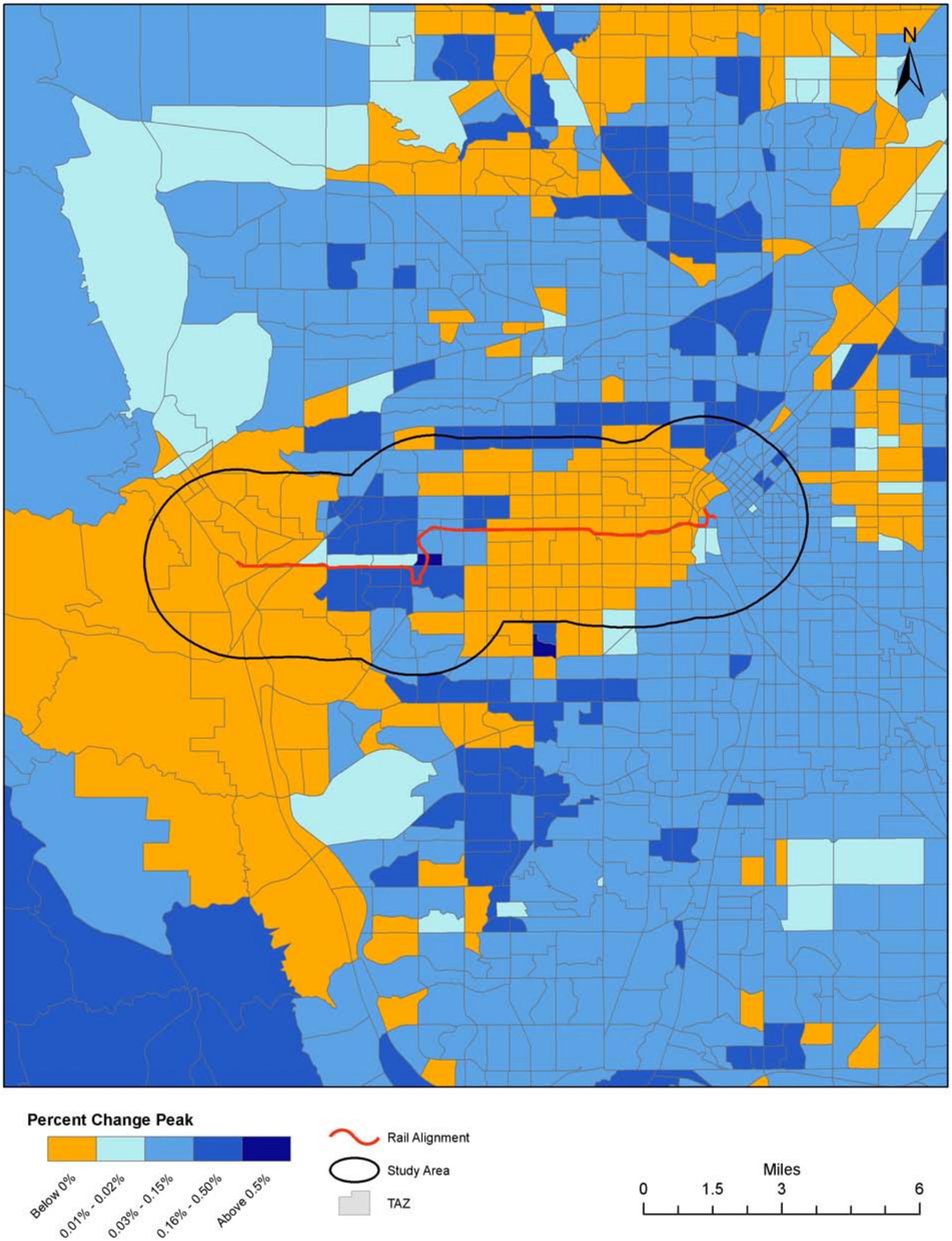


Figure D.4 Transit Accessibility Change – Project B
Peak-Period, Gravity-Weighted

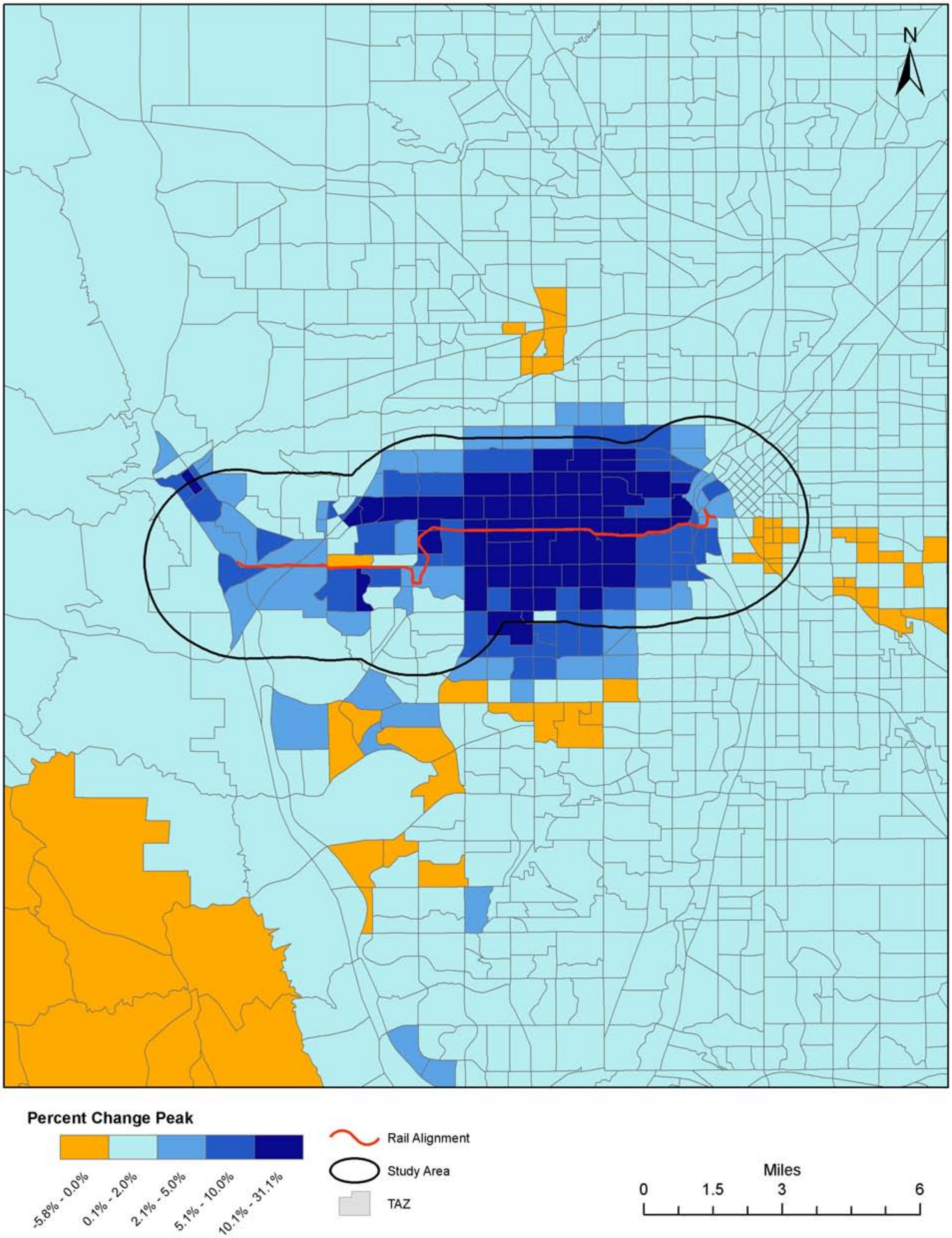


Figure D.5 Transit Accessibility Change – Project C
Peak-Period, 60-Minute Threshold

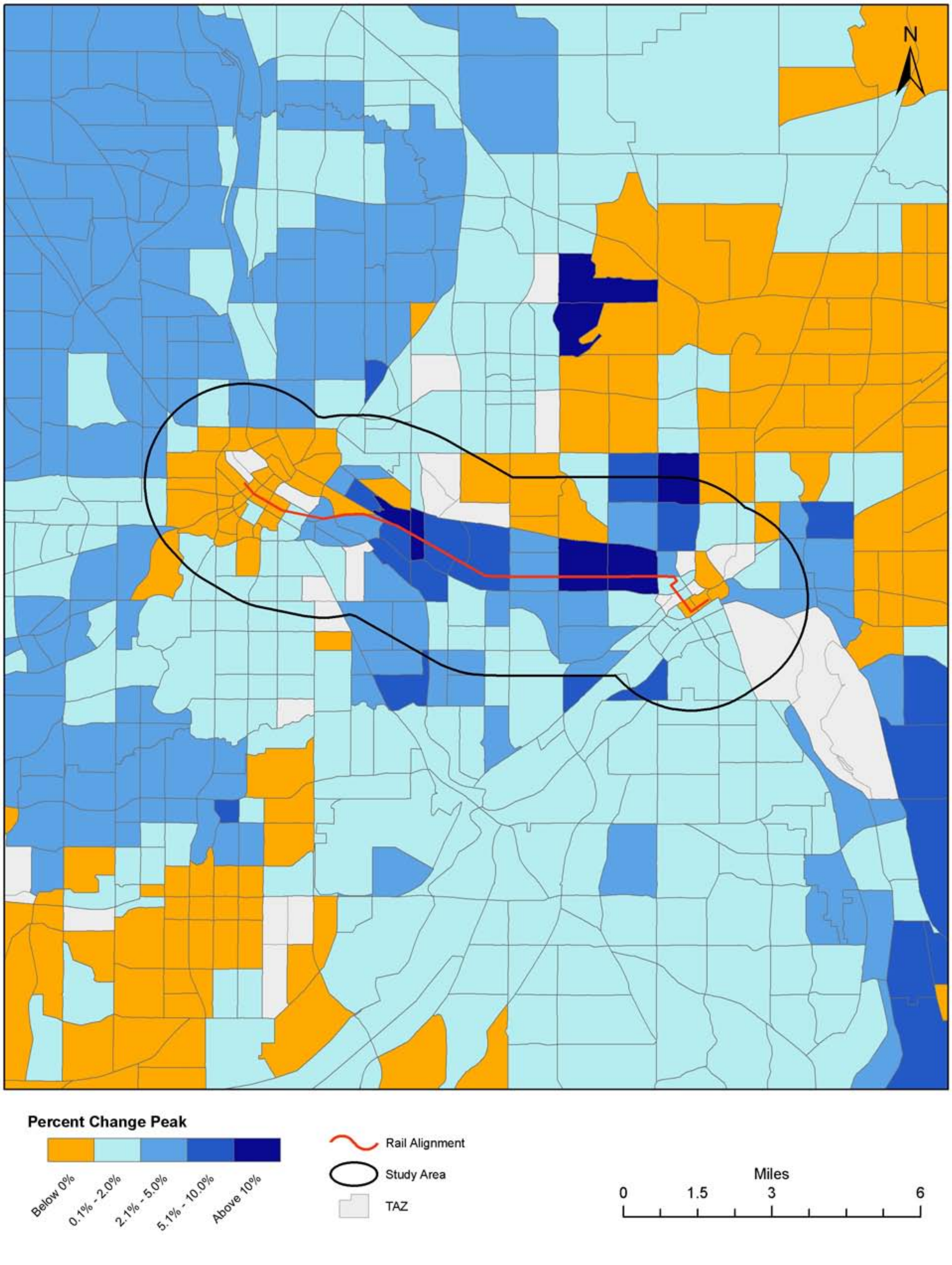
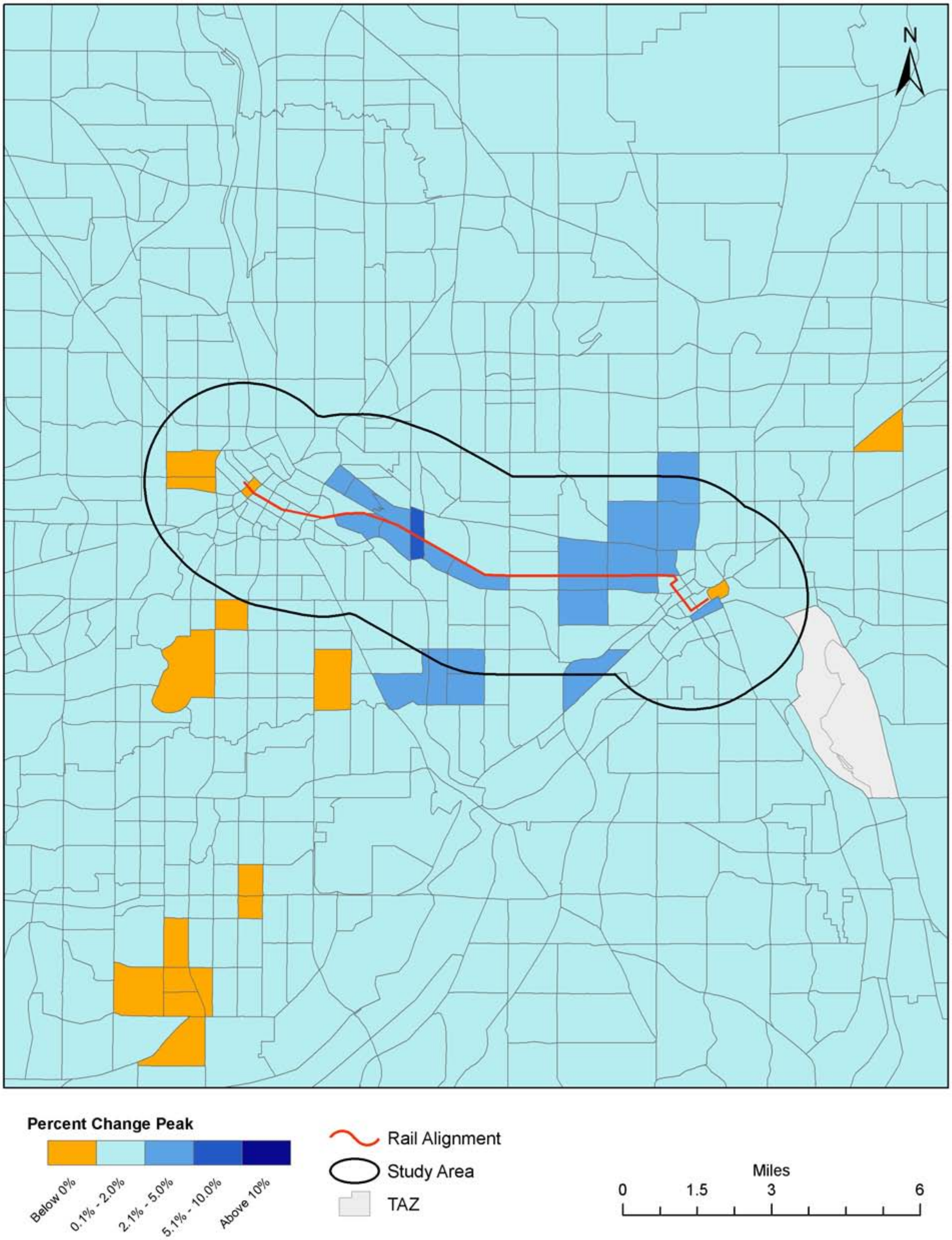


Figure D.6 Transit Accessibility Change – Project C
Peak-Period, Gravity-Weighted



Alternative Indicator – Summit User Benefits Measures

Transit project sponsors already compute (and map) a set of metrics that are related to accessibility as part of their New Starts submission. These are the user benefits metrics computed using FTA's Summit software. The user benefits metrics reflect changes in generalized travel cost (travel time and cost with different weightings for different components of travel time) between TAZs, combined with the forecast number of riders for each TAZ pair. In essence they are an accessibility measure that is based on actual (forecast) attraction between zones, rather than hypothetical attraction based on the amount of population and employment.

Matrices and maps are produced showing total user benefits for individual trip types (e.g., home-based work) and for all trip types by production district (rows) and attraction district (columns). Sample summary maps from Project A's New Starts submission are attached. The user benefits by production zone show a pattern somewhat similar to the distance-weighted accessibility measure, although more concentrated in zones adjacent to or near the transit alignment. The user benefits by attraction zone show strong concentration in zones with a significant employment base near the transit alignment, especially the CBD and airport. The use of Summit-produced measures could be considered as an alternative to computing accessibility changes for the purposes of showing potential impact areas.

Combined Measures of Potential Impacts

While the intent was to weight land uses by potential impact, this was not done due to the challenges encountered with developing consistent and useful land use data. Since a reliable indicator of affected sensitive land uses in the corridor could not be developed, the project team did not see any value in weighting land area by potential impact. Because of this, the project team also determined that it was not worth the effort to compute accessibility measures for additional projects for which travel-time skims were not readily available.

This does not mean that the exercise was a failure. The accessibility measures by themselves are interesting as a graphical means of showing the geographic extent of a project's potential benefits as well as the relative magnitude of those benefits as measured in terms of increased accessibility. However, these outcomes describe the transportation benefits of the project rather than the environmental benefits. An application to use the accessibility data to develop reliable indicators of environmental impact could not be produced with currently available data.

D.2 Metric IIIE – Adequacy of State, Regional, and Local Habitat Protection Plans

This metric is based on a qualitative assessment of state, regional, and local wildlife and habitat protection plans and measures. The objective of the metric is to describe the extent to which any potential negative environmental impacts associated with development induced by the transit project are likely to be mitigated or avoided through conservation planning. This metric is similar to FTA's current land use criterion in that it relies on reviewer assessment of plans and policies. (There is some overlap with the current "growth management" evaluation factor under land use plans and policies.) However, it attempts to establish greater objectivity through specific evaluation factors, defined as objectively as possible, with points assigned to each. It is designed as a proxy for likely environmental impacts related to transit-induced growth, without attempting to forecast actual growth impacts, which has proven to be a challenging if not impossible exercise.

A review procedure was developed and tested that contains a mix of objective and subjective criteria, scored on a scale to total 100 points. The procedure was developed by one team contractor and independently applied by two others to determine its utility and ease of use. The template includes categories (factors to be assessed), criteria for assessing these factors (objective where possible), and scoring for each factor. The template is shown in Table D.4. Table D.4 also includes sample results for two pilot projects. The assessments were conducted by two different contractors, and the assessments were not cross-checked for consistency.

Table D.4 Template for Assessment of State, Regional, and Local Habitat Protection Plans

Category	Criteria	Draft Scoring
Federal – 25 points possible		
Are there threatened or endangered species under the Endangered Species Act (ESA) in the project area (i.e., county or counties)? See: "Find endangered species in your county": http://www.fws.gov/endangered/.		If no threatened or endangered species, or critical habitat, are present = 25 points.
If so, do one or more of the following ESA-related protections exist for each species? 1. Local Recovery Plans (ESA §4(f)): http://www.fws.gov/endangered/. 2. Critical Habitat (ESA §4): http://criticalhabitat.fws.gov/. 3. Habitat Conservation Plans (ESA §10): a. See Conservation Plans and Agreements Database: http://ecos.fws.gov/conserv_plans/public.jsp. **[25 points]**	a. The plans identify specific conservation areas, or provide other guidance that would help avoid habitat impacts when siting a project. b. The plans identify specific actions to be taken, with a timeline. c. Conservation lands that might be affected by a project (e.g., transit) require specific mitigation.	Plans in place (10 pts possible): • All listed species = 10 points; • Half of listed species = 5 points; and • None of listed species = 0 points. Quality of plans, per criteria: • High = 15 points; • Medium = 10 points; • Low = 5 points; and • No plans = 0 points.
State – 30 points possible		
1. Is there an environmental impact disclosure requirement (i.e., a state analogue to NEPA)? **[6 points]**	a. Potential impacts on ecological values or habitat can trigger a full analysis (unless fully mitigated). b. The statute or rule requires analysis of secondary and cumulative impacts.	No state analogue = 0 points. State analogue exists and: • Meets criteria = 6; • Meets one criterion = 4; and • Meets neither criterion = 2 points.

Table D.4 Template for Assessment of State, Regional, and Local Habitat Protection Plans (continued)

Category	Criteria	Draft Scoring
State – 30 points possible (continued)		
2. Does the state have an approved Comprehensive Wildlife Conservation Strategy (aka **State Wildlife Action Plan** (SWAP) (16 USC 669))? See: http://www.wildlifeactionplans.org/about/action_plans_text.html. **[6 points]**	a. Approved SWAP? b. The SWAP includes strategies to protect any endangered/threatened species, or other species of concern, in the project area. c. Transportation projects are required to be consistent with the SWAP. d. Transportation proponents are required to consult with state/Federal wildlife agencies.	No approved SWAP = 0 points. Quality of SWAP, per criteria: • High = 6 points; • Medium = 4 points; and • Low = 2 points.
3. Shoreline/coastline/wetland/natural area protection law(s). **[6 points]**	a. Extent of lands covered by the law(s). b. Laws include mechanism to identify high natural resource value lands. c. Laws include enforceable protections for identified lands. d. Staffing is adequate to oversee/enforce the laws.	No such laws = 0 points. Weigh coverage and quality of law: • High = 6 points; • Medium = 4 points; and • Low = 2 points.
4. State-based growth management policies, plans, and regulations? **[6 points]**	a. The state requires locally based growth management policies to be developed and adopted. - State requires policies to be enforceable. - State maintains oversight over implementation.	No state role in growth management = 0 points. Plan exists and state role, per criteria: • Meets both criteria = 6; • Meets one criterion = 4; and • Meets neither criterion = 2 points.

Table D.4 Template for Assessment of State, Regional, and Local Habitat Protection Plans (continued)

Category	Criteria	Draft Scoring
State – 30 points possible (continued)		
5. Water quality regulations, including stormwater regulations. **[4 points]**	a. Regulations apply during construction in the transit corridor. b. Regulations apply in new residential, commercial, and industrial development areas. c. Regulations restrict amount of impervious surfaces, and/or construction of new impervious surfaces. d. Regulations restrict quantity and quality of storm-water runoff onto conservation lands.	Quality of regulations, per criteria: • High = 4 points; • Medium = 3 points; and • Low = 1 point.
6. Conservation easement laws. **[2 points]**	a. There is a clear statutory authorization for long-term/ permanent conservation easements.	Yes = 2 points. Murky authorization = 1 point. No law addressing conservation easements = 0 points.
Local (City/County) – 45 points		
1. **Availability of GIS data** related to land cover classifications in the project area? a. GIS allows calculation of acreage of the following land cover types in the affected corridor: - Already-developed land; - Undeveloped land; - Wetlands; - Critical habitat; and - Other high resource value lands. **[5 points]**		One point for each data set.

Table D.4 Template for Assessment of State, Regional, and Local Habitat Protection Plans (continued)

Category	Criteria	Draft Scoring
Local (City/County) – 45 points (continued)		
2. **Regional and Local Land use policies**, including: - Locally based growth management plans; - Comprehensive plans; - Zoning; and - Development and subdivision regulations. **[30 points]**	a. The policies and regulations restrict development (including development that is secondary to, or indirectly induced by, the transportation project) that would affect sensitive habitat areas. - They apply to the entire area affected by the project (i.e., local jurisdictions have adopted regional policies, if such adoption is necessary for policies to be applicable). - Policies and regulations support concentrated development to minimize the overall footprint of development. - They are enforceable: ▪ A permit is required. Additional useful data: How many permits have been a) issued without conditions; b) issued with conditions; and c) denied? How many enforcement actions have been taken? - They are free of major exemptions that would reduce their effectiveness in protecting habitat and ecological values (e.g., for transportation projects). - Local jurisdictions have staff to oversee and enforce the policies. - Regional and local capital improvement programs are required to be consistent with policies and regulations. - Regional and local economic development plans are consistent with policies and regulations. - There are specific growth management boundaries. - They include financial incentives/disincentives to promote desirable development (e.g., impact fees).	No local comprehensive plan or zoning, etc. = 0 points. Quality of plans per criteria: • High = 30 points; • Medium = 20 points; and • Low = 10 points.

Table D.4 Template for Assessment of State, Regional, and Local Habitat Protection Plans (continued)

Category	Criteria	Draft Scoring
Local (City/County) – 45 points (continued)		
3. **Specific local critical area ordinances,** e.g., to protect wetlands or other high resource value lands. **[5 points]**	a. Extent of lands covered by the ordinance. b. Ordinance includes mechanism to identify high natural resource value lands. c. Ordinance includes enforceable protections for identified lands. d. Staffing is adequate to oversee/enforce the ordinance.	No ordinances = 0 points. Weigh Coverage and quality of ordinance: • High = 5 points; • Medium = 3 points; and • Low = 1 points.
4. Is there a mechanism to execute a **Transfer of Development Rights** so that high resource value land can be permanently protected from development? **[5 points]**	a. There an information sharing/brokerage function or facilitators available to match buyers and sellers of development rights.	• TDR program with brokerage function in place = 5 points; • TDR program exists = 3 points; and • TDR program planned = 1 point.
TOTAL SCORE (possible 100 points)		

The criteria are divided into three general categories:

1. **Federal –** State, regional, and local plans to address Federal requirements for endangered species protection;

2. **State –** State environmental review procedures, wildlife action plans, habitat protection laws, growth management regulations, and other laws and tools for environmental protection; and

3. **Local –** Availability of state, regional, and/or local data to inform decision-making; regional and local plans, ordinances, and tools to protect habitat.

The weighting (points assigned) is arbitrary and reflect the project team's judgment regarding the relative importance of each factor. However, the specific weightings are not important for purposes of testing the utility of this evaluation approach.

If this template were to be applied for project evaluation, it should be further tested by applying it to more projects and refining the evaluation and weighting system. However, because of the resource-intensive nature of its application (particularly for assessing local plans and policies) and the difficulty in evaluating some factors (such as staffing and enforcement levels), the project team chose not to conduct further development and application of the template.

Appendix E – Level of Service and Other Measures for Assessing Pedestrian and Bicycle Access to Transit

E.1 Introduction

This white paper discusses multimodal level of service (LOS) measures and other metrics that can be used to indicate the quality of pedestrian and bicycle access in and around transit station areas. The paper has been prepared in support of TCRP Project H-41, the goal of which is to identify environmental performance metrics for transit projects. Walkability and bikeability metrics were identified in the Phase 1 Interim Report for this project (September 2010) as potential proxy measures for the physical activity and associated public health benefits of a project (Table H.1, Metric No. 107). While such metrics do not measure physical activity directly, they do provide an indicator of how likely the project is to support additional levels of walking and bicycling based on the presence of a supportive local (station area or corridor) environment.

Walkability and bikeability metrics, as well as transit LOS metrics, also could potentially be used as indicators of transportation choice, which may be considered a community and quality of life benefit (Table H.1, Metric No. 109). While it was determined to exclude community and quality of life metrics from further consideration in H-41 and to focus instead on more traditional environmental benefits, such metrics may still be of interest to FTA and project sponsors. Finally, the metrics presented also could potentially be used as quantitative indicators for the transit-supportive land use criterion which FTA currently evaluates from a qualitative standpoint.

This paper includes the following sections:

- An overview of level/quality of service measures, including walking, bicycling, transit, and multimodal measures;
- A discussion of design guidelines and how they may inform the development of metrics;
- An overview of area-level walkability indicators;
- A summary of previous research for FTA on pedestrian accessibility measures, conducted in support of the land use assessment process;

- Technology applications for level of service measures; and
- Conclusions regarding application of these metrics to transit environmental benefits evaluation.

E.2 Level/Quality of Service Measures

LOS originated as a concept to measure the quality of automobile travel. The primary methodology for determining transportation LOS measures in the U.S. is presented in the Highway Capacity Manual (HCM). The HCM was first created in 1950 by the Federal government. LOS is represented using a score of A to F (A being the best), and was at first primarily a measure of automobile vehicle speed and levels of congestion along roadway segments and at intersections. The Manual has gone through numerous updates and the most recent version, 2010, includes a multimodal LOS measure (automobile, transit, bicycle, and pedestrian) to compare service changes for different modes along single transportation facilities or corridors. Whereas nonautomobile modes were in earlier versions characterized, often inaccurately, based on travel speeds and capacity, new measures more accurately reflect user perceptions of transit, walking, and bicycling environments.

Multimodal Level of Service

The concept of multimodal level of service includes a number of methodological frameworks that integrate LOS measures for automobile, transit, bicycling, and walking. While measures for each of these modes have been developed as individual methodologies from various sources, the frameworks have recently been combined to integrate calculations to allow for comparison of multimodal LOS measures on segments of road. Multimodal analysis has been incorporated into the 2010 HCM, due to be released in April 2011. The methodology creates LOS measures for each mode that can be compared and used to measure the effects of changes in transportation infrastructure and transit service.

The methods in the 2010 HCM are based on NCHRP Report 616, Multimodal Level of Service Analysis for Urban Streets (and NCHRP Web-Document 128 – Users Guide). This report presents a framework and methods for determining levels of service for the four modes on urban streets. The LOS models were intended to evaluate "complete streets" and "context-sensitive" design strategies and are sensitive to street design (e.g., number of lanes, widths, and landscaping), traffic control devices (signal timing, speed limits), and traffic volumes. For example, improved signal timing increases car and bus speeds which increases car and bus LOS. However, the higher speeds reduce the LOS perceived by bicyclists and pedestrians. Similarly, planners can test the effects on both motorists and bicyclists of reducing a four-lane street to three general travel lanes with bicycle lanes. Table E.1 shows the data required to develop the multimodal LOS.

Table E.1 Multimodal Level of Service Data Needs

Street Geometry	
Number of through lanes (#)	No default
Travel lane widths (feet)	12 feet of local default
Median width (if present) (feet)	12 feet or local default
Bike lane width (if present) (feet)	5 feet or local default
Shoulder width (if present) (feet)	No default
Parking lane width (of present) (feet)	8 feet or local default
Presence of barrier in planter strip (yes/no)	No default
Sidewalk width (if present) (feet)	5 feet or local default
Presence of left turn lane(s) at intersection (yes/no)	No default
Length of analysis segment (feet)	No Default
Presence of right turn channelization islands at intersections (yes/no)	No Default
Cross-street through lanes at intersections (#)	No Default
Cross-street width curb to curb (#)	No Default
Number of transit stops (#)	No Default
Percent of transit stops with shelters (%)	Use local defaults
Percent of transit stops with benches (%)	Use local defaults
Unsignalized intersection and driveways (#/mile)	Use local defaults
Pavement condition (1-5)	3 for satisfactory condition
Demand	
Intersection vehicle turning moves (vph)	No Default
Vehicle right turn on red volume (vph)	No Default
Vehicle peak hour factor (PHF)	0.92 or local default
Percent heavy vehicles	5% or local default
Local bus volume (vph)	No Default
On-time performance of transit (%)	75% or local default
Peak passenger load factor for transit (passenger/seat)	0.80 or local default
Pedestrian volume (pph)	No default
Percent of on-street parking occupied (%)	50% or local default
Intersection Control	
Saturation flow rate through lanes (vphgl)	1,800 or local default
Green time per cycle for through move (g/c)	0.40 or local default
Green time per cycle for cross-street (g/c)	0.40 or local default
Cycle length (sec)	100 seconds or local default
Quality of progression (1-5)	Use 3 for random progress
Speed limit (mph)	Use local defaults
Cross street speed limit (mph)	Use local default

Source: Dowling, R. (2008), *Multimodal Level of Service Analysis for Urban Streets* (2008). NCHRP Report 616, Transportation Research Board, Washington, D.C.

Bicycle and Pedestrian Levels of Service

The HCM, and NCHRP Report 616, have incorporated methodologies from past studies to develop walking and cycling LOS measures. Key studies and reports are summarized below.

One of the first reports to apply an LOS framework to pedestrian and bicycling facilities was by Linda Dixon for the Transportation Research Record. The report illustrated how a basic LOS rating for both pedestrian and cycling facilities could be constructed.[1] The score was based on seven criteria each, presented in Table E.2, with the score total resulting in an LOS rating of A through F.

Table E.2 Bicycle and Pedestrian Level of Service

Bicycle	Score Range	Pedestrian	Score Range
Facility Provided: lane width, off-street	0-6	Facility Provided: type, width, off street	0-6
Conflicts: driveways, barriers, parking, visibility, intersections	0.5-1	Conflicts: driveways, streets, signal delay, crossing dist., road speed, medians	0.5-1
Speed Differential	0-2	Amenities: buffer, benches, lights, trees	0.5-1
Motor Vehicle LOS: lanes	0-2	Motor Vehicle LOS: lanes	0-2
Maintenance	(-1)-2	Maintenance	(-1)-2
TDM/Multimodal Support	0-1	TDM/Multimodal Support	0-1
Segment Weight: Based on corridor length		Segment Weight: Based on corridor length	

Source: Dixon, L. (1996).

The FHWA report *Capacity Analysis of Pedestrian and Bicycle Facilities* provided a methodology to evaluate and implement new types of pedestrian and cycling facilities and incorporate up-to-date information on transportation facility design.[2] The methodology was developed for and included in the HCM.

[1] Dixon, L. (1996). *Bicycle and Pedestrian Level of Service Performance Measures and Standards for Congestion Management Systems.* Transportation Research Record 1538 pages 1–9, Transportation Research Board, Washington, D.C.

[2] Rouphail, N., et al. (1998). *Capacity Analysis of Pedestrian and Bicycle Facilities.* Report No. FHWA-HRT-98-107, Federal Highway Administration, Washington, D.C.

The Florida Department of Transportation (DOT), with Bruce Landis, contributed to the pedestrian LOS measures, most recently in 2001 with a quantitative LOS model.[3] The study identified roadway and traffic variables describing pedestrians' perception of safety and comfort and expands on the methodology in the HCM.

Landis' earlier work also included a bicycle LOS model (Table E.3).[4] The model estimates the suitability of a roadway to accommodate cyclists safely based on a similarly quantitative process. The model can be used to both evaluate existing facilities and evaluate roadways to identify good locations for future bicycle investments.

Ann Vernez Moudon has authored reports empirically studying the attributes of walkable routes and walkable neighborhoods, identifying areas such as grocery stores, parks, and particular land uses as key elements.[5]

In a study by Michael Ianoco, researchers note the difficulties of calculating nonmotorized accessibility measures, citing issues with data availability, data quality, the zonal structure of transportation planning models (versus the small-scale areas associated with walking), and the adequacy of models and travel networks for describing nonmotorized travel.[6] The authors present practical strategies for addressing some issues and also suggest that a high degree of accuracy in measurements is not needed for identifying places needing design applications.

The U.S. Department of Transportation developed bicycling-specific LOS measures with the Bicycle Compatibility Index (BCI).[7] The BCI provides common methods to evaluate existing facilities, identify possible improvements, and determine operational and geometric requirements for new facilities. The index incorporated research on bicyclists' comfort levels on roadways, reflected in operational conditions.

---

[3] Landis, Bruce, et al. (2001). *Modeling the Roadside Walking Environment: Pedestrian Level of Service*. Transportation Research Record 1773 pages 82-88, Transportation Research Board, Washington, D.C.

[4] Landis, Bruce W. et al. (1997). *Real-Time Human Perceptions: Toward a Bicycle Level of Service*. Transportation Research Record 1578, Transportation Research Board, Washington, D.C.

[5] Moudon, Anne Vernez, et al. (2006). *Operational Definitions of Walkable Neighborhood: Theoretical and Empirical Insight*. Journal of Physical Activity and Health, 3, S99-S117.

[6] Iacono, M., et al. (2010). *Measuring Nonmotorized Accessibility: Issues, Alternatives, and Execution*. Journal of Transport Geography 18, pages 133-140.

[7] Landis, Bruce, et al. (1998). *Development of the Bicycle Compatibility Index: A Level of Service Concept*. Final Report, No. FHWA-RD-98-072, Federal Highway Administration, Washington, D.C.

Table E.3 Landis (1997) Methodology for Bicycle Level of Service

Bicycle LOS = a1ln (Vol15/Ln) + a2SPt(1+10.38HV)2 + a3(1/PR5)2 + a4(We)2 + C

Where:		
Vol_{15}	=	Volume of directional traffic in 15 minute time period
Vol_1	=	(ADT x D x Kd)/(4 x PHF)
Where:		
ADT	=	Average Daily Traffic on the segment or link
D	=	Directional Factor (assumed = 0.565)
K_d	=	Peak to Daily Factor (assumed = 0.1)
PHF	=	Peak Hour Factor (assumed = 1.0)
L_n	=	Total number of directional through lanes
SP_t	=	Effective speed limit
SP_t	=	1.1199 $\ln(SP_p - 20) + 0.8103$
Where:		
SP_p	=	Posted speed limit (a surrogate for average running speed)
HV	=	Percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)
PR_5	=	FHWA's five point pavement surface condition rating
W_e	=	Average effective width of outside through lane:
Where:		
W_e	=	W_v – (10 ft x % OSPA) and Wl = 0
W_e	=	$W_v + W_l$ (1 – 2 x % OSPA) and $W_l > 0$ and $W_{ps} = 0$
W_e	=	$W_v + W_l$ – 2 (10 x % OSPA) and $W_l > 0$ and $W_{ps} > 0$ and a bikelane exists
Where:		
Wt	=	Total width of outside lane (and shoulder) pavement
OSPA	=	Percentage of segment with occupied on-street parking
W_l	=	Width of paving between the outside lane stripe and the edge of pavement
W_{ps}	=	Width of pavement striped for on-street parking
W_v	=	Effective width as a function of traffic volume
And:		
W_v	=	Wt if ADT > 4,000veh/day
W_v	=	Wt (2-0.00025 x ADT) if ADT £ 4,000veh/day, and if the street/road is undivided and unstriped.

And:

a_1: 0.507 a_2: 0.199 a_3: 7.066 a_4: – 0.005 C: 0.760

Where:

a_1- a_4 are coefficients established by the multivariate regression analysis.

Source: Landis (1997), ibid.

Variables required for the BCI include:

- Lane configuration (number of lanes);
- Curb lane width;
- Bicycle lane width;
- Pavement condition;
- Motor vehicle speed;
- Traffic volume;
- Heavy truck volume;
- Right turn volumes;
- On-street parking;
- Parking time limits; and
- Land use types (residential or other).

In 2003, Professor Anne Vernez Moudon evaluated 31 bicycling and walking LOS tools, in a broad evaluation of transportation-related "environmental audits."[8] The document synthesized instruments and evaluation methods, including both behavioral and spatial models, and summarized key topics. The inventory included categorization by purpose, user types, professional field, and scale, as well as the year published and a brief description. Nine instruments were categorized as "Level of Service" tools (Table E.4). Nearly all of these applied to the route quality, while one evaluated the surrounding area. Five measures were designed for pedestrian facilities and four were for bicycling facilities.

The study identified nearly 200 variables used in the models to describe the travel environment, which may serve as a catalog of applicable variables for LOS evaluations. The author notes that the large number of variables shows that there is a dearth of research to establish which variables will be best able to reflect relationships between nonmotorized travel and the user's environment. The author also notes that the models are specific to professional fields, noting that "instruments from the health field tend to undervalue the transportation components of walking and bicycling, whereas those from the transportation field disregard the physical activity aspects of travel." This would leave most tools falling short of a comprehensive LOS evaluation tool.

The Bicycle Environmental Quality Index by the San Francisco Department of Public Health was developed in 2009. It created a modified collection of 22 indicators, expanding on the BCI by incorporating indicators such as lane marking, slopes, bicycle parking, surrounding uses, and traffic calming features.

[8] Moudon, A.V., and C. Lee (2003). *Walking and Bicycling: An Evaluation of Environmental Audit Instruments*. American Journal of Health Promotion, Vol. 18, No. 1.

Table E.4 Summary of Environmental Audit Instruments Reviewed
Level of Service

Name	Modes	Description
Botma	Bicycle	Ranking of bicycle paths and trails based on bicyclist and pedestrian behaviors. Method used to validate audit and ranking not explained.
Dixon	Bicycle and Pedestrian	Ranking of road segments based on roadway characteristics and traffic conditions. Method used to validate audit and ranking not explained.
Eddy	Bicycle	Simple formula to rank road segments based on roadway characteristics and traffic conditions. Method used to validate audit and ranking not explained.
Florida DOT	Pedestrian	Ranking of road segments based on roadway characteristics and traffic conditions. Model calibrated and tested on 75 subjects for perception of safety and comfort.
Fort Collins	Pedestrian	Simple assessment of roadway characteristics, visual interest of environment, and sense of security. LOS for a given area yielded from the ranking. Target LOS provided for different types of pedestrian planning areas and corridors.
Khisty-PM	Pedestrian	Qualitative performance measures of pedestrians perception of safety, security, comfort, convenience, attractiveness, way finding and continuity.
Landis	Bicycle	Ranking of road segments based on roadway characteristics and traffic conditions. Model calibrated and tested on 150 subjects for levels of ‘‘perception’’ in real time.
Washington DOT	Pedestrian	Level of service based on design, location, and user factors; designed to audit road segment.

Source: Moudon and Lee (2003), ibid.

Private consulting firms have developed methodologies and tools to measure the quality of walking and bicycling infrastructure and experience. As the details for these methods are not publicly available, they are not covered here. General information, however, indicates that they are based on the principles laid out by previous research, and are often integrated with land use analysis tools and developed through geographic information systems.

Transit Level of Service

The Multimodal LOS measure incorporated into the HCM and presented in NCHRP Report 616 incorporates public transit LOS measures developed in the Transit Capacity and Quality of Service Manual.[9] The manual emphasizes the importance of the transit user's perspective in establishing quality of service and presents an A through F scale. The measure is not based on specific national standards, as the authors suggest individual agencies to set values based on their unique settings. Recognizing the difference between fixed-route and demand-responsive service, a separate demand responsive transit LOS was developed with scores of 1 through 8.

The transit LOS measures incorporate both service availability and comfort and convenience measures, as shown in Table E.5.

Table E.5 Summary of Transit Level of Service Measures

Fixed Route Transit	Demand Responsive Transit
Service Availability	
Headway in minutes	Response time
Number of hours of service	Days and hours available
Share of transit-supportive areas covered by transit[a]	On-time percentage
	Percent trips not served
Comfort and Convenience	
Difference between transit and automobile travel times (or only transit travel time)	Difference between transit and automobile travel time
Passenger load (persons per seat)	
Standing area (sq. ft. per person)	
On-time performance	
Headway adherence	
Missed trips	
Mechanical breakdowns	

Source: Kittleson & Associates, et al. (2003).

[a] Transit-supportive areas is defined in the TQSM as the portion of the area being analyzed that has a household density of at least three units per gross acre or an employment density of at least four jobs per gross acre.

---

[9] Kittleson & Associates, et al. (2003). *Transit Capacity and Quality of Service Manual, 2nd Edition*. Transit Cooperative Research Program Report 100, Transportation Research Board, Washington, D.C. http://www.trb.org/Main/Blurbs/Transit_Capacity_and_Quality_of_Service_Manual_2nd_153590.aspx.

E.3 Design Guidelines

Design guides are available from some municipal governments and can offer features that could be helpful in developing walking and bicycling LOS metrics. The cities of Los Angeles, Portland, and New York City (as well as others) have developed guides to inform the development of new streets. Minnesota DOT has developed a checklist that produces a generalized "score" of facility quality. The United Kingdom has developed a national guide for roadway policy and design, as well as a source of case studies that local governments can apply to a broad range of roadway types. From the sources listed below, metrics include the number of signalized crosswalks, the number or presence of traffic calming design such as bulb outs, posted speed limits, presence of bike lanes, and other nonmotorized safety features. The availability of design guidelines also could be used as a proxy to represent a comprehensive approach to transit supportive planning in an area.

- City of Los Angeles, California: http://www.urbandesignla.com/walkability/Crosswalks.pdf.
- City of Portland, Oregon: http://www.portlandonline.com/shared/cfm/image.cfm?id=84048.
- City of New York, New York: http://www.nyc.gov/html/dot/downloads/pdf/sdm_lores.pdf.
- Minnesota DOT: http://www.dot.state.mn.us/bike/pdfs/Bicycle_and_Pedestrian_Toolbox_2008_04.pdf.
- United Kingdom Department for Transport: http://www.dft.gov.uk/pgr/sustainable/manforstreets/.
- Transport Canada (Tools for Measuring Roadway Suitability for Bicycles): http://www.tc.gc.ca/eng/programs/environment-utsp-casestudy-cs44e-bikeindex-270.htm.

E.4 Area-Level Walkability Indicators

The LOS metrics described above are primarily intended for application at a facility level, although they can be aggregated across facilities to produce an average LOS for an area. Metrics also have been developed to describe the pedestrian environment and accessibility at an area level. Examples described here include pedestrian environment factors (PEF) and "3D" metrics of the built environment.

Pedestrian Environment Factors

Pedestrian environment factors have been defined as area-level metrics for the purposes of improving mode choice prediction in regional travel demand models. The factors are applied at a traffic analysis zone (TAZ) level, which is a similar geographic scale as the one-half-mile radius used by FTA in New Starts evaluation. The factors are designed to measure the quality of the pedestrian environment, and therefore to relate to the likelihood of walk trips occurring within the TAZ.

The specific factors that are included in a PEF metric vary, but can generally be measured through some combination of existing GIS data and field and/or aerial surveys. One example of a PEF is that developed by Portland Metro. The factor is based on four criteria:[10]

- Sidewalk availability;
- Ease of street crossing;
- Connectivity of street/sidewalk system; and
- Terrain.

Each of these is rated on a 0 to 3 point scale for a total of up to 12 points. They can be assessed qualitatively or quantitatively, if data are available. Montgomery County, Maryland developed a similar Pedestrian and Bicycle Environment Factor that is based on:

- Amount of sidewalks;
- Land use mix;
- Building setbacks;
- Transit stop conditions; and
- Bicycle infrastructure.

Each factor is assigned fractional points on a qualitative basis for an overall rating of between zero and one for each zone.

3D Metrics

The U.S. Environmental Protection Agency's (EPA) Smart Growth INDEX model included an approach that used elasticities of travel with respect to 3 "D's" – density, diversity, and design – to predict reductions in vehicle trips and VMT as a result of pedestrian design

[10] Schwartz, W.L., et al. (1999). *Guidebook on Methods to Estimate Nonmotorized Travel: Supporting Documentation.* Prepared for Federal Highway Administration, publication No. FHWA-RD-98-166.

factors. The "3D" methodology has since been incorporated in other sketch planning tools based on D-factors measured at a TAZ or neighborhood level, like the PEFs described above. The same factors would presumably relate to increases in walking and bicycling trips, although the 3D methodology has not been used explicitly for that purpose. The "design" factor in the Smart Growth INDEX model was specified as either the percent change in locally calibrated PEF, or the percent change in the "design index," which was computed as follows:[11]

Design Index = *0.0195 * street network density + 1.18 * sidewalk completeness + 3.63 * route directness*

where:

street network density = *length of street in miles/area of neighborhood in square miles*

sidewalk completeness = *length of sidewalk/length of public street frontage*

route directness = *average airline distance to the neighborhood center/average road distance to the neighborhood center*

The design index for a TAZ or neighborhood can be computed based on data on street centerlines, sidewalks, and location of neighborhood centers if stored in a GIS database.

E.5 Previous Research for FTA on Pedestrian Accessibility Measures

Research was undertaken for FTA in 2006 through 2008 to develop an enhanced set of indicators of the potential economic development benefits of transit projects.[12] These indicators included quantitative metrics describing the existing and planned pedestrian environment in proposed transit station areas. The pedestrian environment indicators were proposed as part of the evaluation factor, "Land use plans and policies encouraging transit-supportive development." As of this date, the rating system developed through this research has not been adopted by FTA.

To inform the research, a literature review was conducted to identify key metrics used to describe the walkability or pedestrian-friendliness of a neighborhood in research studies. Metrics were then tested on real-world data. Metrics were tested in three specific evaluation categories that relate to pedestrian accessibility:

---

[11] Criterion Planners/Engineers and Fehr & Peers Associates (2001). *Smart Growth INDEX Reference Guide.* Prepared for U.S. Environmental Protection Agency.

[12] Cambridge Systematics, Inc. for Federal Transit Administration. *Guidance for Evaluating the New Starts Economic Development Criterion*. Draft working document, September 25, 2008.

- Pedestrian network coverage and directness;
- Sidewalk availability; and
- Street crossings.

Additional metrics were tested relating to urban design (building setbacks and parking design), mix of uses, residential and commercial densities, and parking constraint. The following specific evaluation subfactors and metrics were proposed for pedestrian network coverage and sidewalk availability, and for building setbacks and parking design (which impact the pedestrian environment, if not directly affecting connectivity). It proved too difficult to determine a fair and quantitative metric for plans to provide adequate street crossings.

Subfactor 1 – Pedestrian Network Coverage and Connectivity

Metric: There exists, or plans specify, a continuous pedestrian network in the station area, with an average spacing of pedestrian connections of no more than 600 feet.

Ratings:
- Required (2):[13]
  - Area plan includes public network connections meeting spacing criteria and/or requirements for accessible connections within private developments; ***or***
  - A network meeting the criteria already exists (and there are no major redevelopment plans that would eliminate blocks).
- Recommended (1):
  - Adopted policies recommend a continuous pedestrian network meeting spacing criteria.
- Neutral (0):
  - Network connectivity not required or recommended.
- Not Allowed (-1):
  - Existing street/parcel layout precludes network connectivity; ***or***
  - Area plan shows network not meeting spacing requirements.

Comments:
- For undeveloped areas, refer to area master plans or development policies. For developed areas, use GoogleEarth, a GIS program, or a map and ruler to measure typical block lengths in the vicinity of the transit station. A "block" can be defined by 24-hour publicly accessible pedestrian passages, as well as streets. Parking lots do not count unless there is a defined pedestrian route, primarily separated from traffic, which traverses the lot.

[13] Numbers in parentheses represent points assigned.

- If there is a mix of block lengths, some less than and some exceeding the 600-foot threshold, use the following approach: With a path measurement tool, measure the perimeter of the four blocks located closest to the transit station (i.e., those with any part of the block closest to the station). Compute the average block face length by dividing the total perimeter of all four blocks by the total number of block faces (usually 16).

Subfactor 2 – Sidewalk Availability

Metric: Sidewalks (minimum eight feet wide in commercial areas containing street-fronting retail uses, five feet elsewhere) provided along all street frontage.

Ratings:
- Required (2):
  - Sidewalks required for new development.
- Recommended (1):
  - Adopted policies recommend sidewalks for new development.
- Neutral (0):
  - Sidewalks not required or recommended.
- Not Allowed (-1):
  - Sidewalks discouraged or prohibited (not likely to be assigned).

Comments:
- If the area is already covered by a publicly maintained sidewalk system and there is clear evidence that the city either provides or requires sidewalks in conjunction with new development, a (+1) rating may be assigned even if sidewalk provision is not explicitly addressed in the zoning code or other municipal ordinances.
- Google's Streetview program allows for two-dimensional viewing of some metropolitan areas at street level, in effect allowing one to drive the streets. This tool may be helpful in identifying the existence of sidewalks and pedestrian connections.

Subfactor 3 – Building Setbacks

Metric: Setbacks along street frontages (distance from the front of the building to the lot line) are no more than 15 feet for commercial or mixed-use properties and no more than 20 feet for residential properties.

Ratings:
- Required (2):
  - *Maximum* setbacks (as specified in zoning or binding design guidelines) are less than thresholds.
- Recommended (1):
  - Setbacks may be less than or greater than thresholds; setbacks less than the threshold are recommended in adopted policy or plan documents or design guidelines.

- Neutral (0):
  - Setbacks may be less than or greater than thresholds; no guidance specified in policy or plan documents or design guidelines.
- Not Allowed (-1):
  - *Minimum* setback requirements are greater than the thresholds.

Comments:

- If the setback condition is met for some uses but not others, see the guidance above under "spatial extent."
- Setback requirements will generally be found in the section of zoning pertaining to a specific type of use (residential, commercial, etc.). Different setback requirements may also be specified for overlay districts (e.g., pedestrian or transit overlay).
- It may not be possible to rate this factor for institutional areas (e.g., college or hospital campuses) as the traditional concept of a setback from the street may not be meaningful in a campus environment.

Subfactor 4 – Parking Design

Metric: No more than 30 percent of the street-fronting parcel length is for parking or automobile access/egress.

Ratings:

- Required (2):
  - Zoning code establishes this or a functionally similar requirement (e.g., parking must be in structures or behind building).
- Recommended (1):
  - Design guidelines adopted for this area include this or functionally similar recommendation.
- Neutral (0):
  - Location and design of parking not specified.
- Not Allowed (-1):
  - Parking is required in front of buildings (not likely to be assigned).

Comments:

- This metric is intended to focus on parking for newly built commercial, mixed-use, or multifamily structures. Except for districts with special design standards, such as transit or pedestrian overlay districts, most zoning codes will not specify the location of parking for these types of uses. Some zoning codes prohibit parking in the front yards of residential lots, but this alone should not justify a positive rating for this factor.
- Institutional master plans may be rated for this factor based on the extent to which parking is planned to be in structures versus surface lots. For example, a 2 rating could be assigned for master plans that call for all new future parking supply to be accommodated in structures and for redevelopment of surface lots with buildings.

■ E.6 Technology Applications for Level of Service Measures

Various technical tools (in addition to general statistical and GIS software) have been developed to assist in the evaluation of walking and cycling paths.

- **Walk Score** is available through a web site at no cost to the user.[14] The application is based on a GIS using Open Street Map and other data sources representing facilities, amenities, and other factors. The application produces a score from 1 to 100, based on distances to different types of amenities and destinations and road quality, with the latter, including intersection density, link/node ratios, and average block lengths. However, Walk Score is not available to produce scores for batches of locations, nor for overall corridor accessibility. The developers also have created Transit Score, which applies a similar process to evaluate neighborhood access to public transportation.

- **Ped INDEX** is a GIS application developed by Fehr & Peers to assess a community's pedestrian needs.[15] The process can identify key pedestrian locations through a process developed for the U.S. Environmental Protection Agency's Smart Growth INDEX. (Smart Growth INDEX is a sketch planning GIS tool for comparing alternative land use and transportation scenarios.) The product is an overall index of an area's walking potential and pedestrian facilities, identifying locations where pedestrian improvements can have the greatest safety benefits and encourage walking. The application evaluates demographics and socioeconomic data, distance to amenities, the pedestrian environment, policy areas, and the condition of blocks, traffic, and intersections.

- **WBC Analyst** is a GIS application developed at the University of Washington College of Architecture and Urban Planning. It has been considered theoretical and somewhat difficult to operate.[16] Research to develop the tool included quantitative analysis of land use and transportation data for King County, Washington, as well as a telephone survey to assess residents' propensity for walking and cycling.

---

[14] http://www.walkscore.com/.

[15] http://www.smartgrowthplanning.org/PDFs/PedIndexBrochureWeb.pdf, accessed January 20, 2011.

[16] http://proceedings.esri.com/library/userconf/proc05/papers/pap1040.pdf, accessed January 20, 2011.

E.7 Conclusions Regarding LOS and Walkability Metrics in Transit Project Evaluation

Multimodal LOS measures and other walkability metrics represent a potential way of assessing the existing or planned pedestrian and bicycle-friendliness of transit station areas, and therefore the potential extent to which the transit project may support increased physical activity, reductions in vehicle-travel, transportation choice, and other community quality-of-life factors. (They also can help inform local planning activities by identifying deficiencies in pedestrian and bicycle access.) The multimodal level of service measure, incorporated into the 2010 HCM, combines LOS measures for automobile, transit, bicycling and walking into one widely applicable methodology that allows for basic comparisons between modes.

The LOS measures are primarily intended to inform facility design, and are typically computed at a level of an individual roadway segment, rather than an entire station area. However, the segment-level scores can be averaged across an area to yield one LOS score by mode. Other metrics, including pedestrian environment factors, the walkability metrics developed for FTA, and WalkScore, are designed to be applied at an area level. Computing multimodal LOS or areawide walkability measures requires a fair amount of detail that would need to be collected for all major streets in a station area, although the detail can be combined using a software package such as the HCM methodology or Ped Index. In most cases, project sponsors or their local partners are unlikely to have collected all of the required data, unless they have already conducted areawide bicycle and pedestrian planning studies. Therefore, if such metrics are to be applied in New Starts project evaluation, it may be desirable to rely on simplified assessment methods such as the metrics proposed for FTA's land use assessment process. In the future, as local jurisdictions expand and improve their GIS data to more fully encompass bicycle and pedestrian-related variables, it may be possible to use more sophisticated tools to compute multimodal LOS or walkability metrics for different transit projects.

Appendix F – Environmental Performance Rating Systems for Transit Agencies and Projects

F.1 Introduction

The purpose of this white paper is to provide an overview of environmental performance rating systems that could potentially be applied to transportation projects, including new transit projects. These systems were initially identified in the literature search performed for this project and documented in the Phase I Interim Report (September 2010). The discussion below provides an assessment of whether and how each system might be applied to transit project evaluation. Two systems that have the greatest potential relevance and applicability to transit – FHWA's Sustainable Highways Self Evaluation Tool, and the University of Washington's Greenroads – are then explored in more detail, to provide an example of how they might be adapted.

These rating systems primarily evaluate efforts to mitigate the environmental impacts of the transit agency's own operations, rather than the environmental benefits of transportation system operations from mode shift, travel reduction, efficient vehicles, etc. If applied to evaluate projects in different regions of the country, one or more of these rating systems could be used in a "warrants" approach to determine whether the agency should receive credit in addition to other rating factors. The weight accorded to these factors should be generally proportional to the relative environmental impact; i.e., likely to be modest compared to the impacts from changes in transportation system operations.

F.2 Overview of Rating Systems

Infrastructure rating systems are tools available to transit practitioners to assess environmental performance of transportation investments. Most tools are not specific to public transportation infrastructure and operations, but include metrics that could apply to transit. The systems reviewed include:

- Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL);
- FHWA Sustainable Highways Self-Evaluation Tool;
- Green Globes;
- Greenroads;
- ISO 14000;
- Leadership in Energy and Environmental Design (LEED) and LEED for Neighborhood Development (LEED-ND);
- Ska Rating;
- Sustainable Infrastructure, Land Use, Environment and Transport Model (SILENT);
- STAR Community Index; and
- Sustainability Reporting Framework.

This summary presents possible modifications needed to apply the tools to public transportation projects. Further detail can be found in Appendix A: Annotated Bibliography of this report.

Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL)

Key Uses for Transit – Not applicable.

CEEQUAL is an assessment program aiming to improve sustainability in civil engineering and public infrastructure investments. This tool is not applicable to U.S. transit project evaluation because the review is offered in the United Kingdom only and requires fees to access the manual.

FHWA Sustainable Highways Self-Evaluation Tool

Key Uses for Transit – Possible adaptation for evaluation of planning, projects, and policy.

The FHWA Sustainable Highways Self-Evaluation Tool is used to evaluate the characteristics of highways and provide methodologies to integrate best practices into roadway projects and programs.[1] The tool is a collection of best practices, or credits, that can be identified in a way that assists organizations to research and apply those credits, and establish an evaluation method to measure the benefits of projects, practices and policies. There are 68 credits, grouped into three categories: System Planning, Project Development, and Operations and Maintenance. Each of the categories operates as an independent

[1] https://www.sustainablehighways.org/1/home.html.

evaluation tool for investments related to that category. For example, an evaluation of a highway project would use just the Project Development category and not the other two. Currently, it is not designed to mix credits from different categories. The FHWA did not create a system for third-party certification, so scores are presented as unofficial recognition that an agency or project has met the threshold (generally 30 to 60 percent of the total credits available).

Green Globes

Key Uses for Transit – Transit stations and other transit agency buildings.

Green Globes for Existing Buildings is an assessment and rating system for buildings in North America. The categories are somewhat similar to the United States Green Building Council's LEED system (see above). The points system is geared specifically to buildings and would, therefore, be best applied to those facility types. It differs from LEED by offering points rather than checklists, theoretically allowing for more variation within categories. However, a points-type system could be difficult to apply on a national scale to individual projects.

Greenroads

Key Uses for Transit – Design and construction of transit-only roadways and track.

The Greenroads program is a rating system designed to distinguish new or rehabilitated roads by awarding credits for design and construction choices that meet certain environmental criteria. The program offers four certification levels. The measures were developed for roadway use and would, therefore, be most applicable to roadways developed for transit, such as for BRT systems. The material lists could be adapted and the scores adjusted for use with rail track. Required measures are in a checklist style, such as the presence of a review plan, a waste management plan, a community outreach plan, and a safety audit.

ISO 14000 Environmental Management Systems Certification

Key Uses for Transit – Transit agency management and planning.

The ISO certification programs for environmental management systems (14001 and 14004) provides guidance that enables an organization to develop and implement policy and objectives which take into account legal requirements and other requirements for sustainable development. ISO does not provide specific indicators of environmental performance for transit projects, but does provide a framework for an organization to systematically prepare a comprehensive management plan. ISO suggests that certification is useful in preparing plans, sharing the results with people inside and outside an organization, and setting a framework for ongoing improvement of sustainability planning by committing to compliance with the ISO standards.

Leadership in Energy and Environmental Design (LEED) and LEED for Neighborhood Development (LEED-ND)

Key Uses for Transit – Design and construction of stations and surrounding landscape.

LEED-ND measures are most relevant for the siting and design of transit facilities, in particular large bus, train, and intermodal stations that include surrounding landscaping, including parking lots and walkways. The most direct application in project evaluation would be to include the level of LEED-ND rating awarded by the U.S. Green Building Council (silver, gold, platinum). The rating represents in one metric environmental measure of renewable energy use or purchase of green power, pollution prevention during construction, energy efficiency, water efficiency, waste and stormwater management, building reuse, historic and cultural preservation, heat reflection reduction, passive solar energy, recycled content, waste management, and nonmotorized vehicle access and storage.

Ska Rating

Key Uses for Transit – Not applicable.

Ska Rating is a system that corporations can use to inform fit-out of building projects for their offices. While some indicators also apply to transit facilities, it is more limited than the LEED-ND program. The system may be most interesting due to the program structure using "scopes" that affect which indicators apply to a specific project, allowing for some flexibility in evaluation.

STAR Community Index

Key Uses for Transit – Not applicable.

The STAR Community Index is a national framework for gauging the sustainability and livability of U.S. communities, with the target users being municipal governments. This tool is not applicable to measuring and comparing transit projects, as it is intended for a broad range of environmental, social, and economic indicators.

Sustainable Infrastructure, Land Use, Environment, and Transport Model (SILENT)

Key Uses for Transit – Land use analysis surrounding transit facilities.

The SILENT model is a geographic information system and indicator-based urban sustainability indexing model. Categories include environment, transport, land use, and demography. Transport indicators include transit mode share and proximity to housing and employment, pedestrian and bicycle network coverage, and automobile travel indicators (i.e., VKT, parking supply). Environment indicators cover waste, water use, energy use, GHG emissions, stormwater runoff, and noise pollution. A grid-based analysis is used to condense the analysis into comparable analysis unit sizes. The study could be useful to transit project evaluation by creating a uniform analysis structure. The article details methodologies for calculating indicators which, while not new, could provide some guidance for developing detailed assessment protocols.

Sustainability Reporting Framework (Global Reporting Initiative)

Key Uses for Transit – Provides key categories and measures for evaluation framework, including organizational, planning, operations, and construction.

The Sustainability Reporting Framework assists in the evaluation of organizational efforts to develop and monitor municipal programs. It is used to track policies and programs adopted by an organization rather than direct project performance. The framework categories are broad and include many categories crucial to evaluating the performance of transit projects. Core indicators include, but are not limited to, the amount of materials used, direct and indirect energy use, wildlife habitat impact, and GHG emissions. The framework is less specific than some evaluation frameworks. For example, the section on measuring direct and indirect emissions describes key areas of concern but does not specify facilities or modeling techniques to develop quantitative measures.

F.3 Examples of Application to Transit Project Evaluation

Two of the tools reviewed were selected to provide a more detailed example of how they might be applied to the environmental assessment of transit projects. These are the Greenroads system and the FHWA Sustainable Highways Self-Evaluation Tool. While both were developed for highway project evaluation, the framework fits to transit projects as well. Readers should note that the FHWA tool has simplified or combined many metrics from other highway evaluation tools. Indeed, key authors of the latest documentation on the FHWA Sustainable Highways also created Greenroads. This evaluation of Greenroads shows additional detail that could serve as a platform for creating transit-specific evaluation metrics.

Greenroads

According to the rating system developers, a Greenroads is a "roadway project that has been designed and constructed to a level of sustainability that is substantially higher than current common practice." As noted above, Greenroads awards credits for design and construction choices that meet certain environmental criteria. There are 11 required criteria, all measured by a yes or no value, and 39 other criteria in six categories of environmental health indicators. It is a publicly available tool and results in a ranking system of four levels (platinum, gold, silver, bronze), similar to LEED.

Table F.1 presents an analysis of the Greenroads certification system metrics. The table includes the criteria name, a short description, the number of points awarded for each criteria, the expected effort required to calculate and document the metric, and information on how the criteria might be changed to apply to transit projects. The Greenroads manual provides a high level of detail on how each criteria should be measured, including methodologies and examples. The suggested changes column includes changes to methodology incorporating transit-specific materials and service requirements, as well as changes to score values to adjust the weight given by scores for each criteria.

Please note that Table F.1 includes a column on the expected effort required, while Table F.2, for the FHWA Sustainable Highways Evaluation Tool, does not have this detail. The reason is that the documentation for Greenroads had substantial documentation that allowed for additional detail.

Table F.1 Greenroads Criteria

ID	Credit	Description	Effort Required/Expected	Points	Change for Transit Projects
Required					
PR-1	Environmental Review Process	Environmental compliance tracking system to identify commitments. Follow jurisdictional requirements for more detailed environmental review documents such as EIS or EA to determine the significance of environmental impacts.	Low. Should include the final decision documentation from existing NEPA or state environmental review.	REQ	No change in methodology.
PR-2	Life-Cycle Cost Analysis (LCCA)	Perform LCCA covering 40 or more years. Calculate LCCA, including project alternatives and scenarios. Benefit/cost analysis should include agency costs, user costs and may include third-party costs.	Medium. May require substantial effort where existing policy or funding requirements do not include LCCA.	REQ	Include transit-specific material data, transit ridership and service information, and possibility of including "avoided auto trip" methodology.
PR-3	Life-Cycle Inventory (LCI)	Perform LCI of pavement section. Suggest using PaLATE LCI software. If other software is used, requires documentation of data sources, inputs, and output values for total energy use.	High. Data needs and documentation.	REQ	Changes to materials, material transportation, equipment type and emissions evaluated, and possible adjustment to software.
PR-4	Quality Control Plan	Have a formal contractor quality control plan to monitor and improve construction quality. To address quality control personnel and procedures used to monitor product quality (materials, testing, corrective actions, modifications to plan).	Low. Should not repeat contract specifications, but be specific to quality control, approximately 6 to 12 pages.	REQ	No change in methodology.
PR-5	Noise Mitigation Plan	Address responsible parties and qualifications, nearby receptors, construction activities, work dates and hours, noise-generating activities, permits, monitoring standards and methods, and corrective actions.	Low. Should not repeat local/state noise mitigation documentation. Need not be a large document.	REQ	No change in methodology.
PR-6	Waste Management Plan	Have a plan to divert construction and demolition waste from landfill that is included in work contracts. Address expected waste amount by type, costs, hauling contractor, destinations, mobile offices, and related household waste.	Low. A copy of an existing CWMP is required. Typically completed by a subcontractor.	REQ	No change in methodology.

Table F.1 Greenroads Criteria (continued)

ID	Credit	Description	Effort Required/Expected	Points	Change for Transit Projects
Required (continued)					
PR-7	Pollution Prevention Plan	Stormwater Pollution Prevention Plan that conforms to requirements of the current EPA Construction General Permit or the local or state permit, whichever is more stringent. Address water quality and dust control during construction.	Low. A copy of an existing plan required. Typically prepared by subcontractors.	REQ	No change in methodology.
PR-8	Low-Impact Development (LID)	Create LID best management practices for stormwater management in ROW through a written LID hydrologic evaluation. The evaluation should mimic predevelopment conditions and be completed for all project types.	Medium. Requires creation of separate LID document by licensed professional. Can be scaled based on project scope.	REQ	No change in methodology.
PR-9	Pavement/Bridge Management System	Have a pavement or bridge management systems. Inspect and analyze conditions at least once every two years. Possess documented decision criteria for timing preservation actions and record activities.	Low. Existing documentation sufficient.	REQ	A separate asset management system may be required to cover rail facilities.
PR-10	Site Maintenance Plan	Ongoing site maintenance plan that addresses responsible organizations, standards, schedule, methods. Also include funding for maintenance of roadway, stormwater system, vegetation, snow and ice, traffic controls, cleaning.	Low. Existing documentation sufficient.	REQ	Include guideways, maintenance facilities, stations, and other facilities.
PR-11	Educational Outreach	Increase public, agency and stakeholder awareness of roadway sustainability activities. Must include at least three of eight recommended outreach strategies.	Medium. Development and dissemination of materials likely to be time-intensive.	REQ	Address the use of stations and stops, schedules, and on-line resources used for transit service.

Table F.1 Greenroads Criteria (continued)

ID	Credit	Description	Effort Required/Expected	Points	Change for Transit Projects
Environment and Water (OPTIONAL)					
EW-1	Environmental Management System	Documented environmental management system for prime contractors used on project. Must be in place for duration of construction. ISO 14001 certification or equivalent at minimum.	Low. Where existing certification is not available, effort required will be higher. Higher effort required where subcontractor or other consultant certification required.	2	Combine with EW-2, EW-3, and EW-4.
EW-2	Runoff Flow Control	Reduce runoff quantity through stormwater management plan meeting requirements in PR-8 and PR-10. Show in short paragraph the LID is used; calculate rainfall even values for eight scenarios measuring flow rate, time of concentration, and volume.	Medium. Would only apply to new construction projects.	1-3	Combine with EW-1, EW-3, and EW-4.
EW-3	Runoff Quality	Treat stormwater to a higher level of quality leaving the ROW by developing best practices plan. See EW-2 for process.	Medium. Would only apply to new construction projects.	1-3	Combine with EW-1, EW-2, and EW-4.
EW-4	Stormwater Cost Analysis	Conduct an LCCA for low-impact development techniques for stormwater utilities. Only applies where PR-8 indicates.	Medium. Follows detailed methodology.	1	Combine with EW-1, EW-2, and EW-3.
EW-5	Site Vegetation	Promote sustainable site vegetation that does not require irrigation.	Low. Landscape plans often used standard project documents.	1-3	No change in methodology.
EW-6	Habitat Restoration	Offset the destruction and deterioration of natural habitat caused by construction. Restore and protect natural habitat beyond regulatory requirements.	Low. Use copies of biological assessment, restoration plan, and/or schedule of restoration actives.	3	Combine with EW-6.
EW-7	Ecological Connectivity	Complete a site-specific wildlife assessment. Report impacts on surrounding major ecosystems, nonhuman life impacted by the roadway facility.	Medium. Copy of ecological study, plus documentation of culverts, fencing and crossings.	1 or 3	Combine with EW-7.
EW-8	Light Pollution	Provide lighting fixtures that are Dark-Sky compliant or equivalent.	Low. Lighting safety study, electrical plan, list of products, copy of Dark-Sky certification.	3	Change to standards for rail routes, boarding areas, waiting areas, and maintenance facilities. Overlap with LEED.

Table F.1 Greenroads Criteria (continued)

ID	Credit	Description	Effort Required/Expected	Points	Change for Transit Projects
Access and Equity (OPTIONAL)					
AE-1	Safety Audit	Perform a customized transit safety audit following FHWA guidelines. One point for each for the preconstruction, construction, and post-construction phases.	Medium. Can use existing safety audit programs that meet RSA guidelines.	1-3	Metric would require adaptation to meet guidelines for modal safety requirements and recommendations.
AE-2	Intelligent Transportation Systems	Include intelligent transportation system (ITS) applications listed in the FHWA ITS overview documents. Points allotted for each application.	Low. Document and evidence of each ITS application.	1-5	Modify to include ITS applications for transit.
AE-3	Context Sensitive Solutions (CSS)	Collaborative, interdisciplinary approach to provide transportation facility that fits its setting. Leads to preserving and enhancing scenic, aesthetic, historic, community, and environment, while improving safety, mobility, and infrastructure conditions.	Medium. Evidence of CSS in design process or document CSS in project.	5	No change in methodology.
AE-4	Traffic Emissions Reduction	Show the use of congestion pricing or tolling system and document the reduction in traffic emissions compared to a nonpriced project alternative.	High. Use the EPA MOVES 2010 software. Requires traffic modeling.	5	Include modeling of avoided automobile trips. Include estimates of transit emissions.
AE-5	Pedestrian Access	Describe the need, purpose, and appropriateness for pedestrian facilities in the documentation for Credit AE-3.	Low. Copy of documents used for credit AE-3.	2	Add station/stop amenities for waiting passengers, with additional points or as separate metric.
AE-6	Bicycle Access	Achieve Credit AE-3 and describe the need, purpose, and appropriateness for planned, new, or upgraded bicycle facilities.	Low. Copy of documents used for credit AE-3.	2	Rating methodology should include evaluation of bicycles-on-transit features as well as access to stops, secure parking, and bicycle paths.
AE-7	Transit Access	Measure project support of new or upgraded transit facilities in the project ROW. Demonstrate that at least one transit route and/or HOV facility exists within five years of construction, within one-quarter mile.	Low. Copy of documents used for credit AE-3.	1-5	Adaptation to include connections to other transit routes and modes. Additional documentation on impacts to other transit routes and systems.

Table F.1 Greenroads Criteria (continued)

ID	Credit	Description	Effort Required/Expected	Points	Change for Transit Projects
Access and Equity (OPTIONAL) (continued)					
AE-8	Scenic Views	Provide views of scenery or vistas by location of project on identified scenic byway, or by addition of pull-out areas to access viewing areas.	Low. Copy of plans showing scenic areas.	1-2	Remove metric.
AE-9	Cultural Outreach	Promote art/culture/community values through the application of historical registers where applicable, information kiosks on cultural or historical features, or allocate funding to public art.	Low. Documentation of registration or funding allocation to public art.	1-2	Specific consideration of reusing historic buildings or cultural landmarks, and of public art in facility design.
Construction (OPTIONAL)					
CA-1	Quality Management System (QMS)	Minimum of ISO 9001 certification for prime contractor, or have QMS that meets the ISO 9001 standards.	Low for documentation; High for ISO certification.	2	Consider ISO certification of transit agency.
CA-2	Environmental Training	Provide environmental training for construction personnel to identify environmental best practices.	Medium. Develop and document environmental training program and evaluation.	1	No change in methodology.
CA-3	Site Recycling Plan	Prepare and implement plan to divert waste from landfill. Describe materials to be recycled or reused from construction and mobile office activities.	Medium. Prepare recycling plan.	1	Modify to include transit-specific recyclable materials beyond roadway construction.
CA-4	Fossil Fuel Reduction	Reduce fossil fuel requirements of nonroad construction equipment by using 15 percent or 25 percent biofuel as a replacement for fossil fuel.	Low. Signed letter or receipt summary.	1-2	No change in methodology.
CA-5	Equipment Emissions Reduction	Meet EPA Tier 4 standards for non-road equipment.	Low. Provide a list of equipment used to achieve Tier 4 standards.	1-2	No change in methodology.
CA-6	Paving Emissions Reduction	Place at least 90 percent of asphalt using pavers meeting NIOSH requirements.	Low. Copy of manufacturing certification.	1	Same as Roadway Methodology for projects, including pavers.
CA-7	Water Tracking	Develop data on water use in construction.	Low.	2	No change in methodology.
CA-8	Contractor Warranty	Include three-year warranty on the constructed pavement.	Low.	3	Same as Roadway Methodology for projects, including pavers.

Table F.1 Greenroads Criteria (continued)

ID	Credit	Description	Effort Required/Expected	Points	Change for Transit Projects
Materials and Resources (OPTIONAL)					
MR-1	Life-Cycle Assessment (LCA)	Conduct a detailed LCA by ISO14040 standards for the final project alternative. Three impact categories from EPA FRED:2000 LCA tool.	Medium. Data needs and inventory tasks.	2	No change in methodology.
MR-2	Pavement Reuse	Reuse 50 percent to 90 percent of existing pavement materials or structural elements by estimated volume or weight.	Medium. Design and inventory tasks.	1-5	Remove metric.
MR-3	Earthwork Balance	Minimize earthwork cut and fill volumes to less than 10 percent.	Medium. Provide existing earthwork plan and calculate cut:fill ratio.	1	No change in methodology.
MR-4	Recycled Materials	Use recycled materials in place of 10 percent to 60 percent of virgin materials by weight.	Medium. Show recycled material use and certifications.	1-5	Add reused materials such as rail.
MR-5	Regional Materials	Use regional materials to reduce costs, reduce emissions, and support local economy.	Medium. Inventory of weights, total costs, shipping costs, and location of purchase and/or source.	1-5	No change in methodology.
MR-6	Energy Efficiency	Install lighting systems that meet or exceed 2009 Energy Star standard for roadway lighting. Compliance with safety requirements applicable to the roadway project.	Low. Provide lights specifications.	1-5	Change to standards for rail routes, boarding areas, waiting areas and maintenance facilities. Overlap with LEED.

Table F.1 Greenroads Criteria (continued)

ID	Credit	Description	Effort Required/Expected	Points	Change for Transit Projects
Pavement (OPTIONAL)					
PT-1	Long-Life Pavement	Seventy-five percent of pavement meets 40-year design life.	Medium. Document roadway construction and map sections.	5	Remove metric.
PT-2	Permeable Pavement	Use a permeable pavement to control at least 50 percent of the 90th percentile average annual rainfall event post-construction runoff volume.	Medium. Document relevant drainage and pavement design.	3	Remove metric.
PT-3	Warm Mix Asphalt	Reduce the mixing temperature of hot mix asphalt by a minimum of 50°F from binder supplier specifications.	Low. Provide copy of mix design and photo.	3	Remove metric.
PT-4	Cool Pavement	Use pavement with minimum albedo of 0.3 for a minimum of 50 percent of the pavement area.	Low. Provide copy of albedo tests and pavement plan.	5	Remove metric.
PT-5	Quiet Pavement	More than 75 percent of pavement surface area for lanes where speed limit > 30 mph with tire-pavement noise levels < standards provided.	Low. Document and map pavements, provide noise test results.	2-3	Remove metric.
PT-6	Pavement Performance Tracking	Process to measure and record construction quality over time.	Low. Letter indicating database is operational and collecting data.	1	Remove metric.
Custom Credits (OPTIONAL)					
CC-#	Custom 1, Custom 2	Design a new voluntary credit.		1-5 each	Incorporate transit-specific voluntary credits, which are not covered by the above credits.
			Total Possible Score:	**118**	

Source: Muench, S.T., Anderson, J.L., Hatfield, J.P., Koester, J.R., and Söderlund, M., et al. (2011). Greenroads Manual version 1.5. (J.L. Anderson, C.D. Weiland, and S.T. Muench, Eds.). Seattle, Washington: University of Washington.

F.4 FHWA Sustainable Highways Self-Evaluation Tool

Similar to Greenroads, the FHWA evaluation tool is a collection of sustainability best practices in the form of scored metrics, intended to help transportation practitioners measure sustainability in roadway projects. The tool includes 30 metrics requiring varying levels of effort to calculate and document. The tool designers have created two types of scoring procedures: one, called the Basic Scorecard (20 credits), is used for small construction, preservation and restoration projects, while the second, called the Extended Scorecard (30 credits), should be used for new construction projects or major reconstruction that adds capacity to a roadway. Each scorecard uses a unique combination of the 30 metrics to come to a total score. The score is intended to assist agencies in comparing their projects to industry best practices in sustainable roadway planning, design, and construction. The FHWA evaluation tool was released in a testing phase in April 2011 and is publicly available through the agency web site. The scoring tool is presented as s web-based application that can be used from any computer (registration required). Documentation and other information also is available for download.

Table F.2 presents the 30 metrics from the FHWA tool. The table shows the criteria name, a short description, the number of points awarded for each criteria, and information on how the criteria might be changed to apply to transit projects.

Table F.2 FHWA Sustainable Highways Self-Evaluation Tool Criteria

ID	Credit Title	Description	Credits	Change for Transit Projects
PD-1	Cost/Benefit Analysis	Using the principles of cost/benefit analysis, ensure that user benefits, including environmental and social benefits, exceed full life-cycle costs, including estimates of environmental and social costs.	3	No change in methodology.
PD-2	Highway and Traffic Safety	Safeguard human health by incorporating science-based quantitative safety analysis processes within project development that will reduce serious injuries and fatalities within the project footprint.	1-10	Include Transit Safety and Transit Security. Consider points reduction.
PD-3	Context-Sensitive Project Development	Deliver projects that harmonize transportation requirements and community values through effective decision-making and thoughtful design.	5	No change in methodology.
PD-4	Life-Cycle Cost Analysis	Inform the decision-making process for the project through life-cycle cost analyses of key project features.	1-3	No change in methodology.
PD-5	Freight Mobility	Decrease the impacts from freight movements.	1-7	Require new metrics for rail projects on shared ROW. Fewer points due to fewer freight metrics for bus transit.
PD-6	Educational Outreach	Increase public, agency, and stakeholder awareness of roadway sustainability activities.	2	On-site outreach should specifically address the use of stations and stops, schedules, and on-line resources used for transit service.
PD-7	Tracking Environmental Commitments	Ensure that environmental commitments made by the project are completed and documented in accordance with all applicable laws, regulations, and issued permits.	5	No change in methodology.
PD-8	Habitat Restoration	Offset the loss and alteration of natural habitat caused by road construction. Restore and protect natural habitat beyond regulatory requirements.	3	Reduce possible score, as most transit projects have minimal natural habitat impact.
PD-9	Stormwater	Improve stormwater quality and control flow to minimize their erosive effects on receiving waters using management methods and practices that reduce the impacts associated with development.	1-9	Reduce possible score, as most transit projects have less stormwater impacts than roadways.
PD-10	Ecological Connectivity	Provide or improve wildlife, amphibian, and aquatic species passage access and mobility across roadway facility boundaries.	2-3	No change in methodology.

Table F.2 FHWA Sustainable Highways Self-Evaluation Tool Criteria (continued)

ID	Credit Title	Description	Credits	Change for Transit Projects
PD-11	Recycle and Reuse Materials	Reduce life-cycle impacts from extraction and production of virgin materials.	1-8	No change in methodology.
PD-12	Create Renewable Energy	Offset total operational energy use through autonomous renewable energy sources.	1-6	Include diesel-electric hybrid technology. Include share of electric power purchased from renewable sources.
PD-13	Site Vegetation	Promote sustainable site vegetation within the project footprint that does not require long-term irrigation, consistent mowing or invasive/noxious weed species removal.	1-3	No change in methodology.
PD-14	Pedestrian Access	Promote pedestrian use by providing pedestrian facilities within the project footprint.	1-2	Increase possible score to emphasize non-motorized access.
PD-15	Bicycle Access	Promote bicycling by providing dedicated cycling facilities within the project footprint.	1-2	Increase possible score to emphasize non-motorized access.
PD-16	Transit and HOV Access	Promote use of public transit and carpools in communities by providing new transit and high-occupancy vehicle (HOV) facilities or by upgrading existing facilities within the project footprint.	1-5	Change to multimodal access metric (park-and-ride, shelters, separated HOV facility or lane).
PD-17	Historical, Archaeological, and Cultural Preservation	Respect and preserve cultural and historic assets, and/or feature historic, archaeological, or cultural intrinsic qualities in a roadway.	2	No change in methodology.
PD-18	Scenic, Natural, or Recreational Qualities	Feature National Scenic Byways Program, or similar program, or other route with significant scenic, natural, and recreational qualities.	2	No change in methodology.
PD-19	Low-Emitting Materials	Reduce human exposure to hazardous airborne compounds from construction materials.	2	Remove metric or replace with non-asphalt measure.
PD-20	Energy Efficient Lighting	Reduce lifetime energy consumption of lighting systems for roadways.	1-5	Change to standards for rail routes, boarding areas, waiting areas, and maintenance facilities. Overlap with LEED.

Table F.2 FHWA Sustainable Highways Self-Evaluation Tool Criteria (continued)

ID	Credit Title	Description	Credits	Change for Transit Projects
PD-21	ITS for Systems Operations	Meet economic and social needs and improve mobility without adding capacity, or improve the efficiency of transportation systems.	1-5	Develop separate methodology by mode.
PD-22	Long-Life Pavement Design	Minimize life-cycle costs by promoting design of long-lasting pavement structures.	5	Remove metric.
PD-23	Reduced Energy and Emissions in Pavement	Reduce energy use in the production of pavement materials.	3	Remove metric.
PD-24	Contractor Warranty	Incorporate contractor warranty and construction quality into the public low bid process through the use of warranties.	1-3	No change in methodology.
PD-25	Earthwork Balance	Reduce the need for transport of earthen materials by balancing cut and fill quantities.	1-3	No change in methodology.
PD-26	Construction Environmental Training	Provide construction personnel with the knowledge to identify environmental issues and best practice methods to minimize environmental impacts.	1	No change in methodology.
PD-27	Construction Equipment Emission Reduction	Reduce air emissions from non-road construction equipment.	1-2	No change in methodology.
PD-28	Construction Noise Mitigation	Reduce or eliminate annoyance or disturbance to surrounding neighborhoods and environments from road construction noise, and improve human health.	1-2	No change in methodology.
PD-29	Construction Quality Control Plan	The prime contractor will establish, implement, and maintain a formal construction Quality Control Plan (QCP).	5	No change in methodology.
PD-30	Construction Waste Management	Utilize a management plan for road construction waste materials, and minimize the amount of construction-related waste destined for landfill.	1	No change in methodology.
		Total Possible Credits:	**117**	

F.5 Conclusions

Of the two tools, the FHWA Sustainable Highways Self-Evaluation Tool offers the more simplified platform of project evaluation, from which a checklist or metrics could be developed for public transportation capital projects. In addition, the guidance on how to reach a score is calculated is relatively clear and open to adjustments, which is a fitting characteristic for a broad range of transit agency and project types in public transportation. In Table F.2, changes to 10 metrics are suggested to apply to public transportation projects, in particular to address technology and facility differences between roadway and transit projects. The changes also note the need for different metrics or methodologies by transportation mode. A similar system of two checklists or scorecards could be employed for bus and rail projects; for example, as the construction, procurement, and location types are likely to include very different environmental issues.

In both the Greenroads and FHWA tools, adaptations for public transportation are needed in order to include transit-specific metrics, credits, and methodology. These changes are needed to measure three issues particular to public transportation.

- One is the reduced emissions from avoided automobile trips. As a key metric in understanding the benefits of public transportation, additional effort would be needed to develop a way in a scorecard tool to incorporate estimated changes in automobile travel. The cost/benefit measure in the FHWA tool could incorporate this measure but a stand-alone credit would provide flexibility and added exposure.
- Second, a transit-specific evaluation should include some measure of access via transit to surrounding land uses. This is partially reflected in the nonmotorized and transit access measures in Tables F.1 and F.2. Access also could be worked into the CSS measures in each tool, and should include documentation and discussion of the surrounding land uses and the relationship to transit access and ridership.
- Third, the life-cycle cost analysis will require additional guidance and published assumptions to be applicable to transit projects. The life-cycle costs will need to include elements not included in roadway projects such as vehicles, stops, electrification systems, and other elements that are complex to measure and may create a burden for users.

In each tool, there are a number of metrics that can be used for public transit without significant changes in methodology, including 16 in the FHWA tool and 22 in greenroads. These metrics generally include documentation of existing plans and studies related to environmental categories, as well as steps taken (or planned) to implement recommendations in these studies to maintain or improve environmental conditions. In addition, little change would be needed to evaluate the efforts made to provide outreach and educational material, document construction warranties, and reduce environmental impacts due to construction activity.

In addition, each tool has a number of metrics that do not apply to transit. Most of these deal with paving materials and construction. Some could be replaced by materials and planning steps used for rail projects, particularly in rural areas. Others appear to fit with other evaluation tools, such as LEED, that could be used to evaluate transit facilities such as station areas, bus bays and multimodal facilities. However, many multimodal facilities (i.e., park-and-ride) include paved surfaces and could incorporate pavement metrics.

Appendix G – Model of Construction GHG Emissions from Rail Transit Capital Projects

Sections G.1 and G.2 prepared by Christopher Hanson and Robert Noland, Rutgers University

This appendix describes the process and assumptions made in estimating life-cycle greenhouse emissions for components of a rail system, including track, catenary systems, tunnels, bridges, stations, parking facilities, and rolling stock. The outcome of this work is a simple model of construction materials GHG emissions that can be applied using data readily available during project development, including track-miles by alignment and propulsion type, the number of stations by type, the number of parking spaces by type, and rolling stock.

The work described in this appendix is original research conducted for TCRP Project H-41. It provides new insights into the greenhouse gas emissions associated with the materials used in transit project construction. The model was applied by the H-41 project team to develop estimates of construction GHG emissions for both real and hypothetical rail transit projects with different characteristics. It could be applied by others to develop estimate of emissions associated with transit project construction; however, the data and methods described in this appendix have not been peer-reviewed outside of the H-41 project panel.

This appendix includes three main sections:

1. **Model Development –** The data and process for developing the model of construction GHG emissions;
2. **Case Studies –** Application of the model to case study projects in Colorado and New Jersey; and
3. **Hypothetical Examples –** Examining how emissions vary among hypothetical projects with different characteristics.

G.1 Model Development

Overview of Methods and Data Sources

We first make an inventory of material and energy inputs of these components identifying the materials and quantifying them by weight and by volume in the case of timber ties. The next step is to identify valid emission factors by unit weight or volume. The component emission factors are summarized as the product of weight or volume per unit, and emission factors by weight or volume. These emission factors include upstream and direct emissions for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Our assumptions do not include all components of downstream emissions from materials disposal and recycling.

Material inputs were taken from a variety of sources, including American Railway Engineering and Maintenance-of-Way Association AREMA literature and vendors' specifications for track. A European source (Network Rail n.d.) estimates catenary wire systems, tunnels, bridges, and rolling stock. Their estimation for passenger stations is not usable because it is on a per unit distance basis that is not generalizable to the United States. In addition, the estimate for energy use for passenger stations is based only on concrete and brick. However, they present reasonably valid and usable approximations for copper, wood, and brick, by weight. A doctoral dissertation Life-Cycle Environmental Inventory of Passenger Transportation in the United States (Chester, 2008) was consulted to address various gaps. From this monograph we extract light rail assumptions for track, and average specifications for heavy rail, commuter rail and light rail stations, and specifications for parking facilities, including parking lots and parking garages. The rail portion of Chester is based on five rail systems, including the Bay Area Rapid Transit system (BART), the Caltrain commuter line, The San Francisco Municipal Transportation Authority's Muni line, the Boston Green Line, and the design specifications for the California High-Speed Rail (CAHSR) system.

Material emissions factors were taken from a variety of sources with somewhat divergent methodologies. Our method for accounting for greenhouse gas emissions from material inputs to capital projects is to establish the energy consumption and fugitive emissions of those materials usually by weight, although it also is possible to do this by volume. This is done for every stage of the life of the material, including extraction, transportation, refining and manufacturing, delivery, use or consumption, and disposal. GHG emissions from the use or disposal stage is referred to as direct emissions while everything before or after that stage is referred to as indirect emissions (The Climate Registry 2008, Greenhalgh et al. 2005, Raganathan et al. 2009). Indirect emissions include upstream emissions, i.e., those emissions prior to consumption and downstream emissions, i.e., those associated with disposal or recycling. Electricity from the grid is generally considered indirect emissions because its production is outside of the consumer's control, hence consumers are not directly responsible for the emissions.

Substantial effort was made to support high per unit weight emission factors for the copper used primarily for overhead catenary wire. It is estimated that for electrified rail systems 138 metric tons of copper are present for every route-kilometer (Network Rail n.d.). The steel in rails, the rail bed, and overhead structures and wires is estimated at 821 metric tons. The copper included in the combined rail and catenary systems amounts to 16.8 percent of the steel by weight. This is a substantial fraction of the total materials used in an electrical rail system, and thus must be accounted for in an emissions analysis. Copper emission factors were estimated based on fuel consumption reported by the EPA Office of Solid Waste (EPA 2005). These emission factors were substantially higher than emission factors presented in the Greenhouse Gases, Regulated Emissions, and Energy Use in

Transportation (GREET) model developed by Argonne National Laboratories (ANL, 2007, 2009). The difference may be due to our assumptions that electricity, which represents more than 50 percent of the energy used in copper manufacturing, is taken from the grid. It should also be noted that energy consumption estimates per ton of finished copper are lower in the GREET Model than those reported in this EPA report. For consistency we use the GREET emission factors for copper, but we do so with the caveat that the GREET estimates may be low.

The Components of Track

As described in AREMA's Practical Guide to Railway Engineering (Riley, 2003), track consists of two parallel steel rails that sit on a supporting system that must restrict their movement under the heavy loads of trains of different types. Two rails are kept at a fixed distance from each other by ties that may either be precast, prestressed reinforced concrete or pressure-treated lumber. Concrete and timber ties are connected to rail with different hardware, which is addressed below. Rail segments are spliced with two steel joint bars that are bolted on either side of rail ends. Continuous rolling has increased maximum rail lengths to 1,600 feet, roughly 20 to 40 times what was possible previously. As a result the use of joint bars is diminished but not eliminated. Ballast on top of a stable base and sub-base provide a medium for stabilizing track in relation to the ground. Rail anchors are attached to ties and held in place by ballast in areas subject to longitudinal motion because of changing temperature, grade, and because of traffic patterns or unusually high frequency of brake applications (Riley, 2003).

This section presents the material inputs of the components of commonly used track sizes and a volumetric or weight-based assessment of the material inputs of a mile of track of 100 pounds per yard. We have gathered data for track of a variety of sizes but since the Denver case and the rail systems covered in Chester (2008) are based on 100 pound track it is convenient to use this size for illustrative purposes in this methodology.

Rail

Track is steel rolled in an inverse "T" shape with a massive rounded area on the end of the stem (Riley, 2003). The bar of the inverted T shape provides stability while the more massive stem accommodates steel wheels of locomotives and rolling stock. A thinner section between the base and the running surface is called the web. Rail size is determined by its mass stated in terms of pounds per yard (lbs./yd.) in the United States. Medium-tonnage track is suitable for non-light rail transit purposes (Riley, 2003). This track usually has a 5.5-inch base section and is rated 115 or 119 lbs./yd. Heavy tonnage track usually has a six- inch base section and is rated 132, 133, 136, 140, and 141 lbs./yd. Actual weights per yard differ slightly from the nominal designations (AREMA 2000b). Light tonnage track, used for many light rail transit purposes are usually either 90 or 100 lbs./yd. Other rail sizes are discussed in the literature (Riley, 2003) but will not be incorporated because their use is either rare or they are obsolete. New rail comes in 39-feet or 80 feet lengths, which may be welded together in lengths up to 1,600 feet (0.30303 miles).

To estimate the GHG emissions from rail alone, this model uses the assumptions from the GREET model (ANL, 2009) for rolled steel GHG emissions grams per ton and the calculated mass of the rail in tons using the following formula to determine mass:

$$Qty_{Steelrail} = Size * 2 * 1760/2000$$

Where $Qty_{Steelrail}$ is the mass of steel in the rail; Size is the track size in lbs./yd.; 2 is the number of tracks; 1760 is the number of yards per mile; and 2000 is the number of pounds per ton. For example a mile of 100 lbs./yd. track would weigh 100 * 2 * 1760/2000 = 176 tons from the steel in the rails alone.

Ties

Track ties are made of pressure treated timber, prestressed, precast concrete, steel, or alternative materials (Riley, 2003). Ties made of steel and alternative materials are not in wide use and will not be included in this model. Based on Chester (2008) regional lines are assumed to use concrete ties as specified above and light-rail transit lines are assumed to use timber ties. BART, Caltrain, and CAHSR are heavy, commuter, and intercity rail respectively, and use concrete ties with a volume of six cubic feet and are spaced every 24 inches from center to center. The Muni line and the Boston Green Line are both light-rail systems and use timber ties. However, because most new track, including light rail uses concrete ties, all ties for new construction are assumed to be concrete.

Timber Ties. Timber ties may be hardwood or softwood. Softwood ties are more resistant to rot but are less sturdy than hardwood ties and are preferred for bridges over hardwood ties. Hardwood ties are preferred for most other types of track. Hardwood ties represent 92 percent of timber ties while softwood ties represent 8 percent (Smith & Bolin, 2010). Commonly used timber tie sizes are 7 * 9 * 102 inches and 7 * 9 * 108 inches or 3.719 cubic feet and 3.938 cubic feet, respectively (Riley, 2003).

Concrete Ties. An on-line concrete tie catalog was reviewed and showed that concrete ties suitable for transit hold 100, 115, and 136 lbs./yd. track and typically weigh 610 pounds per tie.[1] Ties considered suitable for transit weighing 595 pounds and 700 pounds are considered outliers. It is assumed that all concrete ties modeled weigh 610 pounds Concrete ties are precast and their composition is outside of the control of contractors. We assume that they are an architectural precast concrete with a mix of 16.4255 percent cement, 6.5532 percent water, and 77.0213 percent coarse and fine aggregates.[2]

Tie Spacing. We assume that medium and light tonnage track (100-119 lbs./yd.) has 22 ties per 39 feet and that heavy tonnage (132 lbs./yd. or greater) has 24 ties per 39 feet (Riley, 2003) or 21.25 inches and 19.5 inches respectively from tie center to tie center. This gives 2,981.647 ties per mile of medium weight track and 3,249.231 ties per mile of heavy

[1] See http://www.lbfoster.com/cxt_ties/CXT_Concrete_Tie_Catalog.pdf.

[2] Based on Marceau et al. 2007.

weight track. GHG emissions for ties are the results of these constants and the per tie emission factors stated above.

Tie Hardware. Rail is usually attached to timber ties with a tie plate and spike system. Tie plates and spikes are made of stamped steel. According to one vendor the tie plates for medium weight track weigh between 13.45 and 22.90 pounds.[3] Tie plates for heavy weight track weigh between 14.94 and 23.32 pounds. The weight differences are quite small and the overlap of the two ranges is extensive. However 7.75x14 inch sizes are the most commonly used timber tie plates (Riley, 2003). We assume their use for medium track and a slightly larger 7.75x14.75 inch tie plate for heavy track. Based on these assumptions individual tie plates weigh 22.90 pounds and 23.32 pounds for medium tonnage and heavy tonnage track, respectively.

Standard spikes come 244 to the 200 pound barrel or 13.115 ounces each.[4] Typically tie plates have four holes and are spiked twice at opposite ends, i.e., inside right and outside left or outside right and inside left. The exception is at joint bars, in which case four spikes are driven. This applies typically to two ties under each rail splice. We assume two tie plates and four spikes for every timber tie. This means that the hardware for a timber tie consists of 49.079 pounds or 49.919 pounds of stamped steel for medium or heavy track respectively. In addition four spikes are used at every rail splice in both of two adjoining ties with a total additional stamped steel content of 6.5575 pounds.

Concrete ties have additional fastening surfaces embedded within them. These can be roughly accounted for by increasing the steel content beyond an allowance for reinforcing steel by no more than 50 pounds. According to a vendor the hardware for concrete ties includes C Plate and C Clip systems, e 2063 clips, and J clips.[5] These systems are applied to both sides of the rail and consist of stamped steel. The C plate and clip system weighs 3.1 pounds. The e and J clips weigh 1.6 pounds and 1.7 pounds, respectively. In addition a cushioning material, probably plastic is placed under the rail and insulation is added to rail that uses electricity as power (Riley, 2003). Neither the cushioning material nor the insulation are addressed here, due to lack of sufficient information on their composition.

Joint Bars

Rail joints connect two lengths of track. The splice is accomplished by bolting the track ends to stamped steel bars (Riley, 2003). Joints are classified as standard, compromise, or insulated. Standard joint bars connect two rails of the same size. These may have four holes and measure 24 inches or six holes and measure 36 inches. Compromise joint bars are used to connect rails of different sizes. They have two holes and measure 24 inches. Insulated joints include insulating material that prevents current from passing between

[3] See http://www.harmersteel.com/wp-content/catalog/cache/harmer-steel-catalog-2007/48.pdf.

[4] See http://www.sizes.com/tools/spikes_railroad.htm.

[5] See http://www.pandrolcanada.ca/literature/JointBarDateSheet.pdf.

rail sections and is sold in the same dimensions as standard joint bars. Because we do not account for insulating material and to avoid making underestimates, it is assumed that all joint bars are 36-inch standard joint bars.

One vendor sells joint bars weighing 80.3 pounds each for 100 lb./yd. rail, 99.8 pounds for 155 lb./yd. rail, and 106.5 pounds for rail sized 132 lb./yd. or heavier.[6] Medium-track joint bars have 1-3/16-inch holes. Heavy track joint bars have 1-5/16-inch holes. Joint bar holes are pre-punched at the factory while track end holes are drilled on site. Joints are secured by bolts, square nuts, and spring washers. Based on one vendor, bolts for medium track and heavy track are 6 inches and 5.75 inches in length respectively.[7] Diameter is assumed to be the same as the holes. The weight of a bolt is calculated in cubic feet using 490 pounds per cubic foot as the density, which is used in this model.[8] Bolts for medium and heavy track weigh 0.5998 and 0.7022 pounds, respectively. These estimates do not account for the greater size of the bolt heads. As pictured on a vendor web site the bolt head is a half-sphere with a radius that measures about 0.7 times the apparent diameter, based on visual inspection. No square nut specifications were found. A nut pictured on a vendor web site had sides measuring 1.4 times and thickness measuring 0.8 times the diameter of the bolt.[9] If we assume these relationships to be constant, the weight of individual nuts is 0.4462 pounds for medium track and 0.6025 pounds for heavy track.[10] Assuming that washers have an outside diameter of 1.4 times the inner diameter as pictured, and arbitrarily assuming that the thickness is a constant one-eighth inch washers weigh 0.0377 pounds and 0.0460 pounds for medium and heavy track, respectively.[11]

Ballast

Ballast is used to stabilize track, preventing lateral, longitudinal, and vertical movement (Riley, 2003). Ballast should be hard, heavy, and well-drained. Usually it consists of crushed stone, although recycled materials, including open hearth and furnace slag also are used. Failure occurs as a result of settling, abrasion, and deposition of dirt and mud. Ballast is laid to a depth of 18 to 24 inches on a compacted sub-base. The bed should extend at least 12 inches beyond the ties in both directions. We might assume that a ballast bed is 2 feet high extending one foot beyond the ties and sloping roughly 45 degrees so that the base extends two feet horizontally beyond the top of the ballast bed. The density assumption for aggregate is 100 pounds per cubic foot. A linear foot of track supported by standard nine foot ties would need at a minimum to be supported by 22.4 cubic

---

[6] See http://www.centralrailsupply.com/bars.htm.

[7] See http://www.crownrail.com/crownbolts.htm.

[8] $W_{bolt} = L \times 0.25\, d^2 \times 490/1728$.

[9] See http://www.crownrail.com/crownbolts.htm.

[10] $W_{nut} = [(1.4d)^2 - \Pi(0.5d)^2] \times 0.8d \times 490/1728$.

[11] $W_{washer} = \Pi\, [(0.5{*}1.4d)^2 - (0.5d)^2] \times 0.125 \times 490/1728$.

feet of ballast weighing 2,240 pounds. A linear mile of track would need ballast weighing 118,272 pounds. These assumptions are not inconsistent with AREMA standards (AREMA 2000a). Emission factors for ballast are assumed to be the same as for aggregate.

However our estimate of 22.4 cubic feet per linear foot is based on the AREMA minimum. If at a minimum we assume double track the minimum volume per linear foot is 44.8 cubic feet. Based on Chester (2008) we estimate roadbed ballast at 71 cubic feet per linear foot for two-way heavy and commuter rail track and 50 cubic feet per linear foot for two-way light-rail track. For single track we halve these estimates so that ballast is 35.5 cubic feet per linear foot for heavy and commuter rail track and 25 cubic feet per linear foot for light-rail track.

Anchors and Other Miscellaneous Items

The materials covered so far are the components that recur at regular intervals. As such they embody the largest share of GHG emissions and these emissions are readily estimated with some minor omissions. Other items such as rail anchors, switches, derails, gauge rods, sliding joints, miter rails, and others mentioned in Riley (2003) are not included because of the difficulty of obtaining their composition and consequent emissions factors, and the diminishing benefit on their inclusion in any estimates. The vast majority of material-based GHG emissions are almost certainly captured in the procedure just outlined.

Assumptions for an Average Mile of Track

We attempt here to illustrate our estimate of the combined material inputs of a mile of track. In Table G.1 we assume continuous 100 pound track with quarter-mile (1,320 feet) lengths. Light-rail transit is assumed to use concrete ties, appropriate hardware, and ballast at the rate of 25 cubic feet per linear foot of track. Heavy and commuter rail is assumed to have reinforced concrete ties, appropriate hardware, and ballast at the rate of 35.5 cubic feet per linear foot of track. Based on Table G.1, a mile of 100 pound light rail includes 202.50 tons of steel, 788.13 tons of concrete, and 6,600.00 tons of ballast. A mile of commuter 115 pound rail includes 228.91 tons of steel, 788.13 tons of concrete and 9,372.00 tons of ballast. These figures are based on track that is 100 percent on the grade.

Table G.1 Inputs for One Mile of 100 Pound Track with Continuous Rail

	Material	Value	Unit	Tons/ Route-Mile
Rails (Single Track = Two Rails)	Steel	5,280.00	Linear Feet	176.00
Concrete Ties	Concrete	10,620.84	Cubic Feet	788.13
	Reinforcing Steel	57.62	Cubic Feet	17.07
Concrete Tie Hardware, J Clips	Stamped Steel	5,280.00	Pair	8.98

Table G.1 Inputs for One Mile of 100 Pound Track with Continuous Rail (continued)

	Material	Value	Unit	Tons/ Route-Mile
Joint Bars, Stamped Steel, 1,320 Foot Rail Lengths	Stamped Steel	8.00	Pair	0.46
Ballast, ½ * 50 Cubic Feet per Linear Foot (Light-Rail Transit)	Crushed Rock	13,200,000.00	Cubic Feet	6,600.00
Ballast, ½ * 71 cubic Feet per linear foot (heavy/Commuter Rail)	Crushed Rock	18,744,000.00	Cubic Feet	9,372.00

Grade

Based on Chester (2008) we make the following assumptions for additional structures for track that is above- and below-grade. Two types of elevated track are discussed, aerial track and retained fill tracks. Aerial track is supported by concrete or structural steel supports. For elevated track, based on BART we assume 2,400 cubic feet of reinforced concrete supports and footers spaced every 63.316 feet for concrete supports and 2,250 pounds of rolled steel per linear foot for structural steel supports based on the Green Line case. For retained fill tracks 12-feet reinforced concrete retaining walls, presumably with some sort of footer, support 54 cubic feet of ballast per foot of track. For CAHSR Chester's estimate for a cross section of the retaining wall was 214 cubic feet per linear foot. The default assumptions for above-grade track are 214 cubic feet per linear foot of reinforced concrete and 54 cubic feet of ballast per linear foot of track. Chester (2008) does not address excavation of below-grade track or shoring up of the sides. We assume that greenhouse gas emissions from excavation and stabilization of excavated areas are one-half the GHG emissions resulting from electricity consumption of tunneling and one-half of the GHG emissions embodied in the concrete, soil, and steel from stabilizing tunnels. These tunnel assumptions are taken from the Network Rail report (n.d.).

Other Components of Rail Systems

Our assumptions for the other components of rail systems differ from our track assumptions in that we use abstract assumptions based on inventories that claim to approximate global averages (Chester 2008; Network Rail n.d.). As a result we use constant values to address each component. This approach suits the type of data that is likely available from transit agencies.[12] Rail stations are attributed status as either platforms or hubs. The attributes of parking facilities include parking garages or surface parking lots, and the number of parking spaces in each. Rolling stock is counted as vehicles and not described in any way. The Denver system is described as electrified so we assume an overhead catenary system. Many of the New Jersey rail systems are not electrified or only partially so. We assume no catenary system over the nonelectrified portions of rail systems. No tunnels or bridges are included. As a result it is useful to use a bottom up approach in which we address an average mile of standard 100 pound track from its components (as done above in Table 1). We cannot vouch for the averages assumed in the other parts of the rail system because we don't know the variation that might exist in the other subsystems.

The Network Rail study (n.d.) provides estimates of energy consumption for overhead catenary wire systems, bridges, tunnels, and rolling stock. There are significant limitations with our use of this study. The Network rail study is from the United Kingdom and should be used with care as a basis for generalization. We should be aware that there may be differences in construction practices, the overhead wire systems, and passenger station design and construction. The service life expectancy of any structure is likely to be affected by climate. There is enough variability of climate among places in the United States that have transportation systems that the validity of a single set of life expectancy estimates for the United States also becomes questionable. Life expectancy estimates based on the United Kingdom are not used. We chose to use this study because written documentation for U.S. rail systems did not provide a basis for documenting material inputs. A doctoral dissertation by Mikhail Chester (2008) provides estimates for a basis for estimating the material inputs of passenger stations and parking facilities.

The material inputs taken from the Network Rail study (n.d.) are presented in metric tons (tonnes) per route-kilometer, which we convert into short tons of material per route-mile. The Network Rail report (n.d.) assumes that 10 percent of the total length is made up of tunnels and 1 percent is made up of bridges. Units of distance of track are converted by dividing by these proportions.

- Catenary systems include 887 tons per mile of steel, 124.18 tons per mile of aluminum, and 244.81 tons of copper.

- Tunnels account for 478,979 of soil per route mile of tunnel, as well as 78,056 tons per mile of concrete, 3,725.40 tons per mile of steel, and 19,521 MWh per mile of electricity.

- Bridges account for 157,886 tons of concrete per mile and 8,692.59 tons of steel per mile of bridge.

- The per vehicle material inputs of rolling stock are 43.53 tons of steel, 20.28 tons of aluminum, 1.93 tons of copper, 1.32 tons of glass, 1.01 lifetime tons of lubricating oil, 2.33 tons of wood, and 5.52 tons of rubber and plastic.

[12] The Denver case study for TCRP H41 lists total track length and apportions it among at-grade, above-grade, and below-grade track.

Third-Rail Systems

Catenary systems provide electricity for light and commuter rail and third-rail systems power heavy rail, including subway systems. Historically a third-rail system provided electricity literally through a third steel rail. Common rail sizes were 100 lbs./yd., 106 lbs./yd., and 150 lbs./yd. (Elliott 2009). Modern third rails are made of aluminum and steel. One vendor web site has diagrams of electrified track with steel capping over an aluminum core.[13] These rails are lighter than steel but include items that are volumetrically equivalent to 100 lbs./yd. and 150 lbs./yd. steel track. In addition sizes that are volumetrically equivalent to 54 lbs./yd., 81 lbs./yd., and 155 lbs./yd. are offered. On this basis, this model will include 100 lbs./yd. and 150lbs./yd. steel track, and the volumetrically equivalent steel-covered aluminum track.

Passenger Station Assumptions

The Network Rail report (n.d.) addresses passenger stations as a per route kilometer input. We are hesitant to generalize to the United States based on their estimates of materials consumption for passenger station construction. Their estimate includes twice the mass of bricks as concrete. Chester (2008) states that concrete is the primary material input for emissions and describes station designs that bear this out. Based on his discussion, we assume that the BART system is typical of heavy rail passenger stations. Stations in the BART system include aerial platforms, surface stations, and underground stations. We assume that the passenger platforms of the Caltrain system are typical of commuter rail. The Caltrain system consists of concrete platforms over a sub-base that we assume to be aggregate which we treat as equivalent to ballast. We assume that passenger stations of the Muni line are typical of light rail.

For our analysis it is assumed that unless otherwise stated, stations are at the surface level. For light rail, we assume a two type typology of stations based on size. There are large primary stations, which have more or less extensive parking facilities and may offer an opportunity to transfer to other modes of transportation. There also are smaller platform stations with less parking opportunities, and much simpler construction. This assumption is made based on one case, for Denver. The case includes four primary stations and eight secondary ones. We do not have estimates for platform stations for heavy rail or large stations for commuter rail. Table G.2 shows the material inputs for passenger stations. We assume that all concrete is reinforced with a default concrete to steel ratio of 85.39 pounds of steel per cubic yard of concrete based on NJDOT engineering drawings for pipe.[14] Smaller stations are assumed to be at-grade and of the platform variety.

---

[13] See the Brenknell Willis at http://brecknell-willis.co.uk/systemscr.htm.

[14] See http://flh.fhwa.dot.gov/resources/pse/standard/st60101.pdf.

Table G.2 Material Inputs of Rail Passenger Stations

Heavy Rail	BART	Total Volume ft³	Concrete Volume ft³	Concrete Short Tons	Steel Volume ft³	Steel Short Tons
	Aerial	520,000	517,194	38,789.56	2,806	822.27
	Surface	440,000	437,626	32,821.93	2,374	695.77
	Underground	770,000	765,845	57,438.38	4,155	1,217.60
Commuter Rail	**Caltrain**	**Total Volume ft³**	**Concrete Volume ft³**	**Concrete Short Tons**	**Steel Volume ft³**	**Steel Short Tons**
	Platforms	27,000	17,903	1,342.72	97	28.46
			Sub-Base Volume ft³	**Sub-Base Volume ft³**		
			9,000	450.00		
Light Rail	**Muni line**	**Total Volume ft³**	**Concrete Volume ft³**	**Concrete Short Tons**	**Steel Volume ft³**	**Steel Short Tons**
	Platforms	9,000	8,951	671.36	49	14.23
	Stations	310,000	308,327	23,124.54	1,673	490.20

Source: Chester (2008).

Parking Facilities

Off-street parking is of two types, parking lots and parking garages (Chester 2008). Use Chester's assumption that a parking space has 300-square feet of surface area and an additional 30-square feet of surface area per parking space for access. Parking lots include a six-inch sub-base, which is assumed to be aggregate, and two three-inch courses of asphalt concrete.

Chester assumes that asphalt used in parking lots is 90 percent hot mix asphalt, 3 percent cutback, and 7 percent warm mix asphalt. We assume 100 percent hot mix asphalt. Because our data is at a high level of abstraction we are not able to model a user designed mix of asphalt pavements that would include warm mix or cutback asphalts.

Parking garages are complicated by the addition of a structure. Chester (2008) models parking garages as steel structures based on Guggemos and Horvath (2005). The latter study compares environmental impacts between steel and concrete framed buildings. We model parking garages as a skeletal steel framed building with a reinforced concrete slab and nothing else. Guggemos and Horvath postulate two buildings, one is concrete-framed and the other is steel-framed. Both buildings have an area of 4,400 cubic meters spread over five stories. From Guggemos and Horvath we take the structural steel and reinforced concrete implied in a steel framed building and add a 12-inch reinforced concrete slab that has 330 square feet for every parking space. A 500 space lot has 165,000 square feet of area. Table G.3 shows the calculations of material inputs per parking space in a parking garage. We begin with the material inputs based on Guggemos and Horvath's 4,400 square meter steel framed building. Metric weight and area units are converted to U.S. standard. The area of the hypothetical building would accommodate roughly 143 parking spaces. The structural material inputs are divided by 143 to obtain the structural material inputs per parking space. Concrete is converted to cubic feet assuming density of 150 pounds per cubic foot. We then add 330 square feet of 12-inch reinforced concrete slab using a default ratio of steel to concrete to obtain the total estimate.

Table G.3 Material Inputs for One Parking Space of Garage Parking

	4,400 m^2 Building[a]		Per Parking Space	
Steel Structure Building[a]	**Kg**	**Lbs.**	**Lbs.**	**Ft^3**
Concrete	3,064,752.00	6,756,627.10	47,249.14	314.99
Steel Reinforcing Bars	151,225.00	333,394.33	2,331.43	
Structural Steel	207,346.00	457,120.06	3,196.64	
Parking Slab – Single Parking Space			**Lbs.**	**Ft^3**
Concrete Slab 330 ft^2			49,232.90	328.22
Steel Reinforcing Bars			1,043.66	1.78
Total Material Inputs Per Space			**Lbs.**	**Ft^3**
Total			96,482.04	643.21
Concrete			6,571.73	
Steel			49,232.90	328.22

[a] Taken from Guggemos and Horvath 2005.

Estimation of Material and Electricity Emission Factors

Previous work reproduced here, has established GHG emission factors for steel, aluminum, cement and concrete, asphalt concrete and coating materials, aggregate, process fuels solvents and lubricants, limited plastics, and equipment inputs. These emission factors include upstream and direct emissions for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Emission factors for materials are stated as grams of GHG per unit weight of material supplied. New emission factors are presented for brick, copper, wood and pressure treated wood, as these are commonly used in rail systems.

We attempt to account for all GHG emissions that occur during the lifetime of the material from extraction to disposal. Process fuels are used in the production of the materials. We account for all stages of process fuels, including extraction, transportation, refining, delivery, and combustion. Process emissions such as calcination of lime in cement making are accounted for as are fugitive emissions from such things as fuel or solvent evaporation or HFC leakage from cooling systems. Our model does substantially less well at accounting for downstream emissions.

Emission factors for specific process fuels are presented in Table G.4 which is based primarily on the GREET Model developed by Argonne National Laboratory (ANL, 2007, 2009). Emission factors are presented as grams per million Btu (MMBtu). The GREET Model allows for the conversion of emission factors for fuels from an energy content basis a weight or volume basis and vice versa using lower heating values (LHV) or higher heating values (HHV). Life cycle analyses (LCA) were sought that provide the provide process fuel information.

Table G.4 GHG Emissions of Process Fuels in g/MMBtu

Upstream Emissions of Process Fuels (g/MMBtu)							
	Coal[a]	**Natural Gas[a]**	**Conventional Gasoline[a]**	**Distillate Fuel Oil[b]**	**Residual Oil[b]**	**LPG[a]**	**Petroleum Coke[b]**
CO_2	1,648	12,693	16,812	15,487	7,326	9,195	22,427
CH_4	119.20	199.10	108.74	104.52	37.23	115.28	127.68
N_2O	0.0313	0.2610	1.1400	0.2483	0.1179	0.1583	0.3866
Combustion Emissions of Process Fuels (g/MMBtu)							
	Coal[b]	**Natural Gas[a]**	**Conventional Gasoline[a]**	**Distillate Fuel Oil[a]**	**Residual Oil[a]**	**LPG[a] (Propane)**	**Petroleum Coke[b]**
CO_2	108,363	59,379	75,645	78,169	85,045	68,024	104,716
CH_4	4.00	1.10	5.19	0.18	3.24	1.08	4.00
N_2O	1.0000	1.1000	2.4000	0.3900	0.3600	4.8600	1.0000
Upstream and Combustion Emissions of Process Fuels Combined (g/MMBtu)							
	Coal[b]	**Natural Gas[b]**	**Conventional Gasoline[b]**	**Distillate Fuel Oil[b]**	**Residual Oil[b]**	**LPG[b] (Propane)**	**Petroleum Coke[b]**
CO_2	110,012	72,072	92,457	93,656	92,370	77,218	127,143
CH_4	123.20	200.20	114	104.70	40.47	116.36	131.68
N_2O	1.0313	1.3610	3.5400	0.6383	0.4779	5.0183	1.3866

[a] GREET Fuel Cycle Model 1.8c (ANL, 2009).

[b] Our Calculations for Crude Extraction and Refining Share – energy basis from Fuel Cycle model and Summation of Combined Emissions.

Table G.5 shows the materials identified as components of a rail system with emission factors expressed as tonnes of GHG per short ton of material. The basis for these emission factors are documented below. Some materials, notably aluminum, glass, lubricating oil, plastic and steel were taken directly from the GREET Vehicle Cycle Model (ANL, 2007). These emissions factors were expressed as grams of GHG per short ton in the GREET

Model. The GREET Model provides combined emission factors for steel but provides separate emission factors for virgin and recycled aluminum. Emissions of GHG from electricity are expressed as tonnes per MWh using default assumptions from the GREET Fuel Cycle Model (ANL, 2009) assuming the default mix of process fuels used in the United States. Emissions based on the mix of process fuels used in the United States are higher than those based on the northeastern U.S. mix. The United States mix was chosen because it better represents U.S. transit systems.

Table G.5 Material and Electricity Emission Factors

Material	CO_2 Tonnes/ Short Ton Material	CH_4 Tonnes/ Short Ton Material	N_2O Tonnes/ Short Ton Material
Aluminum[a]	5.575	1.063E-02	7.627E-05
Asphalt[i]	0.024	5.819E-05	3.876E-07
Ballast[h]	7.583E-03	5.680E-06	1.708E-05
Bricks[d]	0.618	5.539E-04	9.077E-06
Concrete[f,g]	0.224	2.022E-04	1.731E-05
Copper[a]	7.358	1.216E-02	8.832E-05
Glass[a]	1.242	6.601E-03	1.879E-05
Lubricating Oil[a]	3.929	4.040E-03	2.404E-05
Plastic[a]	3.258	5.272E-03	3.884E-05
Soil[e]	2.426E-03	2.712E-06	1.7E-08
Steel[a]	4.188	4.002E-03	2.203E-05
Timber Ties	-1.173	1.723E-02	2.501E-04
Wood (Plywood)[c]	0.202	4.644E-04	1.642E-03
Electricity (MWh)[b]	0.705	1.300E-05	9.100E-06

[a] GREET Vehicle Cycle Model.
[b] GREET Fuel Cycle Model.
[c] Puettmann Wilson 2005.
[d] EPA 2003.
[e] EPA 2003 transportation emissions only.
[f] Process fuels Choate 2003.
[g] Concrete precast mix specifications Marceau et al 2007.
[h] BCS 2002.
[i] Estimates of average mix and heating requirements (Hunt, 2010, Zapata et al., 2005).

Brick and Soil

Emission factors for brick (EPA, 2003) were estimated based on a life-cycle analysis paper published on the EPA web site. This paper estimated combustion and *pre-combustion* energy per ton of brick produced in MMBtu. Emission factors for brick were estimated from the combustion energy numbers only. Upstream emissions were attributed from the factors listed in Table G.4 to ensure consistency with the GREET Model. In descending order brick production uses natural gas (2.6724 MMBtu per short ton) electricity (2.0087 MMBtu per short ton) and diesel (0.1072 MMBtu per short ton). These figures include process and transportation energy. Emissions from soil as topsoil and clean fill are assumed to be identical to brick transportation emissions. This estimate does not account for the equipment used to extract, load, and unload soil. However, soil emissions are not considered in this model. They are rather used to derive equipment and transportation factors input.

Copper and Aluminum

A similar process was used to estimate emissions from production and transportation of virgin and recycled copper wire (EPA, 2005). Embodied energy was estimated from a copper LCA paper (EPA, 2005). That paper includes estimates for all fuel types of energy inputs in MMBtu and GWP expressed as metric tons carbon equivalent (MTCE) per MMBtu for combustion CO_2 and fugitive CH_4. MTCE may be converted to GWP by dividing by the carbon fraction of CO_2 (12/44). Electricity is the largest source of energy consumption used in virgin (61.2 percent) and recycled (53.2 percent) copper wire production followed by natural gas (virgin 36.0 percent, recycled 39.9 percent). Our calculations of emissions based on energy inputs were consistently higher than those in the EPA LCA paper because the latter used a source that did not account for upstream emissions from process fuels. Copper is a convoluted, energy-intensive, and specifically electricity-intensive process for both virgin and recycled copper wire. Grid electricity use drastically increases GHG emissions because it uses process fuels, which adds a step to energy production with a necessary loss of efficiency. The general GREET assumptions for process fuels in the U.S. produce especially high GHG emissions because of high dependence on coal. The GREET model uses lower assumptions about process fuel consumption for copper manufacturing than those used in EPA (2005). Estimates using the GREET model are about 60 percent lower, mainly because the process fuel consumption is less than those of EPA (2005). For consistency we use the GREET model estimates but with the caveat that GHG emissions may be underestimated.

Emission factors for aluminum and copper are taken directly from the GREET Vehicle Cycle Model (ANL, 2007). As with copper above, the GREET Model estimates GHG emissions for virgin and recycled aluminum. The United States Geological Survey compiles primary and secondary production numbers for many materials, including aluminum (Buckingham et al., 2010) and copper (Edelstein, 2011). Recycled metals accounted for 61.1 percent of aluminum production in 2009 and 16.3 percent of copper production in 2010. These proportions were used to weight the virgin and recycled emission factors for aluminum only because copper and steel are weighted within the GREET Vehicle Cycle Model. The copper model described above was weighted in the same way as aluminum for emissions factors from virgin and recycled copper production.

Wood as Plywood

Emission factors for wood are taken from Puettmann and Wilson (2005). They provide energy input from process fuels for plywood and other wood products that do not lend themselves to estimation of upstream GHG emissions as done in the GREET model. Emission factors were based on the authors' estimation of GHG emissions despite the fact that those estimates do not include upstream emissions from fossil fuels. For our model this was corrected by adding upstream emissions based on the reported energy from fossil fuels based on the GREET model – roughly half of the energy consumed in plywood production – to the estimates. We added emissions from process fuels, including coal and natural gas as upstream emissions. Upstream emissions for crude oil were substituted for residual oil, which results in a slight overestimation. This overestimation is offset by omitted upstream emissions from uranium, hydropower, and a quite small amount of electricity. Any overestimation of GHG emissions is exacerbated by omission of a credit for an upstream biomass GWP sink. Plywood was chosen as the basis for wood emission factor for stations.

Concrete

Emission factors for concrete were established from Choate (2003). Table G.6 is based on the fuel inputs reported in that paper using emission factors for process fuels reported above. It shows direct and upstream emissions of GHGs assuming a wet concrete mixture of 12 percent cement, 82 percent aggregate, and 6 percent water. This method allows for adjustment to differences in mix specifications. The concrete industry's LCA analysis (Marceau et al., 2007) does not allow these adjustments.

Table G.6 Concrete GHG Emissions Assuming 12 Percent Cement, 82 Percent Aggregates, and 6 Percent Water

	Direct	Upstream	Direct	Upstream	Direct	Upstream
	CO_2 Production	CO_2 Production	CH_4 Production	CH_4 Production	N_2O Production	N_2O Production
	g/Short Ton Concrete	g/Short Ton Concrete	g/Short Ton Concrete	g/Short Ton Concrete	g/Short Ton Concrete	g/Short Ton Concrete
Quarrying (82%)						
Cement Raw Materials	524	386	0.393	0.289	1.181	0.869
Concrete Raw Materials	3,583	2,635	2.684	1.974	8.071	5.936
Cement Manufacturing (12%)						
Energy Consumption	62,012	3,657	2.140	81.986	0.681	0.067
Kiln Reactions (Calcination)	62,978					

Table G.6 Concrete GHG Emissions Assuming 12 Percent Cement, 82 Percent Aggregates, and 6 Percent Water (continued)

	Direct	Upstream	Direct	Upstream	Direct	Upstream
	CO_2 Production	CO_2 Production	CH_4 Production	CH_4 Production	N_2O Production	N_2O Production
	g/Short Ton Concrete	g/Short Ton Concrete	g/Short Ton Concrete	g/Short Ton Concrete	g/Short Ton Concrete	g/Short Ton Concrete
Concrete Manufacturing (100%)						
Raw Material Mixing	5,906	761	0.146	33.781	0.110	0.016
Transport	6,313	1,251	0.015	8.441	0.031	0.020
Total	**141,316**	**8,690**	**5.377**	**126.471**	**10.074**	**6.908**

Sources: Table A.11 – Energy Use per Tonne Associated with U.S. Cement Manufacturing and Concrete Production from U.S. Cement (Choate, 2003). Source Table A.8 – Energy Consumed by Fuel Type in Cement Manufacturing (excluding Quarrying) (Choate, 2003). GREET Fuel Cycle Model 1.8c (ANL, 2009).

The adjustment process is straightforward with a known mix. All emissions from quarrying are divided by 82. Those from cement are divided by 12. Concrete manufacturing emissions are not adjusted. The result is a series of factors that will allow a user to estimate the GHG emissions of any mix specified in percentages. We assume that concrete is a typical precast made from a mix that is 16.41 percent cement, 77.02 percent aggregate, and 6.57 percent water. Emissions from aggregate are taken from an analysis of fuel consumption from limestone and crushed rock extraction (BCS, 2002). Greenhouse gas emissions are attributed based on the emission factors shown in Table G.6. We assume that emission factors are the same for limestone, aggregate, and ballast rock.

Asphalt

This section is an abbreviated version of work we did previously. We assume an average mix for hot mix asphalt of 5 percent binder and 95 percent aggregate with moisture content of 4 percent in the aggregate (Zapata et al., 2005). Upstream emissions of aggregate are taken from BCS (2002). The upstream emissions from binder are similar to those from residual oil. We correct on an energy basis using LHV and refinery efficiencies based on Wang (2008). We estimate the heating requirement based on the specific heat of binder, aggregate, water, and steam and the latent heat required to convert water into steam (Hunt, 2010). We then correct for imperfect heating efficiency using an average energy consumption estimate from Zapata et al. (VTC, 2010).

Creosote Treated Timber

The life cycle of timber railroad ties includes four stages, including production of green cut timbers, pressure treatment of timbers with creosote, active life, and disposal. Smith and Bolin (2010) address all four of these stages however we amend some of their assumptions to make our approach to timber ties consistent with other emission factors presented here. First, Smith and Bolin assume that the green timber contributes no GHG emissions because the carbon in it results from recent photosynthesis and not fossilized hydrocarbons. While the assumption is correct, this approach discounts emissions associated with harvesting, cutting and air drying the timber, and transportation. This error is corrected by supplementing from the life cycle analysis study of wood products, including green lumber, conducted by Puettmann & Wilson (2005).

A green 8.5 feet timber tie measures 3.719 cubic feet or roughly 0.105 cubic meters, and weighs 252 pounds. If we assume that carbon monoxide (CO), and volatile organic compounds (VOC) oxidize to CO_2, production of a cubic meter of green timber produces 27,579 grams of CO_2, 20 grams of CH_4, and 310 grams of N_2O (Puettmann & Wilson, 2005). Production of a green 8.5 feet timber produces 2,905.158 grams of CO_2, 2.107 grams of CH_4, and 32.655 grams of N_2O. A green 9 feet timber produces 3,076.049 grams of CO_2, 2.231 grams of CH_4, and 34.576 grams of N_2O. We assume that the timber was air dried by the time it arrived at the pressure treating location. Total emissions are associated with farming, felling, and drying the timber. The wood life cycle analysis addresses energy consumption in processing wood (Smith Bolin, 2010). It does not give a credit for carbon sequestration as the GREET Model (ANL, 2009) does. This means the wood portion of a railroad tie should not contribute to GHG emissions so Smith and Bolin consider only emissions from the creosote.

Because Smith and Bolin do not estimate energy consumed in the pressure treating process or fugitive emissions resulting from evaporation, we cannot either. Most commercial creosote wood preservative products are diluted with solvents (IPCS, 2004). As a result uncontrolled fugitive emissions may be substantial. The pressure treating process results in the loss of some of the water in the timber and addition of creosote (Smith & Bolin, 2010). An 8.5 feet (102 inches) untreated tie weighs roughly 252 pounds of which 148 pounds are dry mass or 0.074 tons. The water weight of a green timber tie is 104 pounds. Coal tar creosote is a distillate of coal tar that is composed of aromatic hydrocarbons of a variety of densities, but lacking the heaviest materials found in coal tar (Agency for Toxic Substances and Disease Registry, 2010). Coal tar is a byproduct of carbonization of coal to produce metallurgical coke or natural gas for gasification (CDC, 2010). The pressure treating process reduces the water weight of the tie to 59 pounds and adds 20 pounds of creosote to the tie.

The carbon weight of the creosote is 10.637 pounds, so that the carbon fraction estimate of creosote is 0.818 (Smith and Bolin, 2010).[15] This is somewhat low but not unreasonable for solvent-diluted aromatic (cyclic) hydrocarbons with some minor replacement of carbon with oxygen, nitrogen, sulfur, and similar radicals found in such compounds as tar acids and bases, aromatic amines, phenolics, and nitrogen, sulfur, and oxygen heterocycles that make up 10 percent or slightly more of the weight of undiluted coal tar creosote (IPCS, 2004). As 7 pounds of creosote are outgassed per tie, the resulting CO_2 would weigh 9,525 grams if all of the carbon is outgassed as CO_2 (Smith and Bolin, 2010).

[15] 39 * 12/44 = 10.637 where 12/44 is the proportion of CO_2 made up of Carbon by weight.

This approach has some gaps. Smith and Bolin assume that all decayed wood and lost creosote are released as VOCs, CO or CO_2 and that the non-CO_2 components quickly oxidize to CO_2 in the atmosphere (2010). This assumption probably ignores a small amount of CH_4 and N_2O emissions from the wearing of timber ties. It also ignores scientific evidence that a significant part of commercial creosote solutions used as wood preservatives are released in rain runoff and not into the atmosphere (Tran et al., 2009). Therefore, these are minor shortcomings in our knowledge of creosote emissions.

Smith and Bolin (2010) estimate emissions for two disposal scenarios: recycling as fuel, and landfill disposal. Each tie offsets 1.4 million Btu (MMBtu) of energy from coal. It is assumed in the GREET Model (ANL, 2009) that combined upstream and direct emissions from burning 1.4 MMBtu of coal are 154,017 grams of CO_2, 172.480 grams of CH_4, and 1.444 grams of N_2O. These are the emissions that are saved as a result of burning used railroad ties instead of coal. Combustion of the wood in the ties is assumed to be carbon neutral since it is not fossil-based. The 13 pounds of creosote remaining at the end of the service life of a railroad tie produce 17,690 grams of CO_2. Smith and Bolin assume no CH_4 or N_2O emissions from combustion of creosote, or wood. Based on our interpretation of this model, net emissions from burning used railroad ties as fuel is -136,327 grams of CO_2, -172.480 grams of CH_4, and -1.444 grams of N_2O.

Smith and Bolin (2010) estimate CO_2 and CH_4 emissions for landfill disposal at 3,175 grams of fossil CO_2 and 2,354 grams of CH_4. These emissions are offset by 3 pounds or 1360.776 grams of captured natural gas, which could be used as fuel. Natural gas has a lower heating value of 983 Btu per cubic foot and a density of 22 grams per cubic foot. The fuel offset would produce 0.060802 MMBtu of heat and save 72,072 grams of CO_2 emissions, 200.20 grams of CH_4 emissions, and 1.361 grams of N_2O emissions. Smith and Bolin do not account for carbon sequestration of the wood portion of the railroad tie. They state that 77 percent of the ties' mass remains in the earth for an extended period. By applying this fraction to the dry weight of the wood in the used tie we obtain a result of 108.57 pounds or 49,247 grams. If we adopt a commonly used benchmark for carbon fraction of dry wood of 0.5 (Lamlom and Savidge, 2006) the carbon content of the wood portion of a used tie is 24,624 grams, which would produce 90,288 grams of CO_2 sequestration. We estimate that net emissions from sending used railroad ties to the landfill are -159,185 grams of CO_2, 2,154 grams of CH_4, and -1.361 grams of N_2O.

Smith and Bolin (2010) state that the purpose of their analysis is to compare differences in GHG emissions between two alternative approaches to disposal. As a result they do not intend to present a full life-cycle analysis; they leave upstream emissions out of the analysis. We add upstream emissions from another source for wood and assume that as a byproduct of coal and coke production coal tar creosote has no upstream GHG emissions. This assumption neglects the upstream emissions of solvents used to cut creosote for wood preservation. Another gap is that there is no treatment of energy consumption or fugitive emissions in the pressure treating process. We assume that emissions during the service life consist only of the carbon content of fugitive emissions that are outgassed as CO_2. The CH_4 emissions from solvents are likely to be quite small and a N_2O component is likely nonexistent. The large net savings with either disposal method are probably valid given the large fuel credits for coal substitution and the large credits for landfill sequestration of carbon in wood. However Smith and Bolin do not address CH_4 and N_2O emissions from combustion. Table G.7 summarizes emission factors for one cubic foot of timber rail tie.

Table G.7 GHG Emission Factors for Creosote Pressure-Treated Timber Railroad Ties

	CO_2	CH_4	N_2O	
	g/ft³	g/ft³	g/ft³	GWP
Upstream Emissions	781	0.567	8.781	3,515
Pressure Treating	0	0	0	0
Fugitive Emissions	2,561	0	0	2,561
Disposal				
Use as Fuel	-36,656	-46.378	-0.388	-37,751
Landfill	-42,803	579.188	-0.366	-30,754
Total				
Fuel	-33,314	-45.812	8.392	-31,674
Landfill	-39,461	579.755	8.415	-24,677

Smith and Bolin (2010) recommend that ties be recycled as fuel at the end of their service life, which could provide an offset to other fuels. That study is biased against landfill disposal because it does not account for carbon sequestration in landfills. Carbon sequestration in landfills was our adjustment to the model. Although they cite EPA sources for their estimation of methane production in landfills, we have not looked at their work in depth. However, the methane levels they claim are quite high and bare further investigation. For our analysis we will assume that timber ties are disposed of in landfills.

Summary of Model

Table G.8 shows updated emission factors for all rail system components. Overhead line equipment, tunnels, bridges, and rolling stock are taken from Network Rail (n.d.). Rail stations and parking facilities are taken from Chester (2008) except for parking garages, which are based largely on Guggemos and Horvath (2005) for the building structure and our conversion of Chester's flexible pavement to a rigid slab for the parking surface.

Table G.8 Estimates of GHG Emissions for Rail System Components

	Material	Tonnes per rt-km	Short Tons per rt-mi	CO_2 Tonnes/	CH_4 Tonnes/ Mile	N_2O Tonnes/ Mile	GWP/ Mile[e]
Track (Com. Rail)	Steel		228.91	958.7	9.16×10^{-1}	5×10^{-3}	979.5
115 lb./yd.	Concrete		788.13	176.6	1.59×10^{-1}	1.4×10^{-2}	184.1
Continuous	Ballast		9,372.00	71.1	5.3×10^{-2}	1.6×10^{-2}	121.8
Track (Mun. rail)	Steel		202.50	848.1	8.10×10^{-1}	4.5×10^{-3}	866.5
100 lb./yd.	Concrete		788.13	176.6	1.59×10^{-1}	1.4×10^{-2}	184.1
Continuous	Ballast		6,600.00	50.0	3.7×10^{-1}	1.13×10^{-1}	85.8
Catenary[c,f]	Steel	500.00	887.00	3,714.8	3.6	2.0×10^{-2}	3795.4
	Aluminum	70.00	124.18	692.3	1.3	9×10^{-3}	723.0
	Copper	138.00	244.81	1,801.4	3.0	2.2×10^{-2}	1804.4
3rd Rail – Steel							
100 lb.	Steel		88.00	368.5	3.52×10^{-1}	1.94×10^{-3}	376.5
150 lb.	Steel		132.00	552.8	5.28×10^{-1}	2.91×10^{-3}	564.8
3rd Rail-Modern							
37.87 lbs./yd.	Aluminum		22.49937	125.44	2.39×10^{-1}	1.72×10^{-3}	131.0
(101 lbs./yd. eq)	Steel		10.82578	45.34	4.33×10^{-2}	2.38×10^{-4}	46.3
49.79 lbs./yd.	Aluminum		34.92324	194.70	3.71×10^{-1}	2.66×10^{-3}	203.3
(149 lbs./yd. eq)	Steel		10.82578	45.34	4.33×10^{-2}	2.38×10^{-4}	46.3
Tunnels[a,f]	Soil	270,000.00	478,979.49	1,161.9	1.3	8×10^{-3}	1191.7
	Concrete	44,000.00	78,055.92	17,487.5	15.8	1.4	18237.7
	Steel	2,100.00	3,725.40	15,602.0	14.9	8.2×10^{-2}	15940.5
	Electricity[d]	12,130.00	19,521.34	13,762.6	2.54×10^{-1}	1.78×10^{-1}	13822.9
Bridges[b,f]	Concrete	89,000.00	157,885.83	35,372.4	31.9	2.7	36889.8
	Steel	4,900.00	8,692.59	36,404.6	34.8	1.9×10^{-1}	37194.5

Table G.8 Estimates of GHG Emissions for Rail System Components (continued)

Rail Stations[g]		ft³ per Unit	Short Tons per Unit	CO_2 Tonnes/ Unit	CH_4 Tonnes/ Unit	N_2O Tonnes/ Unit	GWP/ Unit[e]
Heavy Rail							
Aerial	Concrete	517,194	38,789.56	8,690.3	7.8	6.71×10^{-1}	9063.1
	Steel	2,806	822.27	3,443.7	3.3	1.8×10^{-2}	3518.4
Surface	Concrete	437,626	32,821.93	7,353.4	6.6	5.68×10^{-1}	7668.8
	Steel	2,374	695.77	2,913.9	2.8	1.5×10^{-2}	2977.1
Underground	Concrete	765,845	57,438.38	12,868.4	11.6	9.94×10^{-1}	13420.4
	Steel	4,155	1,217.60	5,099.3	4.9	2.7×10^{-2}	5210.0
Commuter Rail							
Platforms	Concrete	17,903	1,343	300.8	2.72×10^{-1}	2.3×10^{-2}	313.8
	Steel	97	28	119.2	$1.14\ 10^{-1}$	1×10^{-3}	119.8
	Sub-Base	9,000	450	3.4	3×10^{-3}	8×10^{-3}	5.8
Light Rail							
Platforms	Concrete	8,951	671	150.4	1.36×10^{-1}	1.2×10^{-2}	156.8
	Steel	49	14	59.6	5.7×10^{-2}	3×10^{-4}	59.9
Stations	Concrete	308,327	23,125	5,180.8	4.7	4.00×10^{-1}	5403.1

[a] Per unit distance of tunnels.
[c] Per unit distance of bridges.
[c] Per unit distance of track.
[d] Mwh.
[e] GWP = Wgt CO_2 + 21 X Wgt CH_4 + 310 X Wgt N_2O.
[f] Network Rail. N.D. Comparing Environmental Impact of Conventional and High-Speed Rail.
[g] Chester. 2008. Life-Cycle Environmental Inventory of Passenger Transportation in the United States.

Table G.9 Non-Track Estimates of GHG Emissions

Parking Facilities	Material	ft³ per Parking Space	Short Tons per Parking Space	CO_2 Tonnes/ Parking Space	CH_4 Tonnes/ Parking Space	N_2O Tonnes/ Parking Space	GWP/ Parking Space[e]
Parking Garage[g,h]	Concrete		48.24	10.8	1.0×10^{-2}	8.35×10^{-4}	11.3
	Steel		3.29	13.8	1.3×10^{-2}	7.2×10^{-5}	14.1
	Total	330	51.53	24.6	2.3×10^{-2}	9.07×10^{-4}	25.4
Parking Lot[g]	Hot Mix Asphalt	165	7.69	1.87×10^{-1}	4.47×10^{-4}	3×10^{-6}	1.98×10^{-1}
	Aggregate	165	8.25	6.3×10^{-2}	4.7×10^{-5}	1.41×10^{-4}	1.07×10^{-1}
	Total	330	15.94	5.0×10^{-1}	4.94×10^{-4}	1.44×10^{-4}	3.05×10^{-1}

Table G.9 Non-Track Estimates of GHG Emissions (continued)

Rolling Stock[f]	Material	Tonnes Per Vehicle	Short Tons per Vehicle	CO_2 Tonnes/ Vehicle	CH_4 Tonnes/ Vehicle	N_2O Tonnes/ Vehicle	GWP/ Vehicle[e]
	Steel	27.05	29.82	124.9	1.19×10^{-1}	6.57×10^{-4}	127.6
	Aluminum	12.60	13.89	77.4	1.48×10^{-1}	1×10^{-3}	80.9
	Copper	1.20	1.32	14.2	2.3×10^{-2}	2.35×10^{-4}	14.8
	Glass	0.82	0.90	1.1	6×10^{-3}	1.7×10^{-5}	1.2
	Lubricating Oil	0.63	0.69	2.7	3×10^{-3}	1.7×10^{-5}	2.8
	Wood (Plywood)	1.45	1.60	0.4	2×10^{-3}	2×10^{-3}	1.2
	Plastic and Rubber	3.43	3.78	12.3	2.0×10^{-2}	1.47×10^{-4}	12.8

[a] Per unit distance of tunnels.
[c] Per unit distance of bridges.
[c] Per unit distance of track.
[d] Mwh.
[e] GWP = Wgt CO_2 + 21 X Wgt CH_4 + 310 X Wgt N_2O.
[f] Network Rail. N.D. Comparing Environmental Impact of Conventional and High-Speed Rail.
[g] Chester. 2008. Life-Cycle Environmental Inventory of Passenger Transportation in the United States.
[h] Guggemos, A.A.; Horvath, A. 2005. Comparison of Environmental Effects of Steel- and Concrete-Framed Buildings.

We have added GHG emission factors for copper in order to adequately address catenary wire systems. By weight catenary wire systems have about one sixth as much copper as they have steel, yet the GHG emissions from copper wire production and rolled steel production are roughly equivalent. The catenary systems are massive with steel content larger than 132 pound track on reinforced concrete ties. Our model assumes 887 tons of steel per route-mile for catenary systems and 582 tons per route-mile for 132 pound track.

Other additions include wood as plywood and pressure treated timber, glass, lubricating oil, brick, and soil. We cannot precisely estimate from the bottom up for many factors, including catenary wires, bridges, tunnels, rolling stock, passenger stations, or parking garages. It was designed to address the type of data likely to be available from transit agencies. Our analysis of a case-study for Denver found that it included counts of miles of track, vehicles of rolling stock, primary hub rail stations and secondary feeder stations, and parking spaces for parking lots and parking garages. The model will handle above and below-grade track as well as at-grade track. Although 100 pound track is shown for illustrative purposes, this model will handle other track sizes. A gap of some concern is that we do not account for HFC fugitive emissions for rolling stock or rail stations.

G.2 Rail Case Studies

Case study data were obtained from the Denver Regional Transportation District (DRTD) and New Jersey Transit (NJT). DRTD provided data for the part of the electrified light rail line known as the West Corridor LRT that runs from Auraria West Station to the Jefferson Federal Center.[16] An older atlas of NJT commuter rail lines (NJT, 1993) was obtained and provides the basis of our analysis of the Morristown line, the Montclair line, the Princeton line, the Bergen County line, and the Pascack Valley line. In addition bid sheets were obtained from New Jersey Transit for three rail stations, including Lindenwold station, the Pennsauken Transit Center, and Ridgewood station.

These case studies are aimed at demonstrating the applicability of using readily available transit data to evaluate the life-cycle greenhouse gas emissions from construction projects. We document the information that is available for one light rail line and various commuter rail lines in New Jersey and evaluate its usefulness. GHG emissions from the construction of track, overhead catenary structures, tunnels, bridges, passenger stations, parking facilities, and rolling stock are included in our analysis.

West Corridor LRT (DRTD)

The Project Description form received for the West Corridor LRT indicates that the length of the line is 12.17 miles of electrified light rail track. Of this distance 0.94 miles are described as above-grade, 0.08 miles are described as below-grade, and 11.15 miles are described as being at-grade. Twelve stations are named, four of which are described as having major transfer facilities with other modes. Parking facilities are described as either surface or structure, which refer to parking lots and parking garages respectively. The rolling stock in this inventory includes 32 vehicles. Table G.10 shows the GHG emissions inventory by subsystem. Because the West Corridor LRT is light rail we assume that rail size is 100 lb./yd. We assume that concrete ties would be used for new construction.

Table G.10 DRTD West Corridor LRT GHG Emissions Inventory

DRTD West Corridor – Light Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP[a] Tonnes
Type of Rail	**Light Rail**				
Track Miles	19.67	21,139.1	19.814	2.574	22,353
Above-Grade	1.52	40,066.8	36.764	2.295	41,550
Below-Grade	0.13	889.8	0.016	0.011	894

[16] http://en.wikipedia.org/wiki/West_Corridor_%28RTD%29.

Table G.10 DRTD West Corridor LRT GHG Emissions Inventory (continued)

DRTD West Corridor – Light Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP[a] Tonnes
Type of Rail	**Light Rail**				
At-Grade	18.02	0.0	0.000	0.000	0
Electrified Track Miles (Catenary)	19.67	122,121.2	154.376	0.996	125,672
Tunnel Miles	0	0.0	0.000	0.000	0
Bridge Miles	0	0.0	0.000	0.000	0
Stations	4	28,932.0	26.548	1.644	29,999
Platforms	8	1,671.7	1.534	0.095	1,734
Surface Parking Lot	2,400	449.7	1.074	0.007	475
Multistory Parking Garage	3,349	36,194.6	32.667	2.796	37,747
Rolling Stock	32	7,456.0	10.239	0.150	7,718
Total		**258,920.9**	**283.033**	**10.569**	**268,141**

Source Global warming potential (GWP) is defined as the total of the contributions to global warming of all GHGs expressed as CO_2 equivalence. CH_4 is 21 times as effective a GHG as CO_2 and N_2O is 310 times as effective so that GWP = wgt CO_2 + (21 x wgt CH_4) + (310 x wgt N_2O).

The data received did not indicate whether the track was single or double tracked. A Wikipedia search (cited above), showed that the entire length of the line is 12.1 miles and that the track is double from Auraria West Station to the Denver Federal Center and single from there to the Jefferson County Government Center, which is the end of the line. Based on a map from Google Maps the Jefferson County Government Center is just less than nine miles from Auraria West Station as the crow flies.[17] In the absence of a more precise estimate from DRTD 9.5 miles is not an unreasonable best guess for the length of this segment. We assume from this 9.5 miles of double track and 2.67 miles of single track that there is a total of 19.67 miles of track or roughly 162 percent of the total 12.17 miles length of the line. Adjustments were made to the track data, including above and below-grade track, as well as electrified track using this proportion. Our estimate is much closer to correct than either an assumption of all single track, all double track, or equal lengths of each. Since we cannot be certain about where the track is above or below-grade these amounts

[17] http://www.maps.google.com.

were adjusted proportionately as well. Catenary is increased by the same proportion because two wires will be used; the structural proportion will be larger for double track (although not twice the amount, so this is a minor overestimate). No tunnels or bridges are mentioned in the DRTD data, and we assume that there are none.

There are four primary stations that connect with other modes of transportation, including Denver Union Station, Auraria West Station, Denver Federal Center, and the Jefferson County Governmental Center. They are assumed to have material inputs equivalent to large light rail stations as identified in our methodology description. The eight smaller stations are assumed to have material inputs equivalent to stations with just platforms. These include Federal/Decatur, Knox, Perry, Sheridan, Lamar, Wadsworth, Garrison, Oak, and Red Rocks Community College. A total of 5,749 parking spaces were reported of which 2,400 are located in parking lots, and 3,349 are located in parking garages. Thirty-two light rail cars were reported.

Figure G.1 Subsystem Contribution to Total GHG Emissions (GWP)
Denver West Corridor Light Rail Line

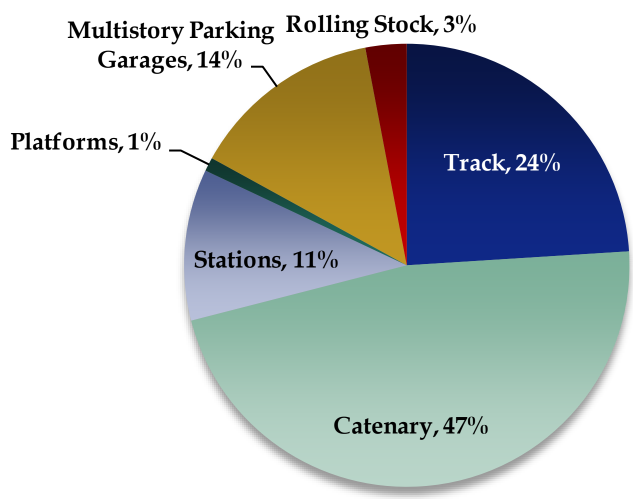


Table G.9 shows the GHG gas emissions from the materials used in the DRTD West Corridor LRT. This includes upstream emissions and direct process emissions, but does not include emissions from construction equipment activity. Based on Table G.9, 47 percent of GHG emissions (GWP) are from the catenary system and 24 percent are from track, accounting for above and below-grade sections. Parking construction is the next largest component accounting for 14 percent of GHG emissions. These emissions come almost entirely from structured parking garages. Surface parking lots account for 0.18 percent of total GHG emissions. Passenger stations account for 12 percent of total GHG emissions. This portion comes primarily from the four stations (11 percent) rather than the eight platforms (1 percent). Rolling stock accounts for 3 percent of GHG emissions. The data provided for this case did not specify tunnels or bridges, although miles of track above- and below-grade were specified.

New Jersey Transit Commuter Lines

At the suggestion of a contact at New Jersey Transit, data for NJT commuter lines were taken from a NJT publication (1993) that presents commuter lines as schematic diagrams called *map pages*. The diagrams show single, double, triple, and quadruple track, electrified and nonelectrified portions, tunnels, bridges, and passenger stations. They are drawn to scale. Pedestrian tunnels and overpasses are shown, as are cross streets, overpasses, and water features. Mile markers and distance from the origin are shown for most features. Crossovers are shown but not included because they are clearly not to scale and are not quantifiable. Power supply substations are shown but not included because they are accounted for as part of the catenary systems.

Table G.11 shows the quantified components for these five NJT commuter rail lines. Because this is commuter rail we assume that rail size is 115 lbs./yd. and that concrete ties are used. As with DRTD light rail we assume that the material inputs from catenary systems are multiplied by the number of tracks for the portions of track that are doubled, tripled, or quadrupled, as are tunnel miles and bridge miles. We assume that whenever rail crosses over a street, undivided highway, small water feature, or a pedestrian tunnel that a bridge of 0.01 miles (52.8 feet) is constructed. The length of bridges over divided highways is doubled. Larger water features are assessed by an approximation of their apparent size on the map provided by NJT. We make a large assumption by assuming that bridges are drawn to scale, however distances measured by mile marker positions and feature locations suggest that the diagrams are drawn to scale. Consistent with our methodology, all stations are assumed to be of the platform type. We recognize that many stations have structures, but information on these was unavailable. Parking facility capacity is estimated from the NJT 2010 Parking Guide. This document establishes the number of parking spaces at each station but does not apportion them between surface parking lots and structured parking garages. We established garage and surface lot parking from various sources. No information about rolling stock was available from our sources. Track spurs and private facilities are not included in our analysis.

Table G.11 GHG Emissions from Five New Jersey Transit Commuter Rail Lines

Morristown Line – Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes	GWP Percent
Type of Rail	Commuter					
Track Miles	121.8	146,929.0	137.484	21.774	156,566	13%
Electrified Track Miles	94.92	589,311.0	744.961	4.806	606,445	50%
Tunnel Miles	7	336,097.1	225.723	11.330	344,350	28%
Bridge Miles	1.2	86,132.4	80.058	3.508	88,901	7%

Table G.11 GHG Emissions from Five New Jersey Transit Commuter Rail Lines (continued)

Morristown Line – Commuter Rail (continued)		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes	GWP Percent
Platforms	25	10,539.0	9.655	0.789	10,986	1%
Parking Lot Spaces	6,055	1,134.5	2.709	0.018	1,197	0%
Parking Garage Spaces	906	9,791.7	8.837	0.756	10,212	1%
Total		1,179,934.6	1,209.427	42.982	1,218,657	100%

Princeton Line – Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes	GWP Percent
Type of Rail	Commuter					
Track Miles	3.75	4,523.7	4.233	0.670	4,820	16%
Electrified Track Miles	3.75	23,281.9	29.431	0.190	23,959	79%
Tunnel Miles	0	0.0	0.000	0.000	0	0%
Bridge Miles	0.01	717.8	0.667	0.029	741	2%
Platforms	2	843.1	0.772	0.063	879	3%
Parking Lot Spaces	285	53.4	0.128	0.001	56	0%
Parking Garage Spaces	0	0.0	0.000	0.000	0	0%
Total		29,419.8	35.231	0.953	30,455	100%

Pascack Valley Line – Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes	GWP Percent
Type of Rail	Commuter					
Track Miles	24.15	29,132.5	27.260	4.317	31,043	72%
Electrified Track Miles	0	0.0	0.000	0.000	0	0%
Tunnel Miles	0	0.0	0.000	0.000	0	0%
Bridge Miles	0.06	4,306.6	4.003	0.175	4,445	10%
Platforms	16	6,744.9	6.179	0.505	7,031	16%
Parking Lot Spaces	2,042	382.6	0.914	0.006	404	1%
Parking Garage Spaces	0	0.0	0.000	0.000	0	0%
Total		40,566.6	38.355	5.004	42,923	100%

Table G.11 GHG Emissions from Five New Jersey Transit Commuter Rail Lines (continued)

Montclair Line – Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes	GWP Percent
Type of Rail	Commuter					
Track Miles	7.81	9,421.3	8.816	1.396	10,039	11%
Electrified Track Miles	7.81	48,488.4	61.295	0.395	49,898	53%
Tunnel Miles	0	0.0	0.000	0.000	0	0%
Bridge Miles	0.20	14,355.4	13.343	0.585	14,817	16%
Platforms	4	1,686.2	1.545	0.126	1,758	2%
Parking Lot Spaces	5192	972.8	2.323	0.015	1,026	1%
Parking Garage Spaces	1535	16,589.7	14.973	1.281	17,301	18%
Total		91,513.8	102.295	3.799	94,840	100%

Bergen County Line – Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes	GWP Percent
Type of Rail	Commuter					
Track Miles	34	41,014.7	38.378	6.078	43,705	72%
Electrified Track Miles	0	0.0	0.000	0.000	0	0%
Tunnel Miles	0	0.0	0.000	0.000	0	0%
Bridge Miles	0.16	11,484.3	10.674	0.468	11,854	20%
Platforms	7	2,950.9	2.703	0.221	3,076	5%
Parking Lot Spaces	1110	208.0	0.497	0.003	219	0%
Parking Garage Spaces	136	1,469.8	1.327	0.114	1,533	3%
Total		57,127.7	53.579	6.884	60,387	100%

Table G.11 also shows the contribution of each component to total GWP emissions for each line. Table G.12 shows our estimates for the ranges of total GHG emissions per mile for four NJT commuter rail systems. Two of the lines, Princeton and Montclair, are fully electrified. Two others, Pascack Valley and Bergen County are not electrified. The Morristown line, which is partially electrified, is not shown. The range of the nonelectrified lines is quite small. The range of the electrified lines is larger due to the relative abundance of garage parking on the Montclair line. Our analysis shows that catenary systems account for most GHG emissions on a material basis where they are present. On nonelectrified track the track itself is generally the largest source of GHG emissions. Tunnels and bridges, although they do not generally account for large portions of track, represent relatively massive material inputs over short distances. Percent emissions from passenger stations are minor when track is electrified. All commuter rail stations are assumed to be of the platform type. These account for between one and two percent of GWP of electrified rail systems. On nonelectrified track commuter rail station embedded GHG emissions are overshadowed to the extent that there are bridges and tunnels on the system. Parking spaces did not account for more than one percent of GHG emissions where garage parking was not present. This is largely due to the larger GHG emissions from garage parking per parking space in comparison with surface parking lots. The GWP of GHG increases 57 fold when a parking garage space is substituted for a surface lot parking space.

Table G.12 Ranges of Estimated GWP for Electrified and Nonelectrified NJT Commuter Rail Systems

	GWP (Tonnes Per Mile)
Electrified Rail	
Princeton Line	8,121
Montclair Line	12,143
Nonelectrified Rail	
Bergen County Line	1,776
Pascack Valley Line	1,777

New Jersey Transit Bid Sheets

We evaluated whether it was feasible to estimate emissions using a bottom-up approach, based on the components specified in contract bid sheets. We received three contract bid sheets for station construction/renovation that were provided by NJT. Detailed data on the material inputs would allow us to estimate the life-cycle emissions associated with each. These need to be provided based on material weight or volume with known densities. Measures used in construction contracts commonly awarded by the New Jersey Department of Transportation are generally quantifiable. They may be stated as volumes, such as cubic feet of concrete, reinforced concrete, aggregate or asphalt. They may also be stated as weight, such as pounds of steel, or aluminum. Areas may be used to a known depth, such as square yards of pavement, or metal plating. Linear distance may be used for which the material for which weight or volume has been worked out for a known distance, as we have done with ballast. Pipe, guard rails, and fencing are examples of the latter. After reviewing the three contract bid sheets it was clear that a bottom-up approach would not work for any of them. Two of the contracts (Pennsauken Transit Center and

Lindenwold Station) do not present any quantifiable material inputs. The third contract (Ridgewood Station) specifies most material inputs as lump sums. This is problematic because the material inputs are not quantified.

The contract bid sheet items that are unquantifiable include items that are exclusively equipment activity inputs. These include such things as site clearing, disposal, drainage, saw-cutting, drilling, grading, excavation, embankment building, and landscaping. To quantify these inputs we could use EPA's NONROAD application with an inventory of the equipment used, including fuel type, power rating for each equipment piece, and ideally vintage year. In addition we would need to know either fuel consumption or duration of operation, or as an alternative, a quantified expression of the work performed with each piece of equipment, such as cubic yards of material excavated, linear feet of a hole drilled to a known diameter, or square yards of pavement broken up. This latter type of information can be theoretically interpreted in a rough sense based on production rates per hour, which are often found on equipment specifications. The Lindenwold contract specifies linear feet of drilled shafts of 2 and 3 feet diameters. These could be interpreted if we knew the power rating, fuel type, and production rate of the drill or drills used.

Many of the material inputs are not quantifiable. Lump sums are specified for sub-base courses, sidewalks, curbs, ballast, cast-in-place and precast concrete, concrete wearing surfaces, glass pavers, structural steel, handrails, timber, tiles, sheet metal, doors of a variety of materials, trims of various kinds, and so on. The Lindenwold contract specifies square yards of broken stone surface course, but not the depth. The specification of square feet of nonslip membrane coating is quantifiable but we have not identified the material. The under platform fence and chain link fencing, expressed as linear feet, could be easily quantified if we knew the height. Assuming a default mixture cast-in-place concrete expressed as cubic yards is easily quantifiable, as are brick masonry walls and concrete block expressed in square feet. Retractable platform edges and timber bumper strips expressed in linear feet are not quantifiable.

Our conclusion is that that most of the material inputs in these station contracts are not fully quantifiable. To successfully accomplish the type of inventory we attempted with data readily available from New Jersey Transit it would be necessary to work from the engineering plans and schematic diagrams.

Conclusions

We have examined data obtained from three sources in an attempt to establish what sorts of information might be readily available from municipal and regional transit agencies with which to conduct GHG inventories of construction projects. We have analyzed data received for this study by DRTD and documents that we were able to obtain from New Jersey Transit. It is impossible to discuss what we have done as a full GHG inventory because we have not been able to present equipment activity data, except for averages for drilling in tunnel construction. An ideal approach is to first quantify the material inputs and then assess the embedded energy and process emissions for each material. These emissions are largely upstream in nature; the fugitive process emissions are the only direct emissions. These can be readily calculated for all major material components. One key input that is missing is that data is not available on construction equipment activity. Specifically, equipment use data would need to be collected either based on fuel consumption or on the total number of hours of equipment operation. Other necessary equipment parameters are fuel type, power rating, and some approximation of average load. To accomplish such a study from the bottom up these data are indispensible. Equipment emissions factors are readily available from NONROAD if these data were available.

Based on our experience with these data it is clear that most analyses of GHG emissions from rail system construction will be based on averages, similar to what we have done. The data from New Jersey Transit and DRTD include, at best, totals of track miles that are either at-grade, below-grade, or above-grade, as well as the proportion of track that is electrified and supported by bridges or tunnels. The material inputs of stations of a handful of types are assumed based on totals from other rail systems. We are able to estimate track based on a bottom up approach, but no other rail system component. Our attempt to estimate the material inputs of rail passenger stations was not successful. Significant changes will be necessary in the ways that transit agencies present data before valid construction-related greenhouse gas inventories are possible.

G.3 Application to Hypothetical Projects

The rail model data shown in Table G.8 also was applied to a set of hypothetical projects with similar characteristics, to examine how emissions varied based on factors such as at-grade versus tunnel and bridge construction, extent of structured versus surface parking, etc.

Figure G.2 shows variations in emissions for a set of hypothetical LRT projects. The projects all have the following similar characteristics:

- 10.0 miles in length, double-tracked;
- One station per mile;
- 2,500 parking spaces; and
- 32 new vehicles are purchase.

The "base" project has eight platform and two structured stations, 80 percent surface/ 20 percent structured parking, 10 percent of its alignment on bridges/structures, and no tunnel alignment. Construction materials for this project result in a total of 261,000 tonnes CO_2e, or 26,100 tonnes per mile. Variations with 50 percent elevated and 50 percent subsurface alignments, respectively, roughly double this to 59,000 tonnes/mile for elevated and 50,000 tonnes/mile for subsurface. Converting the base alignment to 80 percent structured parking increases CO_2e emissions by about 15 percent to 29,900 tonnes/mile. If the project also includes a majority (six) structured stations, emissions increase by another 10 percent to 32,800 tonnes/mile. In terms of emissions by component, catenary is the largest contributor to GHG for surface alignments, although track and structures begin dominate when there are substantial fractions of above-grade and below-grade alignments.

Figure G.2 GHG Emissions Embodied in Construction Materials
Hypothetical Light Rail Transit

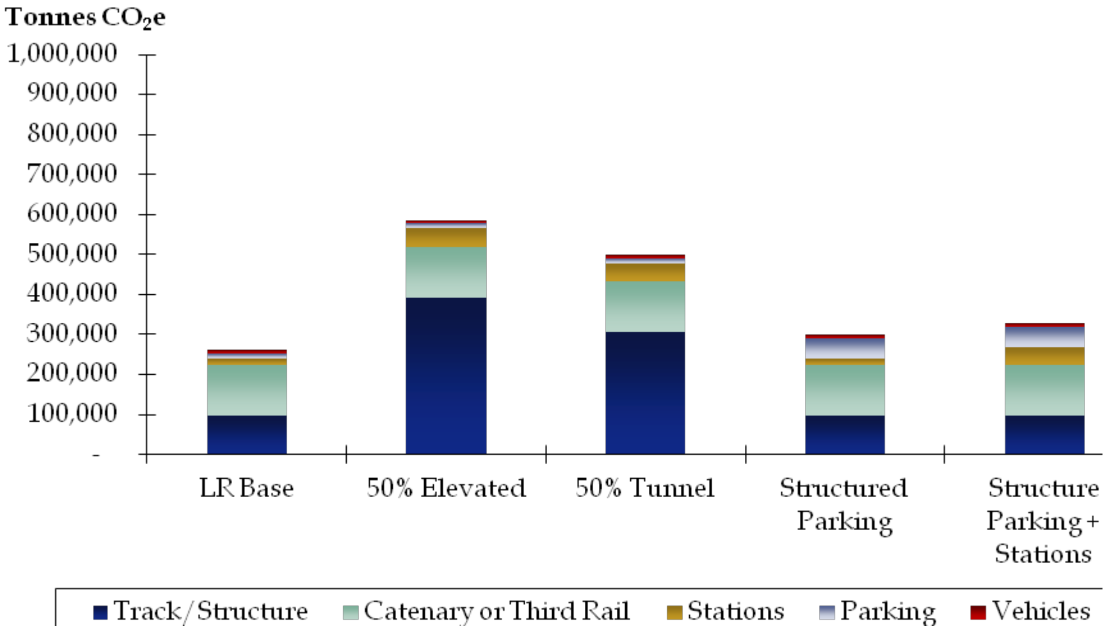


Figure G.3 shows emissions for three variations on a hypothetical heavy rail project. The project is 10 miles of double-track with 2,500 parking spaces (80 percent in structures), and 32 new vehicles. The "base" alternative is one-third at-grade, one-third elevated, and one-third tunnel, with 10 stations. A second alternative is two-thirds tunnel with no at-grade, while a third alternative has only five stations. (All stations are structured). The base alternative produces about 630,000 tonnes GHG in construction (63,000 tonnes/mile), over twice that of the base LRT. The all elevated/tunnel alignment increases that by over 20 percent to 80,000 tonnes/mile, while reducing the number of stations results in a 10 percent decrease in emissions from the base.

Figure G.3 GHG Emissions Embodied in Construction Materials
Hypothetical Heavy Rail Transit

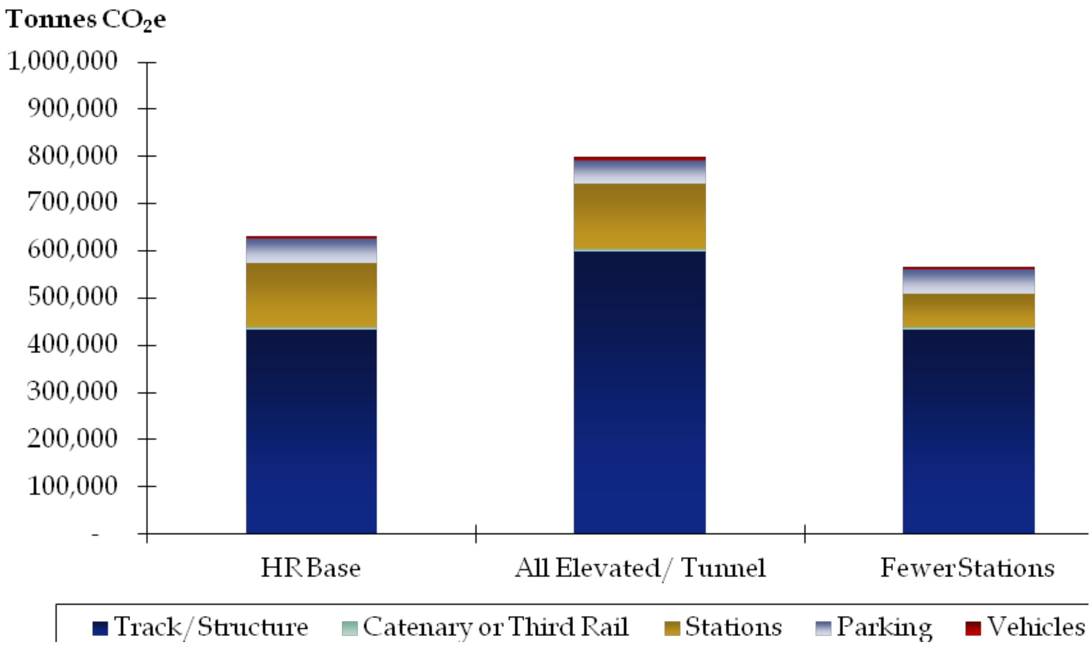
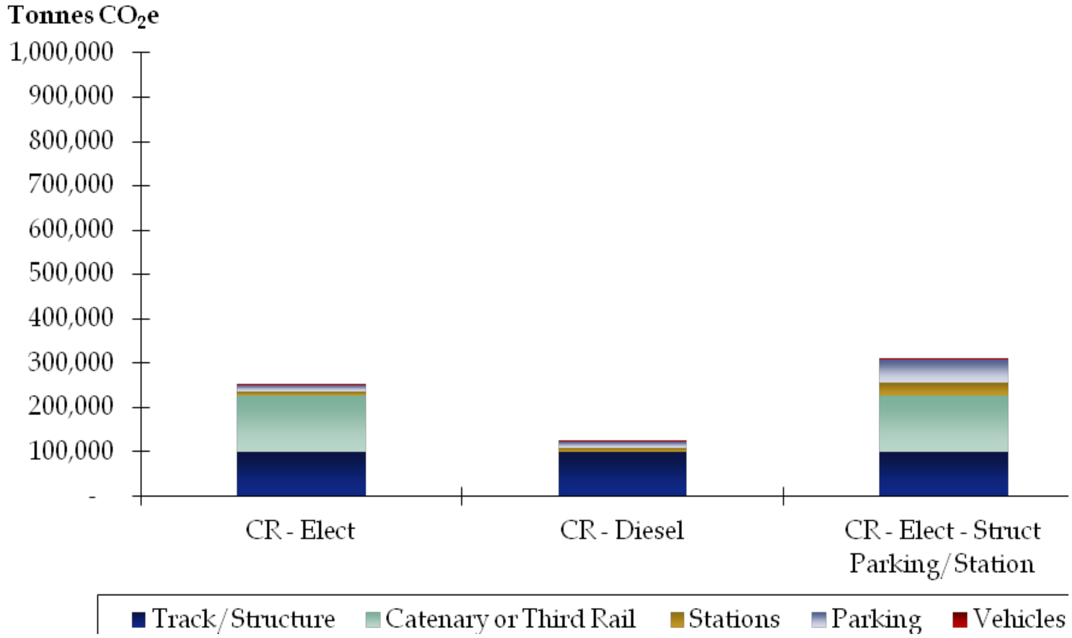


Figure G.4 shows emissions for three variations on a hypothetical commuter rail project. The project is 10 miles of double-track with 2,500 parking spaces, five stations, and 16 new vehicles. All alternatives are 90 percent at-grade with 10 percent bridges/elevated. The first alternative is electric and the second is diesel. The third alternative is electric with structured parking and stations (at four of the five stations). The base electrified alternative produces about 253,000 tonnes of GHG (25,300 tonnes/mile) whereas the diesel alternative produces about half that (12,600 tonnes/mile). Structured stations and parking increase GHG emissions by about 23 percent for the electric rail alternative to 31,200 tonnes/mile. The electrified alternatives are in the same range as the LRT project; the diesel is less GHG-intensive due to not having catenary.

Figure G.4 GHG Emissions Embodied in Construction Materials
Hypothetical Commuter Rail



An interesting question is the extent to which the construction GHG savings of diesel offsets any operating benefits in GHG emissions from the cleaner electricity source. This will vary depending upon the GHG intensity of the local electricity generating mix. In this study, the electric rail alternative for Project 2 also showed higher ridership (and therefore higher GHG reductions from automobiles) due to its faster operating speeds.

Another interesting question is the extent to which the GHG emissions from construction, if annualized over the life of the project, compare with GHG emissions savings from project operation. Table G.13 presents all the assumptions and outputs for the hypothetical projects described above, including GHG emissions annualized assuming a 50-year project lifetime and no discounting. Annualized emissions are in the range of 3,000 to 6,000 tonnes for commuter rail, 5,000 to 12,000 tonnes for light rail, and 11,000 to 16,000 tonnes for heavy rail. For comparison, those pilot study projects with GHG reductions showed reductions in the range of 5,000 to 10,000 tonnes per year, with one electric commuter rail project showing reductions of 26,000 tonnes per year. While direct comparisons cannot be made due to the hypothetical nature of these sample calculations, this suggests that GHG emissions from construction are not trivial when compared to operating emissions savings, especially since the construction estimates shown here do not include equipment activity. Furthermore, the hypothetical examples show that the choice of project construction methods and alignment alternatives can make a significant difference.

Table G.13 Project Assumptions and Embodied GHG Emissions by Component for Hypothetical Projects

	LR Base	LR 50 Percent Elevated	LR 50 Percent Tunnel	LR Structure Parking	LR Structure Parking + Stations	HR Base	HR All Elev./ Tunnel	HR Fewer Stations	CR Elect	CR Diesel	CR Elect. Structure Pkg./Sta.
Alignment											
System-Mi (Double-Track)	10	10	10	10	10	10	10	10	10	10	10
At-Grade (Percent)	90%	50%	45%	90%	90%	34%	0%	34%	90%	90%	90%
Bridge/Elevated (Percent)	10%	50%	5%	10%	10%	33%	33%	33%	10%	10%	10%
Tunnel (Percent)	0%	0%	50%	0%	0%	33%	67%	33%	0%	0%	0%
Stations											
Platform (Number)	8	4	4	8	4	0	0	0	4	4	1
Structure (Number)	2	6	6	2	6	0	0	0	1	1	4
HR – Aerial (Number)						3	3	1			
HR – Surface (Number)						4	4	2			
HR – Underground (Number)						3	3	2			
Parking											
Surface (Number of Spaces)	2,000	2,000	2,000	500	500	500	500	500	2,000	2,000	500
Structure (Number of Spaces)	500	500	500	2,000	2,000	2,000	2,000	2,000	500	500	2,000
Vehicles	32	32	32	32	32	32	32	32	16	16	16

Table G.13 Project Assumptions and Embodied GHG Emissions by Component for Hypothetical Projects (continued)

	LR Base	LR 50 Percent Elevated	LR 50 Percent Tunnel	LR Structure Parking	LR Structure Parking + Stations	HR Base	HR All Elev./ Tunnel	HR Fewer Stations	CR Elect	CR Diesel	CR Elect. Structure Pkg./Sta.
Total GHG Emissions, Tonnes CO_2e											
Track/Structure	96,812	393,150	305,734	96,812	96,812	432,522	599,778	432,522	99,792	99,792	99,792
Catenary or 3rd Rail	126,456	126,456	126,456	126,456	126,456	4,992	4,992	4,992	126,456	–	126,456
Stations	16,733	45,865	45,865	16,733	45,865	136,219	136,219	71,134	9,257	9,257	30,438
Parking	13,310	13,310	13,310	50,953	50,953	50,953	50,953	50,953	13,310	13,310	50,953
Vehicles	7,722	7,722	7,722	7,722	7,722	7,722	7,722	7,722	3,861	3,861	3,861
Total	261,033	586,502	499,087	298,675	327,807	632,408	799,663	567,323	252,676	126,220	311,500
Per Mile	26,103	58,650	49,909	29,868	32,781	63,241	79,966	56,732	25,268	12,622	31,150
Annual (50 years)	5,221	11,730	9,982	5,974	6,556	12,648	15,993	11,346	5,054	2,524	6,230

G.4 References

Agency for Toxic Substances and Disease Registry. 2010. Toxicological Substances – Creosote. Available April 15, 2011 at http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=66&tid=18.

ANL. 2007. GREET 2.7 Vehicle Cycle Model. Argonne National Laboratory.

ANL. 2009. GREET 1.8c Fuel Cycle Model. Argonne National Laboratory.

AREMA. 2000a. Chapter 1 Roadway and Ballast. In *Manual for Railway Engineering*. Lanham, Maryland: American Railway Engineering and Maintenance-of-Way Association.

AREMA. 2000b. Chapter 4 Rail. In *Manual for Railway Engineering*. Lanham, MD: American Railway Engineering and Maintenance-of-Way Association.

BCS, Inc. 2002. Chapter 4 – Iron. *In Energy and Environmental Profile of the U.S. Mining Industry*. U.S. Department of Energy. Office of Energy Efficiency and Renewable Energy. Available April 22, 2010 at http://www1.eere.energy.gov/industry/mining/pdfs/iron.pdf.

Buckingham, D.A.; Plunkert, P.A.; Bray, E.L. 2010. Aluminum Statistics, 1900-2009. USGS. Mineral Resources Program. Available April 13, 2011 at http://minerals.usgs.gov/ds/2005/140/aluminum.pdf.

Chester, M. V. 2008. *Life-Cycle Environmental Inventory of Passenger Transportation in the United States.* (Doctoral Dissertation, Institute of Transportation Studies UC Berkeley, 2008). *eScholarship*, 7n29n303. Available April 15, 2011 at http://escholarship.org/uc/item/7n29n303.

Choate, W.T. 2003. Energy and Emission Reduction Opportunities for the Cement Industry. U.S. Department of Energy, Energy Efficiency and Renewable Energy.

The Climate Registry 2008, *General Reporting Protocol: Version 1.1*, the Climate Registry.

Edelstein, D.L. 2011. Copper. USGS. Mineral Commodity Summaries. Available April 13, 2011 at http://minerals.usgs.gov/minerals/pubs/commodity/copper/mcs-2008-coppe.pdf.

Elliot, R. 2009. 3rd and 4th rail dimensions and settings. Available May 26, 2011 at http://homepage.ntlworld.com/russelliott/3rd-4th.html.

EPA. 1995. AP 42, Fifth Edition. Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. 12.3 Primary Copper Smelting. Available April 8, 2011 at http://www.epa.gov/ttn/chief/ap42/ch12/final/c12s05.pdf.

EPA. 2003. Background Document for Life-Cycle Greenhouse Gas Emission Factors for Clay Brick Reuse and Concrete Recycling. EPA530-R-03-017 Available April 11, 2011 at http://www.epa.gov/climatechange/wycd/waste/downloads/ClayBrickand Concrete_11_07.pdf.

EPA. 2005. Streamlined Life-Cycle Greenhouse Gas Emission Factors for Copper Wire. Available April 2, 2001 at http://www.epa.gov/climatechange/wycd/waste/downloads/ Copperreport6-2.pdf.

Greenhalgh, S., Broekhoff, D., Daviet, F., Ranganathan, J., Acharya, M., Corbier, L., Oren, K. & Sundin, H. 2005, *The Greenhouse Gas Protocol for Project Accounting*, The World Resources Institute and World Business Council for Sustainable Development, Washington, D.C.

Guggemos, A.A.; Horvath, A. 2005. *Comparison of Environmental Effects of Steel- and Concrete-Framed Buildings*. Journal of Infrastructure Systems, Vol. 11, Num 2, pages 93-101. Available at http://dx.doi.org/10.1061(ASCE)1076-0342(2005)11:2(93).

Hunt, D. 2010. Overcoming Operating Challenges with Warm Mix Asphalt [PowerPoint presentation]. Gencor. Available April 25, 2010 at http://76.12.53.242/submissions/ 50_20080101_Dennis%20Hunt%20-%20Gencor.pdf.

IPCS. 2004. Coal Tar Creosote. Concise International Chemical Assessment Document 62. International Programmed on Chemical Safety. Available March 7, 2011 at http://www.inchem.org/documents/cicads/cicads/cicad62.htm.

Lamlom, S. H.; Savidge, R. A. 2006. *Carbon Content Variation in Boles of Mature Sugar Maple and Giant Sequoia*. Tree Physiology Vol. 26, pages 459-468.

Marceau, M. L.; Nisbet, M. A.; VanGeem, M. G. 2007. Life Cycle Inventory of Portland Cement Concrete. PCA R&D Serial No. 3011. Skokie, Illinois: Portland Cement Association.

Network Rail. n.d. Comparing Environmental Impact of Conventional and High-Speed Rail. Available April 4, 2011 at http://www.networkrail.co.uk/documents/ About%20us/New%20Lines%20Programme/ 5878_Comparing%20environmental%20impact%20of%20conventional%20and%20high%20speed%20rail.pdf.

NJT. 1993. Physical Characteristics of NJ Transit Including Portions of Conrail and Amtrak Territories. Fourth Edition.

NJT. 2010. Parking Guide. 2010 Edition.

Puettmann, M. E.; Wilson, J. B. 2005. *Life-Cycle Analysis of Wood Products: Cradle –to–Gate LCI of Residential Wood Building Materials*. Wood and Fiber Science Vol. 37 Corrim Special Issue, pages 18-29.

Raganathan, J., Corbier, L., Bhatia, P., Schmitz, S., Gage, P. & Oren, K. 2009, *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*, The World Resources Institute and World Business Council for Sustainable Development, Washington, D.C.

Riley, J. E. 2003. Basic Track. In *Practical Guide to Railway Engineering*. Second Edition. Lanham, MD: AREMA.

Smith, S.; Bolin, C. 2010. Creosote-Treated Ties End-of-Life Evaluation. Helena, MT: AquAeter. Available March 2, 2011 at http://www.rta.org/Portals/0/Documents/Research%20Paper%20&%20Articles/RTA%20Sponsored%20Research/Creosote%20Tie%20Evaluation%20Article%20_4_.pdf.

Tran, L. H.; Drogui, P.; Mercier, G.; Blais, J. F. 2009. *Electrolytic Oxidation of Polynuclear Aromatic Hydrocarbons from Creosote Solution Using TI/IRO$_2$ and TI/SNO$_2$ Circular Mesh Electrodes*. Journal of Environmental Engineering October 2009, pages 1051-1062. Available March 7, 2011 at http://www.ascelibrary.org.

VTC. 2010. Review of Energy and Material Inputs to Transportation Construction Projects. Report to New Jersey Department of Transportation.

Wang, M. 2008. Estimation of Energy Efficiencies of U.S. Petroleum Refineries. Argonne National Laboratory.

Zapata, P.; Gambatese, J. A. 2005. *Energy Consumption of Asphalt and Reinforced Concrete Pavement Material and Construction*. ASCE Journal of Infrastructure Systems, Vol. 11 No. 1, pages 9-20. Available April 25, 2010 at http://cedb.asce.org/cgi/WWWdisplay.cgi?145645.

Appendix H – List of Candidate Environmental Performance Metrics

The metrics presented below represent the original list assembled and considered by the project team in Phase 1 of this research. This list was originally presented to the project panel as part of a technical memorandum, and later included as part of the Phase 1 Interim Report. From this list were selected the metrics evaluated in more detail in Phase 2.

Table H.1 Candidate Environmental Performance Metrics

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
1	**Energy Use and GHG Emissions**				
2	***Benefits or Impacts***				
3	Net change in energy consumption (BTUs)	Fuel use, energy content, energy input to manufacture	[See below by "source"]	• Proxy indicator of environmental and social impacts related to energy use; avoids issue of geographic discrimination based on electricity grid.	• Not a direct measure of any environmental or social impacts; different fuels have different impacts.
4	Net change in GHG emissions	Emission factors by vehicle and fuel type, emissions from manufacture	[See below by "source"]	• Most direct measure of climate change-related impact.	• Not a direct measure of energy security impact (e.g., foreign oil).
5	Net change in petroleum use	Petroleum fuel use	[See below by "source"]	• Most direct measure of energy security impact.	• Not a direct measure of GHG emissions.
6	***Sources***				
7	Direct operating – transit and private vehicles	• VMT by vehicle type (roadway, transit) • Fuel consumption and/or emission rates (miles/gallon, BTU/gallon, gallon/mile) for all vehicles with changing service levels • Speeds by vehicle type • Energy content or GHG emission factors (BTU/gallon, GHG/gallon)	• VMT and speeds: travel demand model, transit operating plans • Fuel consumption or emission rates: MOVES, EMFAC, manufacturers' data • Energy or GHG factors: U.S. DOE	• Most significant emissions impact/benefit.	• Change in regional emissions very small compared to total emissions, and may not be reliably estimated by travel demand model.
8	Transit and private vehicles – full fuel cycle (upstream and downstream)	Fuel-cycle emission rates	• U.S. DOE – GREET Model • U.S. EPA – eGRID (electricity)	• Essential if alternative fuel transit vehicles or electric propulsion are to be evaluated.	• Added information probably not worth the additional effort if only fossil-fuel vehicles are evaluated.
9	Transit construction – activity, embodied in materials	• Materials inputs • Construction activity • Energy or GHG factors for these	• Research on construction and embodied emissions (Chester, NCHRP 25-25/58, NJDOT)	• Impacts shown to be nontrivial.	• Highway project evaluations currently do not include this factor.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources Data Requirements (for Forecasting)	Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Disadvantages
10	Transit infrastructure – operations and maintenance	• Energy and materials inputs • Energy or GHG factors for these	• Research on life-cycle emissions (Chester)	• Impacts shown to be nontrivial.	• Highway project evaluations currently do not include this factor.
11	Transit vehicles – manufacture, disposal	• Energy or GHG factors	• Research on life-cycle emissions (Chester)	• Impacts shown to be nontrivial.	• Would require analysis of avoided auto ownership and associated savings for fair comparison.
12	Avoided infrastructure (highway)	• Amount of highway infrastructure need avoided through transit construction • Materials inputs • Construction activity • Energy or GHG factors for these	• Research on construction and embodied emissions (Chester, NCHRP 25-25/58, NJDOT)	• Inclusion may be one way of "leveling playing field" if highway project evaluation does not include similar metrics.	• Difficult to attribute a particular amount of "avoided" highways to transit construction. • Inconsistent with NEPA and New Start practice of comparing project build with no-build.
13	***Ways of Expressing or Normalizing***				
14	Total	[See above]		• Direct measure of gross impact/benefit.	• Not normalized by scale of project.
15	Per passenger-mile: all modes	+Total passenger miles in study area with and without project	Regional travel demand model	• Measure of transportation system efficiency.	• Size of impact will depend upon study area – larger area will dilute impact.
16	Per passenger-mile: transit	+Total transit passenger miles in study area with and without project	Regional travel demand or transit ridership forecasting model	• More narrow measure of transit service efficiency; can help transit agencies focus on efficient service.	• Size of impact will depend upon study area – larger area will dilute impact. • Does not account for emissions from private vehicles.
17	Per capita (service area)	+Total population in service area	Regional travel demand or transit ridership forecasting model	• Accounts for benefits of reductions in passenger-miles per capita.	• Size of impact will depend upon study area – larger area will dilute impact.
18	Per unit cost of project	+Annualized cost of project (capital + operating)	Project financial analysis	• Direct measure of cost-effectiveness; normalizes for project scale.	

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
19	***Proxy Measures***				
20	Change in VMT	• Net change in regional VMT	• Regional travel demand model	• Measure of private vehicle use; proxy for other impacts, including air quality, infrastructure needs, community impacts.	• Does not account for added energy use or GHG emissions from new transit service.
21	Consistency of project with regional or local energy or climate action plan	• Is project included in plan as GHG reduction measure?	• Plan document	• Yes/no indicator of project's value for energy/GHG reduction. • Plan development already may have analyzed benefits of project.	• Does not indicate magnitude or cost-effectiveness of benefits. • Many areas will not have specific projects identified in a plan.
22	"Best in class" efficient/low-carbon transit vehicle purchasing	GHG emissions per seat-mi	• Manufacturer specifications for or other test data for fuel/energy intensity, GHG factors by fuel type	• Proxy for minimizing direct operating emissions.	• Does not account for load factors and overall efficiency of transit versus alternatives.
23	Best management practices for GHG reduction in construction and transit agency operations	• Efficiency standards for construction equipment and fleet vehicles • Guidelines for GHG reducing construction practices (e.g., idle reduction, use of recycled materials)	• Contracting guidelines or documents • Agency policies, operating procedures, etc.	• Proxy for minimizing construction and maintenance emissions.	• Does not assess magnitude of GHG reduction. • Would require development of guidelines for BMPs.
23a	Land use multiplier (travel benefits associated with more compact land use)	• Travel and land use patterns in region	• Travel demand modeling, statistical evaluation, and GIS analysis to develop region-specific multiplier	• Potentially simple method for accounting for additional GHG benefits of reduced travel due to more compact land use patterns, if multipliers for different regions can be developed.	• Currently, a national "default" has been established but this multiplier can vary widely by region and is data-intensive to calculate locally.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
24	**Air Quality and Public Health**				
25	***Air Quality Benefits or Impacts***				
26	Net change in criteria pollutant emissions and precursors – by source				
27	Direct operating emissions – transit and private vehicles	• Change in VMT by vehicle type (highway, transit) • Emission rates (g/mi) for all vehicles with changing service levels • Changes in vehicle speeds on highway network	• VMT: Travel demand model (highway), transit operating plans • Fuel consumption or emission rates: MOVES, manufacturers' data, AEO • Speeds: regional travel model, transit operating plans	• Most significant emissions impact.	• Change in regional emissions may be very small compared to total emissions, and may not be reliably estimated by travel demand model. • Same emission reduction may have different benefits depending upon existing air quality issues.
28	Construction activities	• Activity levels and emission rates for construction vehicles	Models developed by UC-Davis for Caltrans, Rutgers for NJDOT, NCHRP 25-25(58)	• May be particular impacts of localized concern.	• Lack of reliable, easy to use data and analysis methods. • Does not consider temporary changes in normal traffic emissions.
29	Other nonlocalized emissions, including upstream fuel, station and facility operations	• Life-cycle emission factors	• U.S. DOE – GREET Model • USEPA – eGRID (electricity)	• More complete accounting of emissions/air quality impacts.	• Impacts of a particular pollutant may vary widely depending upon where emissions take place.
30	Change in ambient air quality (concentration of pollutants)				
31	Maximum concentrations of locally significant pollutants (CO, NO_2, PM, toxics)	• Emissions by location (vicinity of project) • Meteorological and topographical data • Background concentrations	• Microscale emissions models (e.g., CAL3QHC) • Dispersion models (CALINE, AERMOD, CMAQ, etc.) • NATA (air toxics concentrations and emissions by census tract)	• Well-established evaluation methods. • New one-hour NO_2 NAAQS relevant to health benefits and mobile sources.	• Data-intensive to model, although may be possible to do more simply for toxics using NATA data.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
32	Maximum concentrations of regionally significant pollutants (ozone, secondary PM, acid rain precursors)	• Emissions by location (throughout region) • Meteorological data • Background concentrations	• Mesoscale and regional air quality models		• Extremely data and time-intensive to model. • Impacts of a single transit project are not likely to create measurable differences on a regional scale.
33	Exposure measures				
34	Change in population exposure index for criteria pollutants and air toxics	• Changes in emissions (mobile and stationary source) by TAZ/ subarea • Population by TAZ/ subarea • Background concentrations (optional)	• Regional travel demand model • Locations of electricity generation plants and emission rates per KWh • NATA (background concentrations)	• Easiest health-related indicator to calculate. • May be better indicator of benefit of local pollutant exposure across projects of differing extent and demographic scope.	• May not be directly related to health outcomes. • Changes in emissions from electricity generation may not be readily obtainable. • Assumes resident population is proxy for exposure.
35	Change in population exposed to unhealthful air quality	• Change in air quality by TAZ/subarea – frequency of NAAQS expected exceedances of standards • Population in areas with air quality changes	• Ambient air quality concentration models (per above), combined with population data	• Acknowledges importance of NAAQS as "threshold" level related to health effects.	• Difficult to calculate. • Transit project likely to have only incremental impact.
36	Health impacts				
37	Health benefit index	• Changes in emissions by TAZ/subarea • Population by TAZ/ subarea • "Potency" of each pollutant	• Regional travel demand model • USEPA, literature (potency)	• Feasible to calculate from available data.	• Rough proxy for exposure and health impact.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
38	Incidence of pollution-related mortality and morbidity (e.g., asthma, lung cancer)	• Background emissions and changes in emissions over time by TAZ/subarea • Population by TAZ/subarea • Dose-response functions for each pollutant	• Regional travel demand model • USEPA – NATA (background concentrations) • USEPA, literature (dose-response) • USEPA BENMAP methods	• Measure most directly related to ultimate health outcomes. • Focus on criteria and toxic air pollutants most relevant to mobile sources.	• Difficult to calculate at present (though models are emerging).
39	***Proxy Air Quality Measures***				
40	NAAQS nonattainment status	EPA listings of nonattainment status	EPA "Green Book"	• Readily available indicator of areas with air quality problems.	• Does not indicate transit project's "benefits," either in terms of attainment of standards, or exposure of population to unhealthful pollutants. • Differences between areas just above and below NAAQS overemphasized; degree of nonattainment only indicated for ozone. • Designation may be out of date.
41	Air Quality Index	• Daily air quality readings	• Calculated by EPA for six pollutants in major MSAs; see AirData web site	• Preferable to nonattainment status as a readily-available indicator of severity of air quality problem across areas.	• Does not indicate transit project's "benefits" in terms of contributing towards air quality improvement.
42	Conformity of LRTP or TIP containing transit project with AQ objectives	• Conformity analysis of LRTP or TIP containing transit project	• Regional travel demand model and emission factors	• Identifies whether project is part of transportation plan that meets AQ objectives.	• Transit project just one part of overall plan performance; does not indicate incremental benefit or impact of project. • All plans/TIPs ultimately need to be conforming to receive Federal funding.
43	Change in VMT	• Net change in regional VMT	• Regional travel demand model	• Measure of private vehicle use; proxy for other impacts, including GHG, infrastructure needs, community impacts, physical activity benefits.	• Does not account for added emissions from new transit service.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
45	Best management practices for emissions reduction in construction and transit agency operations	• Emissions standards for construction equipment and fleet vehicles • Guidelines for emission reducing construction practices (e.g., idle reduction, dust control)	• Contracting guidelines or documents • Agency policies, operating procedures, etc.	• Proxy for minimizing construction and maintenance emissions.	• Does not assess magnitude of emissions reduction. • Would require development of guidelines for BMPs.
105	**Physical Activity (Proxy Measures)**				
	Direct Impacts				
105a	Forecast number of daily nonmotorized access trips	• Transit ridership forecast, including access mode choice	• Travel demand forecasting model	• Most closely related metric to actual physical activity generated by project than can reasonably be forecasted using available data.	• Access mode choice models may have limited accuracy. • Does not account for additional physical activity by station area residents not directly using transit.
	Proxy Measures				
106	Percent population within half-mile walk of transit stop	• Location of transit stations, population by block group/tract/TAZ • Street networks identifying walkable routes	• GIS overlay or network analysis	• Basic measure of access to transit.	• Does not indicate utility of available transit. • Analysis of street/walking route network requires more work than simple spatial overlay, but spatial overlay may not indicate walk accessibility.
107	Station area or corridor walkability and bikeability metrics (connectivity, sidewalk availability, miles of bike lanes/capita, LOS, etc.)	• Local land use and transportation plans and policies	• Qualitative assessment		• Not a direct outcome of transit investment, but rather of any related land use and infrastructure changes.

Table H.1 Candidate Environmental Performance Metrics (continued)

	Category	Data Needs and Sources		Use of Measure as a Transit Performance Metric:	
Row #	*Subcategory or Measure*	Data Requirements (for Forecasting)	Data Sources and Analysis Methods	Advantages	Disadvantages
46	**Ecology, Habitat, and Water Quality**				
47	Sources				
48	I. Direct: Construction activities (short-term)	• See below under specific "Benefits or Impacts" (Water Quality)			
49	II. Direct: Facility and Operations	• See below under specific "Benefits or Impacts" (all impacts)			
50	III. Indirect – Induced growth/land use changes				
51	***Benefits or Impacts***				
52	**Water Quality**				
53	Hydromodification – change in sediment and nutrient load, temperature, water velocity, erosion, barriers	• Physical/hydrological characterization of receiving water bodies and associated riparian areas • Coefficients for estimated pollutant load due to anticipated hydromodification			
54	*Direct*	• Project footprint	• Project plans	• Direct wetland impacts generally considered in NEPA evaluation.	• Requires detailed data and modeling. • May be small compared to indirect impacts.
55	*Indirect*	• Location and characteristics of development	• Land use forecasting model • Site design requirements	• May be significant compared to direct impacts.	• Impossible to forecast accurately.
56	Change in riparian or floodplain areas	• Area, quality, and functioning of riparian areas • Locations of floodplains			

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources Data Requirements (for Forecasting)	Data Needs and Sources Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
57	*Direct*	• Project footprint	• Project plans	• Direct impacts generally considered in NEPA evaluation.	• May be small compared to indirect impacts.
58	*Indirect*	• Location of development	• Land use forecasting model	• May be significant compared to direct impacts.	• Impossible to forecast accurately.
59	Water quality standards compliance	• Identification of receiving waters • 303(d) list of impaired waters • TMDLs for receiving waters • Coefficients for predicted pollutant loading			
60	*Direct*	• Project footprint	• Project plans	• Direct impacts generally considered in NEPA evaluation.	• May be small compared to indirect impacts.
61	*Indirect*	• Location and characteristics of development	• Land use forecasting model • Site design requirements	• May be significant compared to direct impacts.	• Impossible to forecast accurately.
62	**Wetlands**				
63	Net change in acreage of (high-quality) wetlands	• Locations of wetlands (by quality/ significance)	• GIS wetlands database • GIS habitat database from Regional Ecological Framework or State Wildlife Action Plan		
64	*Direct*	• Project footprint	• Project plans	• Direct wetland impacts generally considered in NEPA evaluation.	• May be small compared to indirect impacts.
65	*Indirect*	• Location of development	• Land use forecasting model	• May be significant compared to direct impacts.	• Difficult or impossible to forecast accurately.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources Data Requirements (for Forecasting)	Data Needs and Sources Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
66	**Habitat/Ecosystems**				
67	Change in acres of fragmented or threatened critical habitat	• Actual or expected locations of critical habitat	• GIS habitat database from Regional Ecological Framework or State Wildlife Action Plan		
68	*Direct*	• Project footprint	• Project plans	• Direct ecological impacts generally considered in NEPA evaluation.	• May be small compared to indirect impacts.
69	*Indirect*	• Location of development	• Land use forecasting model	• May be significant compared to direct impacts.	• Impossible to forecast accurately.
70	Change in acres of native and invasive plants	• Vegetation maps	• GIS habitat database		
71	*Direct*	• Project footprint • Landscape plans	• Project plans		• May be small compared to indirect impacts.
72	*Indirect*	• Location of development • Landscaping characteristics	• Land use forecasting model or indicator of likely impact • Landscaping requirements	• May be significant compared to direct impacts.	• Impossible to forecast accurately.
73	**Land with Resource Value**				
74	Acres of (prime) farmland, forest land, open space				
75	*Direct*	• Project footprint • Land use cover by type	• Project plans • Land cover database	• Direct impacts generally considered in NEPA evaluation.	• May be small compared to indirect impacts.
76	*Indirect*	• Location of development	• Land use forecasting model or indicator of likely impact	• May be significant compared to direct impacts.	• Difficult or impossible to forecast accurately.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
77	***Proxy Measures***				
78	**Water Quality**				
79	Impervious surface area				
80	*Direct*	• Project footprint	• Project plans		• May be small compared to indirect impacts.
81	*Indirect*	• Location and characte-ristics of development	• Forecasts of land use by type/density • Coefficients for percent impervious surface area by type of development • Any requirements related to impervious surface in development	• May be significant compared to direct impacts. • Widely used indicator of water impacts. • Does not require knowing precise loca-tion of induced development.	• Difficult to forecast land use impacts associated with project, even in general sense.
82	Impingement upon water quality protection areas	• Locations of ground-water and sourcewater protection areas, water bodies training into impaired waters	• Local and regional watershed protection plans		
83	*Direct*	• Project footprint	• Project plans		• May be small compared to indirect impacts.
84	*Indirect*	• Location of development	• Land use forecasts	• May be significant compared to direct impacts.	• Impossible to forecast accurately.
85	**Wetlands, Habitat/ Ecosystems, and Other Land with High Resource Value**				
86	*Direct*:				
87	Acres of land used for trans-portation purposes	• Project footprint	• GIS analysis of project plans	• Easy to calculate direct impact measure.	• No indication of environmental value of land.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
88	*Indirect*:				
89	Acres of land developed in corridor due to project	• Development by future analysis year, with and without project	• Land use forecasting model, or qualitative assessment	• Indirect land use impacts likely to be much more significant than direct impacts.	• Very difficult to forecast. • Not clear how to define baseline: simple with versus without transit comparison? Transit systems versus highway systems?
90	Ratio of already-developed land in corridor to undeveloped land (greenfields)	• Location of project • Local land use plans	• Local or regional land use plan data in GIS format	• Scaled/normalized indicator of potential indirect impacts without requiring land use forecast or detailed environmental data.	• Does not indicate likelihood that land in project influence area will actually be developed because of project, or environmental impacts of such development.
93	Potentially impacted acreage of wetlands, critical habitat, and/or other land with high resource value	• Locations of wetlands, critical habitat, or other land with high resource value (protected versus unprotected) • Influence areas where development is likely to occur	• Wetlands or habitat database or assessment (see above) • Existing designated conservation areas • Influence indicator based on proximity to project or accessibility change	• Indicator of indirect impacts that avoids need for precise forecast of land development.	• Measure of potential rather than actual impact.
94	Potentially impacted acreage, weighted by ecosystem service value	• Same as previous, with addition of ecosystem service values for different land use types	• Ecosystem service value methods being developed for SHRP2 Project C06B	• Improves on previous indicator by assigning ecological significance to potential impacts.	• Requires data on ecosystem service values.
95	Adequacy of state or regional habitat protection plans and consistency of project with plans	• Existence of regional habitat protection/conservation plans • Quality of plans and implementation authority in terms of ability to protect critical habitat	• Qualitative evaluation of plans and implementation capacity	• Can indicate potential for avoiding/mitigating habitat impacts without forecasting land use changes.	• Not an actual measure of impact. • Many areas will not have regional conservation plans, although all states have wildlife action plans with varying degrees of focus and quality. • Subjective assessment.
96	Qualitative assessment of expected impacts on sensitive land use	• Location of project • Proximity to developable lands • Market and policy factors influencing development in impact area	• Local land use plans • Expert knowledge, Delphi process	• Easier to apply than quantitative forecast; can incorporate expert judgment. • May be available from environmental documentation.	• Subjective; difficult to reliably know potential impacts or translate into quantitative impact metric.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
97	**Community and Quality of Life**				
98	***Benefits or Impacts***				
99	**Environmental and Social Quality**				
100	Noise – Percent residents exposed to greater than xx DB noise from transportation sources	• Location of transportation facilities, traffic volumes • Noise emitted from transit vehicles and facilities • Detailed information on population by area (block)	• Traffic forecasts • Transit project operating data • Census population data	• Could indicate whether net noise benefit or impact from transit facilities, considering reduced VMT.	• Labor/data-intensive to conduct analysis.
101	Community cohesion/ disruption	• Location and geometric characteristics of transportation facilities • Traffic volumes • Neighborhood connections/linkages	• Transportation network data • Traffic forecasts • Qualitative assessment considering community input		
102	Aesthetics/visual quality	• Location and appearance of transportation facilities • Indirect impacts – land use changes in community resulting from project • Community preferences	• Qualitative assessment of visual impact • Indirect – land use forecasts/assessment • Visual preference surveys		• Difficult to forecast/reliably predict indirect impacts of project.
103	Resident perceptions of community quality	• Resident ratings of various community attributes	• Community surveys	• Self-identified measures of livability/ quality of life.	• Difficult to forecast/reliably predict impacts of project.
104	Historical, cultural, and archeological resources	• Location and value of key resources	• State and local historical preservation offices • Archeological resource databases	• Evaluation required in NEPA and Section 106 process.	

Table H.1 Candidate Environmental Performance Metrics (continued)

	Category	Data Needs and Sources		Use of Measure as a Transit Performance Metric:	
Row #	*Subcategory or Measure*	Data Requirements (for Forecasting)	Data Sources and Analysis Methods	Advantages	Disadvantages
108	**Transportation Choices**				
109	Transit LOS index	• Existing and proposed levels of transit service (frequencies, service coverage) by area	• Transit capacity and quality of service manual (CUTR)	• More sophisticated transit availability measure.	• Still does not indicate how accessible destinations are via transit.
110	Accessibility index by non-auto modes (to jobs, services)	• Travel demand model data – population, employment by type, travel times by mode	• Travel demand model analysis	• Basic measures for auto, transit easy to develop from travel demand model as applied to ridership forecasting.	• More work needed to evaluate accessibility to specific services, or match between resident skills and jobs.
111	Percent population within half-mile walk of transit stop	(See above for Physical Activity)			
112	**Walkability and bikeability metrics**	(See above for Physical Activity)			
113	**Housing Affordability**				
114	Number of affordable units within half-mile walk of transit	• Location of transit stations • Location of affordable housing units (existing, planned)	• Local housing data	• Indicates population most likely to benefit from transit.	• Housing prices and affordability can change over time; no forecasting methods available. • May be more important to look at housing plans/policies than existing characteristics.
114a	Affordable housing policies	• Local and state land use policies and programs related to affordable housing provision	• Qualitative assessment	• May be more feasible than quantitative assessment.	• Subjective; difficult to account for variations in contexts and needs across projects.

Table H.1 Candidate Environmental Performance Metrics (continued)

Row #	Category *Subcategory or Measure*	Data Needs and Sources: Data Requirements (for Forecasting)	Data Needs and Sources: Data Sources and Analysis Methods	Use of Measure as a Transit Performance Metric: Advantages	Use of Measure as a Transit Performance Metric: Disadvantages
115	**Safety and Security**				
116	Transportation-related accidents or fatalities per capita (auto, ped, bike, transit)	• VMT and/or PMT by mode • Accident rates by mode	• VMT/PMT from travel demand forecasting model • Analysis of local/ regional crash data		• Forecasts of nonmotorized travel and future crash rates may not be reliable. • Cannot forecast any project-specific impact aside from that related to VMT/PMT by mode.
117	Crime rates			• Transit investment could potentially influence crime rates in combination with development and demographic changes in community.	• Numerous factors influence crime rates aside from transportation investments; cannot be forecast.
118	**Support for Existing Communities**				
119	Percent of station area or corridor land that already is developed	• Existing land use data	• GIS analysis	• Basic measure of serving existing communities.	• Does not indicate developed land that is not "community" – e.g., industrial, or underutilized – or not compatible with transit (e.g., low-density single-family).
120	Percent of station area or corridor land that already is developed in "transit-supportive" patterns	• Existing land use data	• GIS analysis, based on qualitative and quantitative metrics (density, mix, walkability, use types)	• Adds information on extent to which transit is reinforcing compatible communities (versus serving noncompatible communities).	
121	Total population living in station areas or corridor	• Population data	• GIS analysis	• Considers population benefiting in existing communities – not just land area of communities served.	• May not indicate distribution/ location of population or "communities" in relation to transit stations.

Appendix I – Literature Review

I.1 Introduction

Transit Cooperative Research Program (TCRP) Project H-41 addresses the need for new measures of the environmental benefits of transit investments. In particular, the objective of the research is to present, evaluate, and demonstrate criteria, metrics, and methods for assessing and comparing the environmental performance of major transit investments. The research results will offer a basis for assessing and comparing these transit projects and will offer project sponsors optional criteria, metrics, and methods for assessing transit projects with regard to environmental performance.

As part of Phase 1 of this research, a review of the literature was conducted to identify environmental performance measures and measurement systems used for transit and other transportation projects. In addition to research studies and reports, this review included systems for rating environmental performance of infrastructure projects, as well as a review of international practice in the environmental evaluation of transportation projects and programs.

The remainder of this appendix is organized as follows:

- Section I.2 presents a summary of the literature review;
- Section I.3 contains an annotated bibliography;
- Section I.4 reviews environmental performance rating systems and tools; and
- Section I.5 reviews international practice in transportation environmental performance measurement.

I.2 Summary of Literature Review

Published Literature

Seventeen relevant literature sources were identified. An annotated bibliography is provided in Section I.3. Types of literature reviewed included:

- Reports enumerating and discussing how to measure benefits and impacts of transit, including environmental effects (e.g., TCRP Reports 20 and 88, Volpe Colloquium);
- Reports examining transportation performance measures and evaluation frameworks both in the United States and abroad; and
- Reports and detailed guidance on specific environmental measures, primarily greenhouse gases (e.g., GHG-reporting protocols).

Measuring emissions – in particular GHG – and the base measure of changes in VMT due to transit investments were covered the most in the literature review. This literature included studies describing and quantifying the direct and indirect effects of transportation on changes in GHG and VMT, with some reports monetizing these measures. These documents were the most specific in identifying steps and data needed to complete the measures and apply them to transit agencies.

Broad catalogues of environmental performance measures tended to offer key categories and issues to consider such as scale of analysis. The most useful of these identified specific measures, data sources, and how to calculate the results. For example, the Strategic Highway Research Program 2, Project C02, produced a library of performance measures for highway capacity expansion investments, including environmental measures, many of which are applicable to transit as well as highway projects.

Environmental Performance Rating Systems and Tools

With growing interest in sustainability, a number of assessment tools have been developed to assist organizations in assessing and rating the "sustainability" or environmental performance of their operations. Most systems are not transit-specific, but many include metrics that may inform transit applications. Some of these are focused on buildings (e.g., LEED), which could be applied to transit agency facilities. Others have been developed for infrastructure projects, primarily highways (e.g., Greenroads), but their principles could be extended to transit project construction. ISO certification is focused on environmental impacts across a full range of an agency's operations. Still others are focused at the community level (e.g., STAR) and include measures of transportation system performance and impacts (including transit). Existing rating/assessment systems are detailed in Section 3.2.

International Practice: Strategic Environmental Assessment

Rutgers University conducted a review of the process and method by which environmental criteria are assessed in a number of countries (Appendix B). The primary focus is on Strategic Environmental Assessment (SEA) or multicriteria analysis. Directive 2001/42/EC of the European Parliament and of the Council on the assessment of the effects of certain plans and programs on the environment ("the SEA Directive") requires all Member States to assess environmental impacts of all policies, plans, and programs that are subject to being prepared or adopted by a governmental authority and by legislative procedure, and which are required by legislative, regulatory, or administrative provisions. All Member States have now adopted legislation to comply with the directive (CEC, 2009). Australia and New Zealand have both adopted similar procedures, but Canada and Chile follow U.S. practice of project-based environmental impact analysis, rather than at the strategic policy level.

Strategic Environmental Assessment seeks to evaluate the environmental effect of policies and plans during early stages of the planning process. The method requires an alternatives analysis and public involvement. One of the key features is that the analysis is a multi-attribute analysis that examines various environmental effects versus economic, equity, and other impacts of interest to policy-makers. We detail below the various criteria used in sampled countries.

One key issue is that no country seems to have a distinct procedure for just public transit planning. Instead, all transport modes are considered. For example, in the United Kingdom it is often a collection of various plans and projects within a Local Transport Plan that are the basis of a multi-attribute analysis. Thus, in theory, all modes are evaluated equally.

The effectiveness of the SEA directive was recently reviewed by the Commission (CEC, 2009). Various difficulties have been found but most of these represent a learning process as various countries develop the capacity to engage in SEA. Difficulties include variation in defining alternatives to evaluate, lack of good quality information for analysis, and a lack of standardized indicators for comparison (CEC, 2009). Insufficient analysis of cumulative effects also has been identified as an issue (Tricker, 2007).

Climate change impacts are dealt with by most countries on a case-by-case basis, with a goal of maintaining carbon neutrality or reductions. Specific guidelines for climate analysis do not yet exist (CEC, 2009).

Several benefits of the SEA process have been mentioned. These include benefits from early consultation and increased transparency of the planning process; actual changes in policies and plans in response to environmental problems; and reduction of the need for various mitigation procedures, due to earlier consideration of environmental impacts (CEC, 2009). Therefore, as a means of improving environmental outcomes, it is widely regarded as effective.

I.3 Annotated Bibliography

[No Author] (2009) ***Performance Driven: A New Vision for U.S. Transportation Policy.*** **Bipartisan Policy Center.**

In this document, the Bipartisan Policy Center builds a case for the development of performance metrics for the U.S. transportation system, with eight suggested performance metrics, two of which are related to the environment: petroleum consumption and carbon dioxide emissions. The former is a proxy for energy security built on existing travel model outputs and average fuel economy. The latter is a proxy for climate change impacts calculated from model outputs and emissions literature. Carbon dioxide emissions would include life-cycle emissions, including upstream emissions and changes in land use. The report encompasses all modes of travel and includes project, policy, and funding recommendations most applicable to national program restructuring and evaluation. Difficulties in state and project-level analysis are noted with general methodology comments. Specific proposals for calculation are not included.

American Public Transportation Association (2009). ***Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit.*** **Project CC-RP-001-09.**

This methodology for transit agencies includes approaches to estimating both emissions generated by transit and the potential reduction of emissions through efficiency and displacement. This is the most comprehensive methodology for a complex performance measure for transit. It is closely related to the methodology used by The Climate Registry and includes clarification of elements particular to transit agencies, such as avoided automobile trips, defining facility types, and operations across state lines. The document provides useful discussion of methodology, in particular descriptions of metrics (emissions per vehicle mile, emissions per revenue vehicle hour, emissions per passenger mile), scale and sources of data.

Bailey, L., P.L. Mokhtarian, et al. (2008). ***The Broader Connection between Public Transportation, Energy Conservation, and Greenhouse Gas Reduction.*** **Prepared for the American Public Transportation Association and Transportation Research Board by ICF International.**

This report describes the "second-order" effects of public transit availability. The research shows that transit systems enable more efficient land development, leading to increased transit use, shorter driving distances, and increased walking or bicycling due to short distances to destinations. The report outlines measures of land use performance and compiles evidence from existing research. The team uses a model to calculate the effect of public transportation on U.S. VMT and GHG emissions using the National Household Transportation Survey (NHTS), but does not include methodologies to apply at a smaller scale.

Cambridge Systematics, Inc. (1996). ***TCRP Report 20: Measuring and Valuing Transit Benefits and Disbenefits.*** **Prepared for Transportation Research Board.**

This report provides a useful linkage diagram for analyzing the effects of transit on regional economies. Many of the subcategories and elements include direct and proxy performance measures for transit and show where the strongest methodologies existed at the time. The performance measures (grouped by energy, emissions, noise, ecology, and land consumption) include those typically required as part of NEPA and FTA reviews and do not present new methodologies (e.g., land use, resource conservation, and construction impacts are discussed qualitatively). Metrics are not discussed as part of a framework to compare transportation investments.

Cambridge Systematics, Inc. (2009). Strategic Highway Research Program 2 (*SHRP2) Report S2-CO2-RR: Performance Measurement Framework for Highway Capacity Decision-Making.* **Prepared for Transportation Research Board.**

This document presents a performance measurement framework that individual transportation agencies and other public agencies can adapt to support the decision-making process for major highway capacity projects. It emphasizes performance measurement as a tool to place individual projects within a system context. Environmental categories include ecosystems, water quality, wetlands, air quality, climate change, and environmental health with 22 specific measures (e.g., loss of habitats, highway runoff, wetlands plan consistency). The community category includes land use, archeological and cultural resources, social effects and environmental justice, with 13 specific measures. This comprehensive documenting of environmental measures is a particularly useful reference in that many measures could be used to compare environmental performance of different modes. The measures are summarized, applications are described through case studies, and research needs identified.

Canadian Urban Transit Association. ***Transit Vision 2040.***

This document presents the Canadian transit industry's vision of the long-term role of public transportation in Canada. It communicates transit's contribution to quality of life, the nature of change likely to take place in communities by 2040, the implications these changes will have on transit, and strategic directions for actions that can maximize transit's contribution to our quality of life. The vision includes an emphasis on greening transit to reduce its ecological footprint. The vision also sets forth how transit contributes to quality of life, with excerpts relevant to environmental performance shown in Table I.1.

Table I.1 Transit's Contribution to Quality of Life

	Quality of Life Attributes	Transit's Contribution to Quality of Life
Culture/ Community Form	**Distinctive and Vibrant Places –** Supporting identity and sense of place with a varied, human-scale design that encourages activity and allows spontaneity, exploration, and exchange. **Complete Communities –** Offering a variety of opportunities and choice of housing and employment. **Compact –** Bringing these opportunities closer together.	**Quality Design –** Contributing to civilized places and spaces. **Integration –** Proximity to land use and harmonious facility design. **Coverage –** Allowing choice of home, school, and employment. **Competitive –** To minimize automobile use, road needs, parking requirements, etc. (cost, travel time, comfort). **Impact Reduction –** Minimizing overall noise, vibration, emissions, and visual intrusions.
Environment	**Safe, Comfortable, Clean, and Conserving Communities –** Safe from environmental hazards and adverse events related to climate change; have clean air, clean water and land; and where there is conservation of resources; and reduction of waste.	**Reduced Air Emissions –** Greenhouse gases and other contaminants. **Reduced Energy Consumption –** Particularly nonrenewable petroleum fuels. **Reduced Material Consumption and Waste** **Reduced Noise Emissions** All of the above can be achieved through enabling density, modal shift and through cleaner, quieter and more efficient transit operations. Transit also provides resilience, maintaining mobility and response capacity in periods of adverse environmental events.

Source: Canadian Urban Transit Association, Transit Vision 2040.

Davis, T., M. Hale (2007) *Public Transportation's Contribution to U.S. Greenhouse Gas Reduction.* Prepared for the American Public Transportation Association and Transportation Research Board by Science Applications International Corporation.

See American Public Transportation Association (2009). *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit.* Project CC-RP-001-09.

European Commission, DG TREN (2005). *The Strategic Environmental Assessment Manual: A Sourcebook on Strategic Environmental Assessment of Transport Infrastructure Plans and Programs.*

This manual outlines an approach to Strategic Environmental Assessment for European Commission members. See the review of international practice for a complete description.

Gallivan, F. (2010). ***TCRP Synthesis 84: Current Practices in Greenhouse Gas Emissions Savings from Transit.*** **Prepared for Transportation Research Board by ICF International.**

See also: American Public Transportation Association (2009). *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit.* Project CC-RP-001-09.

This report explains in detail the research that supports and otherwise relates to APTA's methodology to calculate GHG emissions. There is useful description of land use "leverage" rates, or multipliers, (i.e., the additional GHG benefit from transit-supportive land use, beyond the direct benefits of VMT reduced through mode-shifting to transit), including state-of-the-practice research on regional surveys and calculation methods. A chapter on GHG planning and policy development could be useful in considering ways to implement environmental performance measures for transit.

ICF Consulting (2006). ***NCHRP Project 25-25 Task 17: Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects.*** **Prepared for American Association of State Highway and Transportation Officials and Transportation Research Board.**

This report identifies a total of 17 tools or methods that can be used to analyze the GHG implications of transportation projects and recommends models for transportation project or strategy analysis. Its primary value for this project is to identify GHG analysis tools that are available and could be used for transit project evaluation, including life cycle as well as direct impacts.

John A. Volpe National Transportation Systems Center (2008). ***Comparing the Environmental Benefits of Transit Projects: Proceedings from a Colloquium*****. Prepared for U.S. DOT Federal Transit Administration, Office of Planning and Environment.**

This document provides the topic base for the current study (TCRP H-41) and is the most directly applicable presentation of performance metrics and discussion of implementation issues. The Colloquium focused specifically on the FTA New Starts program with the intention to create a full list of possible metrics to test with projects in the program pipeline. The document provides a useful outline by organizing metrics into four broad categories (energy use, air quality, land use, and physical activity), and further designating direct versus proxy measures. Of the measures discussed, the land use metrics were not as developed in the available literature, calling attention to metrics dealing with pedestrian access to transit, development density, and parking. The report also is unique in discussing how to implement measures that would apply to projects with different operating environments, based on different regional travel models, and for sponsors with varying experience with performance measures.

Kittelson & Associates, Inc (2003). ***TCRP Report 88: A Guidebook for Developing a Transit Performance-Measurement System.*** **Prepared for Transportation Research Board.**

This Guidebook is targeted to transit system managers to assist in developing a performance-measurement system using measures that will address customer-oriented and community issues (including environmental effects). The guide presents a process for determining appropriate performance measures for a transit agency or MPO based on local conditions and concerns. The document includes a menu of performance measures and a useful summary of each suggested performance measure, including a description, major factors to consider, data requirements, and references. While the Guidebook includes numerous measures on topics such as service quality and operational efficiency, only a few environmental measures are listed, including effects on energy and resource consumption, general environmental impacts (air quality, wetlands, etc. – with no details provided), and noise.

Rahman, A., R. van Grol (2005). ***Sustainable Mobility, Policy Measures, and Assessment (SUMMA) version 2.0.*** **Prepared for European Commission Directorate General for Energy and Transport by RAND Europe.**

This project proposes a set of system-level sustainability performance indicators for transport. Direct environmental indicators include fuel/energy usage per 100 km, emission of air pollutants by transport, and emissions from and raw materials used by industries related to transport. Other indicators are related to environmental impacts (e.g., mean distance to closest public transport stop, percent of surface covered by infrastructure by mode).

The Climate Registry (2008). General Reporting Protocol, Version 1.1. http://www.theclimateregistry.org/downloads/GRP.pdf, accessed May 2010.

The Climate Registry is partnering with APTA to develop a standard methodology for transit agencies to report GHG emissions. This methodology is based on TCR's general procedures for any organization interested in joining the registry and monitoring their carbon use and emissions. The methodology includes detailed steps in calculating direct and indirect emissions and provides detail to avoid double counting or omitting key sources of emissions. The procedures are useful in considering the level of rigorousness required to develop standard procedures for all types of environmental performance measures, in particular complex measures such as the environmental effects of changes in land use.

The Climate Registry (2010). Performance Metrics for Transit Agencies, Version 1.0. http://www.theclimateregistry.org/downloads/2010/07/Performance-Metrics-for-Transit-Agencies-v.-1.0.pdf, accessed June 2010.

See American Public Transportation Association (2009). *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit.* Project CC-RP-001-09.

U.S. Department of Transportation Federal Highway Administration (1987). "Guidance for Preparing and Processing Environmental and Section 4(F) Documents," Technical Advisory T 6640.8A, http://www.environment.fhwa.dot.gov/projdev/impta6640.asp#eis, accessed May 2010.

This document provides specific guidance for transportation agencies on preparing EIS documents required under NEPA. Topic areas addressed include land use, farmland, social impacts (community cohesion, accessibility, safety, cultural resources, equity), pedestrians and cyclists, air quality, noise, water quality, wetlands, wildlife, floodplains, wild and scenic rivers, coastal barriers and coastal zone impacts, threatened and endangered species, historic and archeological preservation, hazardous waste sites, visual impacts, energy, and construction impacts.

U.S. Department of Transportation Federal Transit Administration (2000). "Major Capital Investment Projects; Final Rule." Title 49 Code of Federal Regulations, Appendix A to Part 611.

This rule presents the methodology by which FTA evaluates projects applying for New Starts funding. The project justification categories include comparing projected and baseline environmental benefits, which includes criteria pollutant emissions, energy consumption, and NAAQS-designation status. The justification also requires "existing land use, transit supportive land use policies, and future patterns," including existing land use, change in land use, growth management policies, zoning supportive of development near transit stations, land use policy tools, land use policy performance, and pedestrian facilities.

■ I.4 Environmental "Best Management Practice" Assessment Tools

A number of assessment tools are available to practitioners interested in assessing environmental performance of transportation investments. Most systems are not transit-specific, but are composed of metrics that may be relevant to transit applications. Each of the systems is summarized briefly below, including how the metrics may be most applicable to environmental performance measures for transit.

Leadership in Energy and Environmental Design (LEED) and LEED for Neighborhood Development (LEED-ND)

Developer: United States Green Building Council.

Internet: http://www.usgbc.org/DisplayPage.aspx?=148.

The LEED certification process is means of rating a building's environmental performance. It is based on a checklist of criteria; minimum thresholds are provided for achieving different levels of ratings (silver, gold, platinum). The LEED-ND system extends certification requirements to include measures of the building's location and neighborhood context as well as the building itself, including the mix of uses, walkability, and other factors that relate to the building's likely transportation impact. LEED-ND measures may be relevant for the siting and design of transit facilities. Factors evaluated in LEED certification include:

- Purchase renewable energy attributes;
- Construction activity pollution prevention;
- Certified green building(s);
- Building energy efficiency;
- Infrastructure energy efficiency;
- Building water efficiency;
- Water-efficient landscaping;
- Wastewater management;
- Stormwater management;
- Existing building use;
- Historic resource preservation and adaptive reuse;
- Minimized site disturbance in design and construction;
- Heat island reduction;

- Solar orientation (passive solar);
- On-site renewable energy sources;
- District heating and cooling;
- Recycled content in infrastructure;
- Solid waste management infrastructure; and
- Bicycle/other nonmotorized vehicle storage.

Greenroads

Developer: University of Washington.

Internet: http://www.greenroads.us.

The Greenroads program is a rating system designed to distinguish new or rehabilitated roads by awarding credits for design and construction choices that meet certain environmental criteria. The environmental categories are listed in the table below and include environmental, economic, and social impacts. The program offers four certification levels based on the project score that includes 11 project requirements and a total of 118 points, including all voluntary credits. Performance categories and sample metrics are shown in Table I.2.

Table I.2 Greenroads Performance Categories

Category	Sample Metrics
Project Requirements (11 points)	(All categories) Environmental review process, life-cycle cost analysis, life-cycle inventory, quality control plan, noise mitigation plan, waste management plan, pollution prevention plan, low-impact development, pavement management system, site maintenance plan, outreach.
Environment and Water (21 points)	Level of performance related to issues such as water runoff, site vegetation and habitat restoration.
Access and Equity (30 points)	Presence of a safety audit, use of intelligent transportation systems, use of context sensitive solutions, level of transit access.
Construction Activities (14 points)	Quality management system, environmental training, recycling plan, equipment emission reduction.
Materials and Resources (23 points)	Life-cycle assessment, pavement reuse, energy efficiency.
Pavement Technologies (20 points)	Permeable pavement, warm mix asphalt, quiet pavement.

Suggested uses of the certification include quantitatively tracking sustainability efforts, informing decision-making, increasing public understanding and participation, and rewarding targeted practices. The review can account for both environmental and social impacts of road-building and establish better uses of recycled and virgin aggregate materials, such as crushed rock, much of which must be transported.

Other states are in the process of adapting a Greenroads-type system for their own use, such as New York State DOT's GreenLITES program.

Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL)

Developer: European Council of Civil Engineers.

Internet: http://www.ceequal.co.uk/about.htm.

CEEQUAL is an assessment program aiming to improve sustainability in civil engineering and public infrastructure investments. By guiding improved project specification, design, and construction, it can demonstrate the commitment to improve environmental and social performance of these projects. Performance metrics cover 12 categories, rewarding teams that go beyond legal and environmental requirements to achieve distinctive environmental and social standards. The organization suggests the evaluation can build support for the project, provide quantitative benchmarks, improve project efficiency and safety, and improve internal teamwork. The 12 categories include:

- Project Management (10.9 percent);
- Energy and Carbon (9.5 percent);
- Land Use (7.9 percent);
- Material Use (9.4 percent);
- Landscape (7.4 percent);
- Waste Management (8.4 percent);
- Ecology and Biodiversity (8.8 percent);
- Transport (8.1 percent);
- The Historic Environment (6.7 percent);
- Effects on Neighbors (7.0 percent);
- Water Resources and the Water Environment (8.5 percent); and
- Relations with the Public (7.4 percent).

STAR Community Index

Developer: International Council for Local Environmental Initiatives (ICLEI).

Internet: http://www.starcommunityindex.org.

The STAR Community Index is a national framework for gauging the sustainability and livability of U.S. communities. STAR will be launched in 2010 and is being developed through a partnership between ICLEI-Local Governments for Sustainability, the U.S. Green Building Council, and the Center for American Progress. Local governments have the opportunity to "certify" their work through independent, third-party verification. However, the metrics are intended to be used to track progress toward each locality's unique goals in environmental performance. STAR indicator categories and subcategories are shown in Table I.3.

Table I.3 STAR Community Index Indicators

Category	Subcategories
Natural Systems	Ecosystems and habitat, water and stormwater, air quality, waste, and resource conservation
Planning and Design	Land use, transportation and mobility, and parks, open space, and recreation
Energy and Climate	Energy, emissions, renewable energy, and green building
Economic Development	Clean technologies and green jobs, local commerce, tourism, and local food system
Employment and Workforce Training	Green job training, employment and workforce wages, and youth skills
Education, Arts, and Community	Education excellence, arts and culture, and civic engagement and vitality
Children, Health, and Safety	Community health and wellness, access to health care, and public safety
Affordability and Social Equity	Affordable and workforce housing, poverty, human services, and race and social equity

ISO 14000 Environmental Management Systems Certification

Developer: International Organization for Standardization (ISO).

Internet: http://www.iso.org.

The ISO certification programs for environmental management systems (14001 and 14004) provides guidance that enables an organization to develop and implement policy and objectives which take into account legal requirements and other requirements for sustainable development. An environmental management system is a management tool enabling an organization of any size or type to identify the environmental impact of its activities, improve environmental performance, and implement a systematic approach to setting environmental performance targets and showing achievement of targets. ISO does not provide specific indicators of environmental performance, but does provide a framework for an organization to systematically prepare a comprehensive management plan. ISO suggests that certification is useful in preparing plans, sharing the results with people inside and outside an organization, and setting a framework for ongoing improvement of sustainability planning by committing to compliance with the ISO standards.

Sustainability Reporting Framework

Developer: Global Reporting Initiative.

Internet: http://www.globalreporting.org.

The Global Reporting Initiative's (GRI) mission is to create conditions for the exchange of sustainability information through the GRI Sustainability Reporting Framework. The framework is focused on organizational efforts at developing and monitoring municipal programs and, therefore, tracks many policies and programs adopted by an organization rather than direct performance. GRI has developed sustainability reporting guidelines to provide guidance for organizations, in addition to detailed protocols to provide definitions and methodologies for quantitative indicators. Guidelines and protocols also are included for pilot "sector supplements," including logistics and transportation organizations. Reporting categories and core indicators are shown in Table I.4.

Table I.4 Global Reporting Initiative Categories and Indicators

Category	Core Indicators
Materials	Total materials use other than water by type. Percentage of materials used from wastes, sources external to the organization.
Energy	Direct energy use segmented by source: mobile, nonmobile sources; type of fuel; normalized per cubic meter km, per ton km, per delivery item or per unit km. Indirect energy use: used to produce and deliver energy products used. (Initiatives to use renewable energy sources and increase efficiency.)
Water	Total water use.
Biodiversity	Location and size of land used in biodiversity rich habitat. Description of the major impacts on biodiversity associated with activities and/or products and services in terrestrial, freshwater, and marine environments.
Emissions, Waste	Greenhouse gas emissions: direct and indirect (WRI-WBCSD protocol). Use and emissions of ozone depleting substances. NO_x, SO_x, and other significant air emissions by type. Total amount of waste by type and destinations. Significant water discharge by type. Significant chemical, oil, fuel spill by volume and number. (Initiatives to control urban area emissions by road transportation.)
Products and Services	Significant environmental impact from principal products and services. Share of product weight reclaimable and reclaimed at end of product lifespan. Incidence of noncompliance with environmental regulations.
Fleet[a]	Vehicle types, including alternative fuel vehicles.
Policy[a]	Environmental performance of operations: commitment to alternative fuel vehicles, commitment to modal shift, efficient route planning. Managing highway congestion (off-peak use, alternative modes, etc.). Guided approach to reduce noise and vibration

[a] Category/Indicators suggested specifically for transportation and logistics organizations.

Integrated Sustainability Assessment Toolkit/Framework

Developer: Sustainable Urban Environment, Metrics, Models and Toolkits (SUE-MoT), a consortium of British universities.

Internet: http://www.sue-mot.org.

The SUE-MoT consortium is developing a comprehensive framework that encourages key decision-makers to assess the sustainability of regions, taking account of scale, life cycle, location, context, and residents' values. Early research identified 670 sustainability assessment tools from a comprehensive literature review. The 30 or so most widely used performance categories have been applied to the contexts where use would be most appropriate. While the framework does not provide indicators and metrics useful to comparing transit investments, the exhaustive literature review of sustainability tools may be useful for developing some metrics.

Green Globes

Developer: Green Building Initiative (USA) and Building Owners and Managers Association (Canada).

Internet: http://www.greenglobes.com.

Green Globes for Existing Buildings is an assessment and rating system for buildings in North America. The categories are somewhat similar to the United States Green Building Council's LEED system. The system has developed on-line tools for building managers and is planning to establish the criteria with the American National Standards Institute (ANSI). Green Globes software tools and certification system is based on a 1,000 point scale in multiple categories, with a minimum of 350 points for certification. The assessment categories include energy, indoor environment, site planning, water, resources, emissions, and project management. It differs from LEED by offering points rather than checklists, theoretically allowing for more variation within categories. However, a points-type system could be difficult to apply on a national scale to individual projects.

Ska Rating

Developer: Royal Institution of Charters Surveyors.

Internet: http://www.ska-rating.com.

Ska Rating is a system that corporations can use to inform fit-out of building projects for their offices. Ska has 99 measures across seven categories. Each category has specific targets and suggested methodologies. Because each office build out project is unique in terms of employers' requirements, the building, and scope of works, Ska Rating scores the project on only of those measures that are relevant to the project. These are called

Measures In Scope. Because some measures are more important from a sustainability perspective the measures are ranked from 1 to 99 for each project. To ensure that teams do not just target the easiest measures, the project has to achieve a number of the highest ranked measures in scope – called Gateway Measures – in order to qualify. While some indicators also apply to transit facilities, the system may be most interesting due to the definition of "scopes" that affect which indicators apply to a specific project, allowing for some flexibility in evaluation. Categories and Indicators are shown in Table I.5.

Table I.5 Ska Rating Categories and Indicators

Category	Sample Indicators
Energy and CO_2	Reduce energy use, lighting controls, daylighting, energy efficient HVAC.
Materials	Hard flooring, timber, blockwork, partitions, kitchen fittings, insulation.
Pollution	Low-GWP insulation, refrigerant leak detection, light pollution, plant noise.
Transport	Cycle parking, showers, lockers.
Waste	Waste management plan, site waste plan, reduce material sent to landfill.
Water	Reduce water use, low-flush WC, water meter, leak detection services.
Wellbeing	Thermal comfort assessment, noise standards, low-VOC finish, ventilation.

Sustainable Infrastructure, Land Use, Environment, and Transport Model (SILENT)

Developers: Yigitcanlar, Tan and F. Dur (2010) Developing a Sustainability Assessment Model. Sustainability, 2(1) pages 321-340.

Internet: http://www.mdpi.com/2071-1050/2/1/321/.

This study introduces an urban sustainability assessment model, the Sustainable Infrastructure, Land Use, Environment, and Transport Model (SILENT). The SILENT model is a geographic information system and indicator-based urban sustainability indexing model. The model aims to assist planners and policy-makers in sustainable urban planning and development by providing an integrated sustainability assessment framework. The paper gives an overview of the framework and its constructs, methodological procedures, and future development. The main characteristic of the SILENT Model is that it uses a grid-based system, dividing the study area into grid cells (100 x 100m). The grid-based analysis is seen as useful in accessibility indexing studies due to its strengths in condensing the analysis into comparable analysis unit sizes. The study could be useful for comparing land use surrounding transit investments by creating a uniform analysis structure. The article also details methodologies for calculating indicators which, while not new, could provide some comparison for developing detailed assessment protocols. Index categories and indicators are shown in Table I.6.

Table I.6 SILENT Categories and Indicators

Category	Sample Indicators
Demography	Population density, car ownership, job/housing balance, employment density.
Land Use	Mix use ratio, dwelling density by type, parcel size, community facilities.
Transport	Transit access (to employment, housing), transit ridership, nonmotorized network coverage, VMT by purpose, trips by purpose, parking supply.
Environment	Wastewater, solid waste, energy use, residential water use, GHG emissions, stormwater runoff, noise pollution.

■ I.5 International Approaches to Transportation Environmental Assessment

Introduction

This review, conducted by Rutgers University, examines the process and method by which environmental criteria are assessed in a number of countries. Our primary focus is on Strategic Environmental Assessment or multicriteria analysis. Directive 2001/42/EC of the European Parliament and of the Council on the assessment of the effects of certain plans and programs on the environment ("the SEA Directive") requires all Member States to assess environmental impacts of all policies, plans, and programs that are subject to being prepared or adopted by a governmental authority and by legislative procedure, and which are required by legislative, regulatory, or administrative provisions. All Member States have now adopted legislation to comply with the directive (CEC, 2009). Our survey found that Australia and New Zealand have both adopted similar procedures, but Canada and Chile follow U.S. practice of project-based environmental impact analysis, rather than at the strategic policy level.

Strategic Environmental Assessment seeks to evaluate the environmental effect of policies and plans during early stages of the planning process. The method requires an alternatives analysis and public involvement. One of the key features is that the analysis is a multi-attribute analysis that examines various environmental effects versus economic, equity, and other impacts of interest to policy-makers. We detail below the various criteria used in sampled countries.

One key issue is that no country seems to have a distinct procedure for just public transit planning. Instead, all transport modes are considered. For example in the United Kingdom, it is often a collection of various plans and projects within a Local Transport Plan that are the basis of a multi-attribute analysis. Thus, in theory, all modes are evaluated equally.

The effectiveness of the SEA directive was recently reviewed by the Commission (CEC, 2009). Various difficulties have been found but most of these represent a learning process as various countries develop the capacity to engage in SEA. These difficulties include variation in defining alternatives to evaluate, lack of good quality information for analysis, and a lack of standardized indicators for comparison (CEC, 2009). Insufficient analysis of cumulative effects also has been identified as an issue (Tricker, 2007).

Climate change impacts are dealt with by most countries on a case-by-case basis, with a goal of maintaining carbon neutrality or reductions. Specific guidelines for climate analysis do not yet exist (CEC, 2009).

Several benefits of the SEA process have been mentioned. These include benefits from early consultation and increased transparency of the planning process; actual changes in policies and plans in response to environmental problems; and reduction of the need for various mitigation procedures, due to earlier consideration of environmental impacts (CEC, 2009). Therefore, as a means of improving environmental outcomes, it is widely regarded as effective.

References

Commission of the European Communities (CEC, 2009). On the application and effectiveness of the Directive on Strategic Environmental Assessment (Directive 2001/42/EC), COM (2009) 469 final, Brussels.

Tricker, R.C., 2007. Assessing cumulative environmental effects from major public transport projects, Transport Policy, 14: 293-305.

Australia

Among the countries surveyed, Australia has a well-documented and clear approach toward the evaluation of environmental impacts as part of a comprehensive benefit/cost analysis framework developed for transport policy at the national level. Their guidelines consist of a general benefit/cost framework with some expanded methods developed for the specific needs of public transport. The following sections summarize their process, methods, and impacts addressed.

Assessment Process

The Australian guidelines include an eight-phase appraisal process for evaluating multimodal transportation options. Environmental evaluation of transport decisions is included as a nonmonetized assessment. Two stages of assessment are applied: a rapid assessment followed by a detailed assessment. Additional documentation on environmental impacts, such as detailed, project-specific Environmental Impact Statements, also are incorporated into the appraisal process in the early stages, though the guidelines are not clear on how the timing of such decision-making coincides with detailed project-level analyses.

The additional analyses implemented in Australia for public transport do not include major additional environmental procedures. These are instead consistent across transport modes. The results of the detailed assessment process generate an *Appraisal Summary Table* (AST), a one-page presentation of the proposal and its estimated net benefits, which is meant to be consumed by decision-makers. The AST includes both monetized and nonmonetized impacts, as well as qualitative and quantitative measures where applicable Commonwealth of Australia, 2006, Volume 3 has examples of AST forms, including a completed example on page 43 – see the source document at: http://www.atcouncil.gov.au/documents/NGTSM.aspx.

Methods Implemented

The methods include increasingly detailed analyses as the process carries forward, primarily centered around a benefit/cost analysis, strategic merit assessment, and nonmonetized assessment. Nonmonetized impacts (primarily environmental) are assessed on a seven-point qualitative rating scale from large negative to large positive. All measures in the AST – quantitative and qualitative – are assigned a confidence level on a five-point scale ranging from very low to very high.

Coverage of Impacts

Specific environmental criteria included qualitatively in the Appraisal Summary Table include:

- Greenhouse gas emissions;
- Noise;
- Local air quality;
- Landscaping;
- Biodiversity;
- Aboriginal heritage; and
- Water resources.

References

Commonwealth of Australia, 2006. National Guidelines for Transport System Management, Second edition. Volumes 1 to 4. Accessed at http://www.atcouncil.gov.au/documents/NGTSM.aspx.

Austroads, 2008. Guide to Project Evaluation Part 4: Project Evaluation Data, Austroads Publication No. AGPE04/08.

Canada

The Canadian environmental assessment process is a complex interaction of governmental entities from local agencies to provincial governments to Federal authorities, including the Minister of the Environment. The majority of this review investigates the Environmental Assessment Act as a model process initiated at many different levels of government, but directed by Federal regulations, as described in the following sections.

Assessment Process

Canada has an Environmental Assessment Act that directs agencies on the need for environmental assessment procedures. The Act itself is not specific to transport or public transit, but covers many different actions that can affect the environment. The procedures can fall into one of four types: screening, comprehensive study, mediation, and assessment by a review panel. The last two are conducted by an independent third party. The first two can be self-directed.

The Canadian act also requires the assessment of cumulative environmental effects, or those effects that for a given project may be small, but when taken in the context of other past, present or future impacts, may be significantly harmful to the environment.[1] A detailed significance test is required to determine cumulative environmental effects. This process involves three general steps:

1. Decide whether the environmental effects are adverse;
2. Decide whether the adverse environmental effects are significant; and
3. Decide whether the significant adverse environmental effects are likely.

Methods Implemented

A screening is "a systematic approach to identifying and documenting the environmental effects of a proposed project and determining the need to eliminate or minimize (mitigate) the adverse effects, to modify the project plan, or to recommend further assessment through mediation or an assessment by a review panel" (CEAA, 2003b).

Large projects with the potential to have numerous or far-reaching environmental impacts are subject to more rigorous comprehensive studies. These studies are managed at a high level by the Minister of the Environment, who ultimately issues a decision statement on the significance of the environmental effects of the project and proposed mitigation efforts.

Mediation is used on a self-directed basis to resolve issues between interested parties when issues are limited in scope and number. The results of the mediation are used by the responsible authority for decision-making with regard to the project.

The Minister of the Environment also may initiate an expert review panel to discuss the impacts of a particular project. This process has the benefit of encouraging an open discussion and exchange of viewpoints and public participation.

In 2003, the Canadian government also adopted guidance on determining the needs for climate change considerations as part of the environmental assessment procedures. These

[1] In the United States, the National Environmental Policy Act has a similar requirement to consider cumulative impacts.

methods are broken into two layers: one where a project may contribute to greenhouse gas emissions and another where climate change may impact the project (CEAA, 2003).

These methods are largely based on qualitative assessment strategies and the collection of information from a variety of Federal agencies.

Coverage of Impacts

The criteria for determining whether environmental effects are adverse include:

- Negative effects on the health of biota, including plants, animals, and fish;
- Threat to rare or endangered species;
- Reductions in species diversity or disruption of food webs;
- Loss of or damage to habitats, including habitat fragmentation;
- Discharges or release of persistent and/or toxic chemicals, microbiological agents, nutrients, radiation, or thermal energy;
- Population declines, particularly in top predator, large, or long-lived species;
- Removal of resource materials from the environment;
- Transformation of natural landscapes;
- Obstruction of migration or passage of wildlife; and
- Negative effects on the quality and/or quantity of the biophysical environment.

Other criteria impacting people resulting from environmental changes include:

- Negative effects on human health, well-being, or quality of life;
- Increase in unemployment or shrinkage in the economy;
- Reduction of the quality or quantity of recreational opportunities or amenities;
- Detrimental change in the current use of lands and resources for traditional purposes by aboriginal persons;
- Negative effects on historical, archaeological, paleontological, or architectural resources;
- Decreased aesthetic appeal or changes in visual amenities;
- Loss of or damage to commercial species or resources; and
- Foreclosure of future resource use or production.

References

CEAA, 2003a. Incorporating Climate Change Considerations in Environmental Assessment, Federal Provincial-Territorial Committee on Climate Change and Environmental Assessment, November 2003. Accessed at http://www.ceaa.gc.ca/Content/D/A/C/DACB19EE-468E-422F-8EF6-29A6D84695FC/climatechange_e.pdf.

CEAA, 2003b. Canadian Environmental Assessment Act: An Overview, Canadian Environmental Assessment Agency, December 2003. Accessed at http://www.ceaa.gc.ca/Content/D/A/C/DACB19EE-468E-422F-8EF6-29A6D84695FC/CEAA-Overview_e.pdf.

CEAA, 2007. Project Description Guide: British Columbia: To Determine Federal Roles under the Canadian Environmental Assessment Act, February 2007. Accessed at http://www.ceaa.gc.ca/Content/D/A/C/DACB19EE-468E-422F-8EF6-29A6D84695FC/Project_Description_Guide_under_CEAA_BC_e.pdf.

Federal Environmental Assessment Review Office, 1994. A Reference Guide for the Canadian Environmental Assessment Act: Addressing Cumulative Environmental Effects, November 1994. Accessed at http://www.ceaa.gc.ca/Content/D/A/C/DACB19EE-468E-422F-8EF6-29A6D84695FC/Cumulative-Environmental-Effects_e.pdf.

Chile

Assessment Process

Environmental impact assessment in Chile is based on national legislation with a single structure that has regional components. Chilean law (Ley 19.300, 2007) requires review of the environmental impacts of transportation projects, in conjunction with a broad range of other types of projects, when the concern exists that these might endanger public health or air, water, or soil or cause major upheaval among populations within the country. Review also is required for projects that might harm protected populations, resources, or areas of scenic, touristic, anthropological, or historical value.

Regulation of environmental impacts (D.S. No. 95, 2001) is carried out by regional commissions or by a national commission in cases where impacts may occur in multiple regions. Submissions to these commissions may be one of two types: Environmental Impact Statements or Environmental Impact Studies. The former is a relatively simple document that addresses project particulars of name, purpose, place, costs, scale, roles of participants, and useful life of the project in enough detail that the commission can come to a conclusion about whether or not the latter document is needed.

Environmental Impact Studies are required when significant harm to the interests noted above must be ruled out. These documents require considerably more detail than impact statements, and clarity about potential environmental threats establishes a firm scientific rationale for the level of risk for a given project. Community participation and participation by municipal and provincial governments are provided for.

Methods

The Chilean Environmental Impact Assessment System (SEIA) (https://www.e-seia.cl/) details environmental impact statements but does not include current environmental impact studies. The SEIA web site allows users to specify project types. Bus and rail terminals and track projects are the transit-relevant options on the system. The web site did not include any rail terminal or track projects.

A large scale bus terminal construction project was evaluated based on sewer and water impacts, air pollutants and noise during the construction and operations phases of the project, and generation of liquid, solid, and domestic waste. An environmental sustainability urban transportation study for Santiago, Chile (O'Ryan, 1998) addresses public transit in a manner similar to the general Chilean approach. This study addressed pollution, noise as a public health issue, and resource use and cites reports by CONAMA (the Chilean environmental agency).

Coverage of Impacts

Impacts reported by CONAMA and cited by O'Ryan (1998) are limited to atmospheric pollutants – particulate matter, CO, ozone, NO_X, SO_2, and VOC from mobile, fixed point and other sources. These concerns also were raised by the CONAMA officials who evaluated the bus terminal environmental impact statement.

References

Ministerio Secretaría General del la Presidencia, D.S. No95 de 2001, Reglamento del Sistema de Evaluación de Impacto Ambiental. Available April 3, 2010. Accessed at http://www.sinia.cl/1292/articles-37936_pdf_reglamento_seia.pdf.

Ley 19.300 Sobre Bases Generales del Medio Ambiente, as amended 2007. Available April 3, 2010. Accessed at http://www.olade.org.ec.

O'Ryan, R. 1998. La Sustentabilidad Ambiental del Transporte Urbano: el Caso de Santiago de Chile. Serie Economía No 30. Centro de Economía Aplicada, Universidad de Chile. Available April 5, 2010. Accessed at http://www.webmanager.cl/prontus_cea/cea_1998/site/asocfile/ASOCFILE120030403115940.pdf.

Ireland

Ireland instituted a new transport policy emphasizing sustainability in 2009. Given how recent this is, our ability to properly assess its impact is limited; however, we review it and its history briefly in the sections below. While Ireland is covered by the SEA directive, we were unable to find details on how it has been implemented. The new transport policy does, however, lay out a framework of objectives and goals that would be consistent with implementation of SEAs in the future.

Assessment Process

The Irish government set out five main goals with its transport sustainability policy. These goals include:

1. Reduce overall travel demand;
2. Maximize the efficiency of the transport network;
3. Reduce reliance on fossil fuels;
4. Reduce transport emissions; and
5. Improve accessibility to transport.

The policy includes a list of 49 specific actions grouped into four overarching goals:

1. Actions to reduce the distance traveled by private car and encourage smarter travel, including focusing population and employment growth predominately in larger urban areas and the use of pricing mechanisms or fiscal measures to encourage behavioral change;

2. Actions aimed at ensuring that alternatives to the car are more widely available, mainly through a radically improved public transport service and through investment in cycling and walking;

3. Actions aimed at improving fuel efficiency of motorized transport through improved fleet structure, energy efficient driving, and alternative technologies; and

4. Actions aimed at strengthening institutional arrangements to deliver the targets.

Methods Implemented

A number of specific methods and measures are mentioned among the 49 actions listed in the policy. Those specific to public transport include:

- Integration of spatial planning, local area planning, and transport planning with the goal of increasing density;
- Implementation of parking maximums for commercial sites with suitable public transport facilities;
- Development of travel plans for large scale developments, schools, workplaces;
- Restrictions on out-of-town retail centers;
- Implement Integrated Transport Systems and other advanced technologies to improve the efficiency of public transport;

- Creation of traffic-free urban centers and investment in cycle and pedestrian networks to facilitate transit, cycling, and walking; and

- Creation of national schemes for car sharing and car clubs.

One key issue facing Ireland is the development of policy concerning freight transport. The policy guidelines are vague surrounding the development of regulations or other restrictions on freight because it is seen as vital to the economic functioning of the country.

Coverage of Impacts

The Irish policy is a high-level guidance document that does not list many specific targets for assessing impacts. As part of the European Union, Ireland will attempt to fall within the guidelines of the EU directives discussed in the section on Europe in this report. A few general impacts are mentioned in the policy and are included below.

- Work-related car commuting will be reduced from 65 to 45 percent modal share by 2020;

- Total kilometers traveled by the car fleet in 2020 will not increase significantly; and

- Carbon-related emissions are targeted to fall by between 4Mts to 8Mts of CO_2 equivalents.

References

Department of Transport, 2008. Smarter Travel: A Sustainable Transport Future. Accessed at http://www.smartertravel.ie/.

Comhar, 2008. Sustainable Travel and Transport Action Plan: Comhar Sustainable Development Council Response to Public Consultation. May 2008. Accessed at http://www.comharsdc.ie/_files/Comhar%20STTAP%20report.pdf.

Department of Transport, 2008b. 2020 Vision – Sustainable Travel and Transport: Public Consultation Document, February 2008. Accessed at http://www.transport.ie/upload/general/10378-0.pdf.

New Zealand

The New Zealand government published the Transit New Zealand Environmental Plan in 2008.[2] This plan gives details about 12 categories of impacts and procedures for

[2] The term 'transit' in New Zealand refers to transportation in general and not public transit specifically.

addressing each issue. The procedures include objectives, the role of transport, performance indicators, and implementation plans. Overall, New Zealand has taken a comprehensive, top-down approach toward tackling the specific impacts related to transport and 12 aspects of the environment defined in this document.

Assessment Process

The Environmental Plan lays out an excellent example of the assessment process for the National State Highway Strategy (NSHS). This process has six main components, and each provide a different measure of the environmental and social issues related to the NSHS. The six components are:

1. Valuation of environmental and social effects;
2. Prioritization of mitigation;
3. Financial implications;
4. Energy efficiency and conservation;
5. Urban design and community impacts; and
6. Balancing competing needs.

As is apparent from the brief descriptions of these elements, they are not necessarily mutually reinforcing, and may in some cases be directly contradictory. The sixth component specifically calls out the challenges of reconciling these contradictions through multi-governmental partnerships among local, regional, and national authorities.

Methods Implemented

Each of the 12 impacts listed in the next section of this summary contains a description of performance indicators, activities, and specific methods for those activities. In summary, the methodological approach taken in New Zealand's environmental plan is to define high-level objectives, assess the effects of those objectives on environmental conditions, determine the specific role transit may play in mitigating or worsening those effects, and give examples of common performance indicators to measure the implementation of mitigation strategies to achieve the stated objectives.

The Environmental Plan provides an extensive list of research tools to draw from for each category of impact. The list includes some of the most up-to-date procedures for assessing environmental impacts from New Zealand, Australia, Europe, and the United States. The New Zealand Environmental Plan provides a detailed set of resources for the specific tools used for each of the impacts listed below.

Coverage of Impacts

The Environmental Plan lays out details on 12 different environmental impacts that are thought to be essential to transport planning. These impacts are:

1. Noise;
2. Air quality;
3. Water resources;
4. Erosion and sediment control;
5. Social responsibility;
6. Cultural heritage;
7. Ecological resources;
8. Spill response and contamination;
9. Resource efficiency;
10. Climate change;
11. Visual quality; and
12. Vibration.

Most of these impacts have stated quantitative or qualitative performance indicators, though some are not specific measures. The notable exception is the social responsibility category, which appears to not yet have a measurement specification defined.

Of particular note is the inclusion of social and culture issues within the overall environmental assessment framework. Though not unique among the countries surveyed, New Zealand has a strong commitment toward the social impacts of transport decision-making. This also is reflected in the methodological approach reviewed above.

References

Transit New Zealand, 2008. New Zealand Environmental Plan 2008. Accessed at http://www.nzta.govt.nz/resources/environmental-policy-manual/docs/environmental-plan.pdf.

Transit New Zealand, 2007. Planning and Policy Manual SP/M/001, Version 1. Accessed at http://www.nzta.govt.nz/resources/planning-policy-manual/docs/planning-policy-manual-complete.pdf.

New Zealand Transport Agency, 2010. Stormwater Management Course. Accessed at http://integration.rwd.com/rocla/courseware/NZTA/main.html.

New Zealand Transport Agency, 2010. Transport Noise. Accessed at http://acoustics.nzta.govt.nz/.

New Zealand Transport Agency, 2010. Economic evaluation manual, Volumes 1 and 2. Accessed at http://www.nzta.govt.nz/resources/results.html?catid=401.

Ministry of Transport, 2010. Ministry of Transport, New Zealand, web site, Environmental section. Accessed at http://www.transport.govt.nz/ourwork/tmif/environmental/.

Spain

Spanish efforts at environmental impact assessment were motivated by the European Community Directive 85/337/EEC on environmental impact assessment (Palerm, 1999) as amended. Spanish environmental impact assessment law is based on Decree 1302/1986 (1986) and Decree 1131/1988 (1988), which respectively establish a national intention to address environmental impact assessment and establish regulations. While they also would be required to implement the SEA directive, we did not find any documents providing information on this (although a law requiring SEA was passed in 2006).

Spain is divided into 17 autonomous regions or communities and two autonomous cities, each of which is empowered to enact environmental law (Palerm, 1999). Spanish national law regarding environmental impact assessment provides minimum standards. The assessment process varies considerably among the autonomous communities, which cannot be adequately addressed in the space of this summary.

Assessment Process

Decree 1131/1988 stipulates that works, installations, and activities within a number of sectors, including transportation construction, are required to submit to environmental impact assessment, except for defense projects or when specifically mandated by Spanish law. Exceptions to the requirement for environmental impact assessment are possible but must be made public. Enforcement is under the responsibility of the General Directorate for the Environment within the Ministry of Public Works and Urban Planning. Law 27/2006 (2006) creates a right to information and public participation that was clearly meant to be interpreted broadly, which applies to those affected by an action or policy, those responsible for it, and supporters of the environment.

Under national law (Decree 1131/1988) environmental impact statements include the following:

- Description of the project and its actions;
- Examination of technically viable alternatives and justification of choice;
- Environmental inventory with a description of key ecological and environmental interactions;
- Impact appraisal for all alternatives, including the one chosen;
- Abatement and corrective measures;

- Monitoring programs; and
- Synthesis of the above elements.

Methods Implemented

Under national law, public and private entities may be required to prepare environmental impact statements for most sectors of the economy, including transportation. Spanish law allows for the application of the concept of environmental impact assessment to the breadth of planning and policy development, although the national law stops well short of mandating this. Strategic Environmental Assessment has been described as a voluntary approach at the national level, by which environmental impact assessment is addressed at all stages of planning and policy development (Arce and Gullón, 2000).

Catalonian law incorporates this approach and applies it to mobility planning, which includes bus and light rail transit (Law 27/2006). The capital of the Basque autonomous community, Vitoria-Gasteiz, conducted an environmental impact assessment of its sustainable mobility plan in 2007.

Coverage of Impacts

The Sustainable Mobility Plan of Vitoria-Gasteiz (Basque Country) includes the following:

- Air pollutants – SO_2, NO_2, PM_{10}, CO, and ozone; and
- Noise pollution.

References

Arce, R. Gullón, N. 2000. The Application of Strategic Environmental Assessment to Sustainability Assessment of Infrastructure Development. Environmental Impact Assessment Review 20 (2000) 393-402.

Ayuntamiento de Vitoria-Gasteiz. 2007. Plan de Movilidad Sostenible y Espacio Público Avance Sección 4.7 Impacto Ambiental. Accessed April 9, 2010 at http://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/23980.pdf.

Law 27/2006 of July 18 [2006] Which Regulates Rights to Information Access, Public Participation, and Justice in Matters of the Environment (Incorporating Directives 2003/4/CE and 2003/35/CE). Accessed April 9, 2010 at http://www.eia.es/web/04/leg_nacional/Ley%2027_2006%20reg%20acceso%20inf_part%20pub%20y%20justicia.pdf.

Ministerio de Medio Ambiente y Medio Rural y Marino. (2009) Spain's Communication to the European Commission, Article 3.2 (a), (b), (c), and (d) of Decision 280/2004/CE.

Royal Legislative Decree 1302/1986 of June 28 [1986] Regarding Environmental Impact Evaluation. BOE No. 155 June 30, 1986. Accessed April 9, 2010 at http://www.cne.es/cne/doc/legislacion/MA_RDL1302_1986_LN.pdf.

Royal Legislative Decree 1131/1988 of September 30 [1988] by which Regulations Are Approved for the Implementation of Royal Legislative Decree 1302/1986 of June 28 [1986] Regarding Environmental Impact Evaluation. BOE No. 239 Wednesday, October 5, 1988. Accessed April 9, 2010 at http://medioambiente.xunta.es/pdf/autorizacionIntegrada/p11ke02c.pdf.

Autonomous Community of Catalonia Law 6/2009, of April 28 [2009], Regarding Environmental Evaluation of Plans and Programs. BOE No. 123 Thursday, May 21, 2009. http://www.eia.es/web/04/leg_autonomica/Catalu%C3%B1a/Ley%206_2009%20de%20EA%20de%20planes%20y%20programas.pdf.

Palerm, J.R. 1999. Public Participation in Environmental Impact Assessment in Spain: Three Case Studies Evaluating National, Catalan, and Balearic Legislation. Impact Assessment and Project Appraisal 17 (1999) 259-271.

Spain's Communication to the European Commission, Article 3.2 (a), (b), (c), and (d) from the Decision 280/2004/CE. Accessed April 9, 2010 at http://www.mma.es/secciones/cambio_climatico/pdf/dec280_final.pdf.

United Kingdom

The United Kingdom has been at the forefront of the development of new procedures to incorporate an expansive approach to transport policy development. Their process largely followed the guidelines specified in European directives on Strategic Environmental Assessment as early as 1998, and they have continued to refine their process, including a major revision currently in the draft stages as this document was being prepared. The United Kingdom's approach also has been the basis for other countries' assessment processes, including Australia and New Zealand. The key component of the UK process is a simple summary of the results of a detailed analysis, easily understood by policy-makers and nontechnical interest groups alike.

Process

The overall goal of environmental assessment in the United Kingdom is to provide detailed guidance distilled into succinct information consumable by policy decision-makers, as well as the general public. The appraisal and study process should, at all levels, be consistent with the following goals:

- Be easily comprehensible, to those commissioning, steering, and undertaking the work; and where possible to a wider public;
- Avoid leading to a particular outcome simply by virtue of the method or process adopted;
- Enable a wide range of solutions and the synergy between combinations of components to be investigated in a cost-effective manner;

- Enable a preferred solution to be developed which addresses the objectives and problems at which it is aimed; and
- Provide a means by which the acceptability of the solution to the public can be tested and taken into account.

The assessment process incorporates the New Approach to Appraisal (NATA) process, with five objectives specified by government policy:

1. Environmental;
2. Safety;
3. Economy;
4. Accessibility; and
5. Integration.

The NATA process is carried out in the following steps:

- Agreeing to a set of overall objectives;
- Analyzing present and future problems of, or relating to, the transport system;
- Exploring potential solutions for solving the problems and meeting the objectives;
- Appraising options, seeking combinations which perform better as a whole than the sum of the individual components; and
- Undertaking supporting analyses of practicality and public acceptability; affordability and financial sustainability; and distribution and equity.

European guidance requires EIA for transportation projects (Planning Policy Guidance 13: Transport). Strategic environmental assessment (SEA) of Local Transport Plans and Regional Transport Strategies "is required under European Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment" (Department for Transport, 2010), and SEA is integrated into the NATA process outlined above.

As part of the multiscalar process, local governments also prepare five-year Local Transport Plans to guide the national government on funding decisions.

Methods Implemented

An *Appraisal Summary Table* (AST) is the primary product of the process described above. An AST is a one-page summary of the major economic, environmental, and social impacts of a transport solution. The target audience for this document is policy-makers and decision-makers who need concise, accurate, and reasonably objective information in order to decide on the appropriate policy or action.

The methods implemented in the development of an AST are based on established techniques from other environmental, social, and economic estimation practices. The four most common among these are transport or land use/transport interaction models; cost/benefit analysis; environmental impact assessment; and a geographic information system. The goal of the AST is to bring these information sources together into a clear and concise document, "without giving prominence to any one type of effect or to benefits expressed in monetary terms compared with those which cannot be monetized" (Department for Transport, 2010).

In addition to the AST, local governments are required to prepare detailed cost/benefit analyses of local projects and present them as part of a five-year Local Transport Plan. Local governments also prepare Transport Assessments "where a proposed development is likely to have significant transport and related environmental impacts" (Department for Transport, 2007). The Transport Assessments take an iterative approach, addressing the following issues:

- Reducing the need for travel, especially by car;
- Sustainability and accessibility – Promote accessibility by all modes of travel;
- Dealing with residual trips – Provide accurate quantitative and qualitative analyses of the predicted impacts of residual trips and proposed management of the impacts; and
- Mitigation measures – Ensure mitigation measures promote innovative solutions and minimize physical highway improvements.

The contents of a Transport Assessment report include:

- Introductory facts;
- Scoping study;
- Assessment;
- Measures to influence travel behavior;
- Identification of impacts and mitigation measures; and
- Implementation mechanisms.

Also included are additional refinement steps for mitigation of residual trips and additional alterations to influence travel behavior.

Impacts

The AST represents a high-level policy document that provides a coherent summary of the various impacts of the plan or program that is being assessed. The impacts an AST is meant to include are shown in Table I.7.

Table I.7 Items in U.K. Appraisal Summary Table

Environment	Economy
Noise	Transport Economic Efficiency
Local Air Quality	Reliability
Greenhouse Gases	Wider Economic Impacts
Landscape	
Townscape	**Accessibility**
Heritage of Historic Resources	Option Values
Biodiversity	Severance
Water Environment	Access to the Transport System
Physical Fitness	
Journey Ambience	**Integration**
	Transport Interchange
Safety	Land Use Policy
Accidents	Other Government Policies
Security	

These are organized according to the five overarching objectives of government policy. The table provides a simple format for assessing tradeoffs. For example, a more expensive project might have less environmental impact, allowing the decision-maker to make this explicit judgment. Detailed analysis underlies each of the specific measures, but can range from quantitative analysis to more qualitative judgments.

Specific techniques for analyzing impacts can be found in the UK Design Manual for Roads and Bridges (http://www.standardsforhighways.co.uk/dmrb/). In particular, quantitative methods are included for air quality assessment, noise calculations, and vibrations. Decibel rating scales for noise, based on a mathematical model, are provided (similar to NPL, 2005). Water environmental quality standards are assessed in four main categories: effects of routine runoff on surface waters; effects of routine runoff on groundwater; pollution impacts from accidental spillages; and assessment of flood impacts (Highways Agency, 2010).

References

Department for Transport, 2007. Guidance on Transport Assessment. Accessed at http://www.dft.gov.uk/pgr/regional/transportassessments/guidanceonta.

Department for Transport, 2010. Transport Analysis Guidance – WebTAG. Accessed at http://www.dft.gov.uk/webtag/.

National Physical Laboratory, 2005. Technical Guides – Calculation of Road Traffic Noise 1988. Accessed at http://resource.npl.co.uk/acoustics/techguides/crtn/.

Europa, 2010. Summaries of EU legislation. Accessed at http://europa.eu/legislation_summaries/environment/.

Highways Agency, 2010. Design Manual for Roads and Bridges. Accessed at http://www.standardsforhighways.co.uk/dmrb/.

European Examples of Strategic Environmental Assessment

The SEA of the High-Speed Rail Network (HSR) for Europe

The outline plan drawn up in 1990 envisioned 9,800 km of new lines and 14,400 km of upgraded lines by 2010. The study was multimodal in nature and compared the impact of high-speed rail with other modes such as roads and air transportation (ECMT, 1998).

Scope. This assessment involved a high degree of abstraction as the exact location of the proposed railway lines had not been decided. Thus, this provided a good overview of alternative modal choices from a high-level policy assessment. Lack of detailed information made it difficult to assess local impacts such as noise and visual impacts. Global warming, congestion, air pollution, traffic safety, energy consumption, and some spatial impacts were assessed.

Methods. Aggregation of impacts was limited. It was not possible to use GIS as the exact siting of the railway lines was not decided at that time. Traffic models were used, but indirect effects were not included. Alternatives were limited to infrastructure alternatives; tolls and economic policies were not included in the analysis. Scenarios were considered for uncertainty analysis.

Results. The SEA concluded that the high-speed railway will have positive impacts on greenhouse gas emissions, emissions of air pollutants, energy consumption, and traffic safety. It will consume about 80,000 hectares of land. The SEA was not able to assess noise, visual impacts and impacts on congestion because the exact routes had not yet been fixed at the time of the study.

Source: European Conference of Ministers of Transport (ECMT), 1998, Strategic Environmental Assessment in the Transport Sector, Paris.

The SEA of Proposed Route Alternatives for the Antwerp-Rotterdam HSR

This study was conducted between 1994 and 1997 to choose the route for a high-speed rail connection between Antwerp in Belgium and Rotterdam in the Netherlands. This was especially significant because of the two different planning systems involved and the inclusion of transboundary effects into consideration. The spatial and economic impacts, natural environment, traffic, and construction costs for each route were studied in this SEA. In particular, the SEA focused on protecting open spaces in Flanders, avoidance of noise is quiet zones in the Netherlands and the spatial development of the Netherlands.

Source: Strategic Environmental Assessment in the Transport Sector, European Conference of Ministers of Transport.

Helsinki Metropolitan Area Transport System Plan 1998

This was a systemwide SEA and, therefore, included all modes of transport. The scope of the environmental assessment included air quality, noise, built environment, landscape, biodiversity, and social conditions. The methods used were traffic-use forecasts, quantifying land use – transportation interactions and measurement of economic impacts of large projects. Pricing was one of the options considered in the alternatives, as were methods to increase competitiveness of nonmotorized modes and transit.

Sources: Kaljonen (1999), The role of SEA in Planning and Decision-Making: the case of the Helsinki Metropolitan Area Transport System Plan 1998, Proceedings from the third Nordic EIA/SEA Conference; Jansson (1999), Strategic Environmental Assessment for Transport in Four Nordic Countries, Proceedings from the third Nordic EIA/SEA Conference.

Gothenburg – Jonkoping Transportation Corridor

This was a Swedish multimodal study which included transit components. Bina characterizes the Swedish approach to the SEA as one based on questions.

Bina also notes the use of traffic, energy consumption, and emission models in the study, as well as the integration of the SEA with a cost/benefit analysis. In the cost/benefit analysis, the direct capital and operating costs, road safety and accessibility costs, environmental impact costs and regional distribution costs are accounted for. Similarly, benefits include income from rail services and travel-time gains. For environmental costs, willingness-to-pay is used as a measure of the cost of mitigating environmental damage from development.

Sources: Bina O., Strategic Environmental Assessment of Transport Corridors: Lessons learned comparing the methods of five member-states, Environmental Resources Management 2001; Jansson (1999), Strategic Environmental Assessment for Transport in Four Nordic Countries, Proceedings from the third Nordic EIA/SEA Conference.

SEA of the Dutch Zuider Zee Line

The Zuider Zee Line connects Amsterdam to Groningen. This study compared various types of rail links for their impacts, including their environmental impacts (which were monetized for the purpose of the cost/benefit analysis). Indicators considered were emissions of CO_2, NO_x, and SO_2, energy consumption, landscape, noise levels and area exposed to noise, and costs of mitigation of environmental impacts. These impacts then were monetized and included in a cost/benefit analysis of the Zuider Zee Line.

Source: Wee, Brink and Nijland (2003), Environmental impacts of high-speed rail links in cost/benefit analyses: a case study of the Dutch Zuider Zee line.

SEA of HSR in Portugal

The scope of the SEA was quite broad. It considered the need for high-speed rail, the networks which were proposed, and the corridors that had been proposed for each connection. A cost/benefit analysis was done and the following costs were considered: accidents, noise, air pollution, climate change, nature and landscape, urban effects and upstream process associated with transport. GIS was used in the assessment of environmental impacts. The balanced scorecard method was applied to the monitoring phase of the SEA.

Source: Coutinho, et al., Strategic Environmental Assessment of the High-Speed Rail Network in Portugal (last accessed at: http://www.ua.pt/idad/ReadObject.aspx?obj=9464).

Specific Methodological Tools

The European Commission recently released a report that lists various methodological tools that can be applied in the environmental assessment of transport projects (EC DG-TREN, 2009). The specific categories of impact tools are as follows:

- Cause effect modeling;
- Screening – Ecological risk assessment tools;
- Transport forecast models;
- Coupled land use/transport models;
- Calculation of emissions and exposure;
- Cost/benefit analysis;
- Life-cycle assessment;
- Intelligent GIS;
- Decision support tools for multicriteria assessment (MCA); and
- Information sharing, group decision taking, and public involvement tools.

Some of these are clearly specific to European practice, such as techniques for emissions modeling, on which EPA already provides guidance. Some are locally oriented, such as transport forecast and land use models, the latter including methods such as URBANSIM and MEPLAN. Cost-Effectiveness analysis is included in the New Starts process, but European practice extends cost/benefit analysis to all modes. Items listed under cause/effect modeling include Bayesian inference (e.g., WINBugs) which are probably not realistically applicable for assessing environmental impacts. Overall, the list in their documentation may provide some useful guidance, but much of it is probably not useful.

Reference

EC DG-TREN, 2009, The SEA Manual: Fact Sheets, A Sourcebook on Strategic Environmental Assessment of Transport Infrastructure Plans and Programmes.

Contacts List

Luc-Alexandre Chayer
A/Manager, Environmental Assessment – Projects
Gestionnaire Intérimaire, Évaluation Environnementale – Projets
Transport Canada/Transports Canada
Ottawa, Ontario

Bruno Jacques, Directeur/Director
Analyse et Recherche Économiques et Environnementales/
Economic and Environmental Analysis and Research
Transport Canada
Ottawa, Ontario

Dave Gennard
New Zealand Transport Agency
Principal Transport Planner
Wellington, New Zealand

Chris Parker
Senior Consultant
Hyder Consulting (NZ) Ltd
Wellington, New Zealand

Anthony Casey
Regulatory Quality Team
The Treasury
Government of New Zealand

Carl Reller
Environment and Urban Design Manager
NZTA, Highways and Network Operations
Wellington, New Zealand

Mike Lascelles
formerly Director of Legislation and then Director of Education, Canadian Environmental Assessment Agency
Ottawa, Ontario

Ralph Buehler
Assistant Professor
Virginia Tech University

Mark Harvey
Research Manager, Regulatory Reform and Investment Analysis
Bureau of Infrastructure, Transport and Regional Economics
Canberra, ACT

Appendix J – Indicators of Ecological Impacts of Land Development

This section discusses how land development – whether occurring in response to a transit project or highway investment or other factors – can lead to various environmental and ecological consequences. Table J.1 provides examples of the range of ecological/ environmental factors affected by various land development activities. The section then discusses how various land development patterns may have different effects on ecological impacts. For example, how would the impacts of a transit project that encouraged infill and redevelopment of existing built-up areas compare with the impacts of projects that encouraged low-density development on greenfields sites?

Following that is a discussion of the extent to which an assessment of ecosystem protection plans can substitute for an analysis of impacts. Finally, a list of references is provided.

While some environmental impacts of land development can be generalized (e.g., amount of land lost due to x units of development at y units per acre), in most cases, the environmental impacts of land development tend to be site and design specific. For example, it is impossible to say that 40 acres of suburban single-family development produces a particular impact on water quality or habitat fragmentation. One needs to know both the details of the design of the development and the natural characteristics of the area in which it is located. This poses a fundamental challenge to assessing the environmental performance of transit investments (or any transportation investment), since it is difficult to know the specific nature of any land use changes that occur in response to the project.

Table J.1 Environmental and Ecological Impacts Related to Land Development

Performance Category	Key Measures	Data Needed to Measure Impact	Specific Metrics Related to Measure
Ecosystem, Biodiversity, and Habitat	Loss of Habitat	• Species of concern (e.g., statewide listed endangered or threatened species); • Habitat areas used by species of concern throughout their life cycle; • Functional value of each identified habitat area for each species; • Size of habitat areas; • Location of habitat areas; and • Project location data.	• Acres of fragmented or threatened habitat in the state or region; • Change in number of acres of a specific habitat; • Change in composition and structure of habitat; • Change in the amount of habitat edge; • Change in the acreage of interior habitat; • Distance of habitat fragments from each other; • Preservation of high-quality wildlife habitat (wetlands, old-growth forest, etc.); • Number of projects that protect sensitive species or restores habitat; • Number of acres of priority conservation areas acres protected annually; • Sustained population ecology (increased size and density of species, balanced age and sex structure, reduced mortality, new growth, etc.); and • Population size of indicator species.
	Loss of Native Plants	• Area of native plant communities; • Acres of predicted disturbance; and • Native vegetation appropriate to the context.	• Change in health and diversity of native plan community; • Change in acres of native plants relative to nonnative plants; • Change in acres of invasive plants within highway corridor right-of-way; • Percent of native vegetation preserved; • Number of acres with newly planted native plants; • Acres sprayed with herbicide; • Total square feet of noxious weed infestation, per 0.10-mile section; and • Total square feet of nuisance vegetation, per 0.10-mile section.

Table J.1 Environmental and Ecological Impacts Related to Land Development (continued)

Performance Category	Key Measures	Data Needed to Measure Impact	Specific Metrics Related to Measure
Water Quality	Water Quality Protection Areas	• Groundwater protection areas; • Source water protection areas; • Areas draining into water bodies with Total Maximum Discharge Limits (TMDL) or appearing on the 303d impaired water bodies list; • Areas identified for protection in watershed and water resource management plans; and • Location of receiving water bodies; pollutant load coefficient.	• Degree of intrusion of transportation infrastructure into water quality protection area; • Proximity of transportation projects to receiving waters; • Proximity of transportation projects to water bodies with established TMDLs; • Change in pollutant loadings for nutrients; • Expected pollutant emissions from construction and operation of new transportation infrastructure; and • Percent of water samples collected that meet state quality standards for clarity when working in water.
	Hydromo-dification	• Preproject physical/hydrological characterization of receiving water body and associated riparian areas; and • Coefficients for estimated pollutant load due to anticipated hydromodification from the project.	• Extent of modification of a water body as a result of new capacity investment (significant, minor, none); • Change in sediment load (predicted or observed); • Change in nutrient load (predicted or observed); • Change in temperature (predicted or observed); • Change in velocity on receiving water body (predicted or observed); • Degree of stream bank and shoreline erosion (predicted or observed); and • Number of culverts retrofitted for fish passage, number of barriers removed at major construction projects.

Table J.1 Environmental and Ecological Impacts Related to Land Development (continued)

Performance Category	Key Measures	Data Needed to Measure Impact	Specific Metrics Related to Measure
	Loss of Riparian and Floodplain Areas (continued)	• Area, quality, and functioning of riparian area affected by project; and • Coefficients for estimated pollutant load due to proposed changes.	• Change in acres of riparian areas; • Acres of riparian areas disturbed or degraded; • Acres of riparian areas improved; • Change in ecological function of riparian areas impacted by a capacity investment; • Amount of watershed improvement achieved after five or more years through appropriate measures; and • Acres of open space land protected from development.
	Water Quality Standards Compliance	• Identification of receiving waters; • 303(d) list of impaired waters; • TMDLs for receiving waters; and • Coefficients for predicted pollutant loading.	• Project TMDLs and water quality standards for specific water bodies; • Available pollutant loads prior to exceeding allowable thresholds; and • Average pollutant concentrations of various metals, suspended solids, and toxic organics in road runoff.
	Impervious Surface	• Impervious surface or land use GIS data layer; and • Estimates of induced growth.	• Increase in impervious surfaces due to direct facility construction; and • Increase in impervious surfaces due to development induced by facility construction.
Wetlands	Ratio of Wetland Acres Taken and Replaced	• Section 404 permit field surveys or other sources of wetland data.	• Annual acreage of wetlands destroyed versus wetlands created.
	Loss of High-Quality Wetlands	• Federal, state, or local natural resource agency databases of wetland quality or primary research.	• Change in acreage of high-quality wetlands; • Expected change in ecological function of wetlands as a result of mitigation for capacity investments; and • Ecological value of wetlands impacted by a capacity investment.

J.1 Relative Ecological Impacts of Different Land Use Patterns

There are many variables to consider as components of land use, including population density, types of uses (residential, commercial, transportation, mixed), patterns and distribution of uses (e.g., sprawl versus cluster), and site-specific activities (low impact). A basic breakdown of land use characteristics is as follows:

- Density (population and development):
  - High versus low.
- Spatial Pattern:
  - Sprawl versus compact (e.g., cluster); and
  - Infill (e.g., within existing urban context).
- Design:
  - Low-impact development techniques (e.g., water management);
  - Mixed use development; and
  - Greenfields preservation.

These are obviously not mutually exclusive and the interactions have varying environmental/ecologic impacts. Additionally, some of the direct ecological impacts of the above depend on a number of site-specific factors (e.g., climate, land form topography, biologic conditions). Varying land use characteristics affect habitat characteristics and quality, hydrology, soils, vegetation, species distribution, biodiversity, air quality, water quality, and human health. Some of these receive significant attention (e.g., endangered species under the Endangered Species Act), while others are less obvious and/or more difficult to assess. These impacts also are not easy to assess individually or independently. Table J.2, taken from Litman (2009), shows one approach to considering benefits (versus impacts) of various land uses.

Table J.2 Environmental Benefits by Land Use Category

Land Use Category	Air Quality	Water Quality	Ecologic[a]	Flood Control	Recreation[b]	Aesthetic	Cultural[c]	Economic[d]
Wetlands	High	High	High	High	High	High	High	High
Pristine Wildlands	High	High	High	Varies	High	High	High	Varies (e)
Urban Greenspace	High	High	Medium	Medium	High	High	High	Varies (e)
Second Growth Forest	High	High	Medium	High	High	Varies	Medium	Medium
Farmland	Medium	Medium	Low	Medium	Low	Varies	Medium	Varies
Pasture/ Range	Low	Medium	Low	Low	Low	Varies	Medium	Low
Mixed Urban	Low	Low	Low	Low	Varies	Varies	Varies	High
Highway Buffer	Low	High	Low	Low	Low	Low	Low	Low
Pavement	None	None	None	None	None	None	None	Varies

Source: Bein (1997), as cited in Litman (2009).

[a] Includes wildlife habitat, species preservation, and support for ecological systems.
[b] Includes hunting, fishing, wildlife viewing, hiking, horse riding, bicycling, etc.
[c] Includes preservation of culturally significant sites and traditional activities such as harvesting resources.
[d] Includes economic benefits to people who do not own the land, such as tourism, fishing, and hunting.
[e] Reflected in tourism and recreational expenditures, increased adjacent property values, water resources quality and availability, and fisheries.

The discussion below describes in more detail some of the land uses and their environmental/ecological effects.

Sprawl and Cluster Development

Sprawl is characterized by low-density development at the edges of cities and in rural areas. Cluster development is a form of (relatively) high-density development where buildings and structures are grouped together on a small portion of a site, leaving remaining land areas for open space, conservation, agriculture, recreation/parklands, and public and semipublic uses. Clustering avoids the impacts commonly associated with sprawl by reducing individual lot sizes and shortening road and thus sewer infrastructure lengths. Cluster development aims to concentrate development in areas already served by sewers and roads helping to reduce ecological impacts (Burchell, 1998).

The Urban Land Institute (ULI) identifies the following "dysfunctions" of sprawl:

- Indiscriminate and incremental use of open land;
- Low-density residential "tract" subdivisions;
- Land-consumptive strip commercial development;
- Lack of connectivity among residential and commercial development projects;
- Transportation systems that are exclusively auto-dependent;
- Social homogeneity; and
- Economic segregation.

The literature recognizes that because sprawl spreads low-density urban development over a wider area than more compact or cluster land use patterns, more land is consumed, generally causing fragmentation of contiguous greenspace and wildlife corridors; loss of natural habitats (i.e., riparian corridors and wetlands); and increased prevalence of non-native, invasive plant and animal species (Heimlich, 2001). Analyses of development impacts on ecologically sensitive lands have found that planned (potentially cluster/compact) versus unplanned (sprawl) development would reduce the consumption of these lands by almost one fifth (U.S. EPA, 2001).

The impervious surface area of a clustered development site is often 10 to 15 percent less than that of more dispersed development and can – in some cases – result in 30 to 80 percent less disturbance of an entire greenfield site, without reducing the number of lots on a site (U.S. EPA, 2001). In a study comparing sprawl and clustered development on a tract of land in rural Virginia, the Chesapeake Bay Foundation concluded that cluster development would convert 75 percent less land, create 42 percent less impervious surface, and produce 41 percent less stormwater runoff (U.S. EPA, 2006).

Compared with compact development, sprawl often results in a greater conversion of vegetation and permeable soils to concrete, asphalt, or residential/commercial structures with impervious surfaces. Sprawl can produce approximately 50 percent more storm runoff than compact development (Schueler, 1995). Urban fringe and rural areas often lack the infrastructure necessary to capture and treat runoff generated from impervious surfaces, which can lead to increased pollutant loads in rivers, lakes, and streams and degrade drinking water quality. A study in South Carolina found that low-density sprawl development generated approximately 40 percent more runoff, four times more sediment, almost four times as much nitrogen, and three times the phosphorous as compared to more compact development (U.S. EPA, 2006).

Infill Development

As succinctly stated in the U.S. EPA's *Our Built and Natural Environment,* "infill development occurs in locations where some development already has taken place and infrastructure already is in place." Compared with other land use patterns, infill directs growth to urban cores by filling undeveloped or underutilized parcels of land. Although per acre impacts tend to increase with density, impacts per capita tend to decline (Arnold and Gibbons, 1996). The literature reports that compared to greenfield development, infill utilizes existing infrastructure (roads and parking lots), which helps to reduce impervious surfaces and associated runoff (U.S. EPA, 2006). Roads and parking facilities have *hydrologic impacts*, concentrating stormwater (potentially leading to increased flooding, scouring, and siltation) and reducing surface and groundwater recharge (lowering dry season water flow and potentially creating fish blockages) (Litman, 2009). Paved surfaces also create *heat island* effects, causing potential increases in ambient summer temperatures, increasing energy demand and levels of air pollutants, while contributing to potential health effects from heat waves (Litman, 2009).

A study completed by George Washington University indicates that one acre of infill development will conserve 4.5 acres of greenfields development (George Washington University, 2001).

Brownfields redevelopment is an unique form of infill development, utilizing abandoned, idled, or underused industrial and commercial facilities complicated by real or perceived environmental hazards or consequences (U.S. EPA, 2006). Brownfields redevelopment, because it tends to be higher density, also tends to improve water quality. Brownfields sites tend to be redeveloped with urban densities, which are associated with lower runoff.

Mixed-Use Development

Mixed-use development locates land uses with complementary functions close together. Complementary uses may include housing, shopping, offices, restaurants, and movie theaters – any destinations that people travel to on a regular basis. Mixing land uses can prevent habitat loss and runoff by reducing impervious surfaces associated with new parking lots and transportation infrastructure. As a type of mixed-use development, transit-oriented development (TOD) provides a mix of land uses (i.e., residential, commercial, and retail space) in the immediate vicinity of transit stops. TODs can benefit regional water quality by concentrating development and reusing previously developed land – thereby reducing development pressure on open space. Reuse of previously developed land often means accommodating new development without any increase in impervious surface or runoff (U.S. EPA, 2010).

Greenfields

Greenfields, greenspace, or open space is characterized as having ecological attributes or being ecologically active and frequently includes wetlands, forests, farms, and parks. These lands can provide external benefits such as wildlife habitat, air and water quality, and beauty. These areas, when preserved in close proximity to urban/densely populated areas can provide the following social and ecological amenities (Litman, 2009):

- Protect groundwater;
- Protect wildlife habitat;
- Preserve natural places;
- Provide local food;
- Sustain farming as a way of life;
- Preserve rural character;
- Preserve scenic quality;
- Slow development; and
- Provide public access.

Relative Ecological Impacts of Land Use Patterns

The following table attempts to summarize the relative ecological impacts of previously discussed land use patterns. The circles in Table J.3 indicate a ranking of ecological impact from the identified land use pattern and range from low (○) to high (●).

Table J.3 Ecological Impact by Development Pattern

	Development Patterns			
Ecological Impact	**Sprawl**	**Cluster**	**Infill**	**Mixed Use**
Habitat and Ecosystem Impacts • Imperilment of native and endangered species; • Degradation of natural habitat and biodiversity (i.e., native plant species, riparian corridors, and wetlands); and • Fragmentation of contiguous open space and wildlife corridors	●	◑	○	○

Table J.3 Ecological Impact by Development Pattern (continued)

Ecological Impact	Development Patterns			
	Sprawl	Cluster	Infill	Mixed Use
Water Quality Impacts • Alteration of natural flows from increased impervious surfaces; • Changes in hydrology and reduced groundwater recharge; and • Increased water pollution and nutrients (i.e., increased sedimentation and pollutant levels).	●	◑	◑	◑

J.2 Assessing Ecosystem Protection Plans

An alternative to assessing the ecological impacts of transit projects directly might be to assess the quality and strength of plans directed at protecting ecosystems. Plans also may be used for the purpose of identifying potential impacts related to transit projects and associated land development.

There are many plans that have been developed for diverse purposes at a multitude of scales to address large area and site-specific ecosystem concerns. Most of these plans address needs of specific species and their habitat requirements, rather than broader ecological conditions. One primary challenge in using ecosystem protection plans is the level of resolution and availability of detailed spatial information about potential ecological resources. In many cases plans are accompanied by maps delineating conditions, generally at relatively small scales. Some plans developed for purposes of wildlife management, watershed protection, and species recovery may be helpful for considering potential broad-scale transit impacts, but they are unlikely to eliminate the need to conduct site assessments for impacts.

Some states have developed specific guidelines to help address concerns of biodiversity and ecological conditions in the face of increasing development (Washington Department of Fish and Wildlife, 2009). Washington also recognizes the significant range of plans that may be available for assessing conditions – see Table J.4.

Table J.4 Key Washington State Natural Resource Agency Guidance Documents for Local Planning

Agency	Document	Primary Focus
Washington Department of Ecology	Wetlands in Washington State, Volume 2: Guidance for Protecting and Managing Wetlands (Granger et al. 2005)	Wetlands
Washington Department of Ecology	Protecting Aquatic Ecosystems: A Guide for Puget Sound Planners to Understand Watershed Processes (Stanley et al. 2005)	Watershed processes
Washington Department of Transportation	Enhancing Transportation Project Delivery Through Watershed Characteristics (Gersib et al. 2004)	Watershed Processes and transportation mitigation
Washington Department of Commerce	Technical Guidance Document for Clearing and Grading in Western Washington (CTED 2005)	Clearing and grading
Washington Department of Commerce	Critical Areas Assistance Handbooks (CTED 2003)	Critical areas ordinance development and implementation
Puget Sound Action Team	Low-Impact Development – Technical Guidance Manual for Puget Sound (Hinman 2005)	Maintaining hydrologic function
Washington Biodiversity Council	Washington Biodiversity Conservation Strategy (Washington Biodiversity Council 2007)	Biodiversity conservation
Aquatic Habitat Guidelines Working Group	Protecting Nearshore Habitat Functions in Puget Sound: An Interim Guide (Envirovision, Herrera, and AHG 2007)	Nearshore development and habitat protection
Washington Department of Fish and Wildlife and Aquatic Habitat Guidelines Working Group	Land Use Planning for Salmon, Steelhead, and Trout. Washington Department of Fish and Wildlife (Knight, K. 2009)	Consideration of salmon and trout in land use planning
Washington Department of Fish and Wildlife	Priority Habitats and Species Management Recommendations (various)	Management recommendations for specific species and habitats
Washington Department of Fish and Wildlife	Landscape Planning for Washington's Wildlife: Managing for Wildlife in Developing Areas (WDFW 2009)	Wildlife in developing landscapes

Source: Washington Department of Fish and Wildlife (2009). *Landscape Planning for Washington's Wildlife: Managing for Biodiversity in Developing Areas*. http://www.wdfw.wa.gov/publications/00023/wdfw00023.pdf.

All states have had requirements, set by Congress, to develop State Wildlife Action plans to be eligible to receive funds through the Wildlife Conservation and Restoration Program and the State Wildlife Grants Program (Association of Fish and Wildlife Agencies). These are considered comprehensive wildlife conservation strategies that assess the health of wildlife and habitats, identify challenges, and outline potential actions for conservation. In some cases, the level of detail included in these documents may be helpful to provide a preliminary understanding of potential ecological impacts based on changing land use patterns as may be affected by transit development.

In some instances, agencies are organizing significant volumes of information, generally available digitally as part of agency GIS databases, including knowledge derived from plans. See for example, the Local Habitat Assessment (LHA) in Washington (Carelton and Jacobson, 2009). LHA uses four basic data layers, including Ecoregional Assessments, the Department of Fish and Wildlife Priority Habitats and Species (PHS) data, land use/land cover data, and a road network coverage, to develop scores that depict where valuable habitat exists, where natural vegetation is intact, where vulnerable concentrations of wildlife exist, where population pressures are significant, etc. Results of this analysis can be shown as a color-coded map to indicate wildlife habitat values across the landscape.

Plans are developed for many purposes, with varying relevance to concepts of ecological conditions. Detailed inventories and accompanying spatial data bases that might be included in plans to address flora, fauna, endangered species, habitat requirements, distribution, threats, and opportunities would all be helpful. Land use plans that have considered all species and ecosystem services and identified potential areas for development given these considerations would also be of use. But this type of planning is costly and seldom undertaken.

J.3 References

Arnold, C. and James Gibbons (1996), *Impervious Surface Coverage: The Emergence of a Key Environmental Indicator*, American Planning Association Journal, Volume 62, Number 2, Spring 1996, pages 243-258.

Association of Fish and Wildlife Agencies (accessed August 19, 2010). State Wildlife Action Plans. http://www.wildlifeactionplans.org/.

Bein, Peter (1997). *Monetization of Environmental Impacts of Roads*. B.C. Ministry of Transportation and Highways.

Brown, J. (2006). *Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects*. Publication FHWA-HEP-06-011. FHWA, U.S. Department of Transportation, 96 pages at: http://www.environment.fhwa.dot.gov/ecological/eco_index.asp.

Carelton, John and John Jacobson (June 2009), *Local Habitat Assessment: Habitat Analysis Techniques for Counties, Watersheds, and Other Planning Areas*. http://www.wdfw.wa.gov/publications/00734/wdfw00734.pdf.

Doyle, K., J. Kostyack, B. McNitt, G. Sugameli, C. Whitaker, K. Whitcomb-Blaylock, J. Byrd, G. Stull, and B. Czech (2001). *Paving Paradise: Sprawl's Impact on Wildlife and Wild Places in California*, Washington, D.C.: National Wildlife Federation.

Ewing, R., J. Kostyack, D. Chen, B. Stein, and M. Ernst, (2005). *Endangered by Sprawl: How Runaway Development Threatens America's Wildlife.* National Wildlife Federation, Smart Growth America, and NatureServe. Washington, D.C., http://www.nwf.org/News-and-Magazines/Media-Center/Reports/Archive/2005/~/media/PDFs/Wildlife/Endangered BySprawl.ashx.

Galster, George (2001). *Wrestling Sprawl to the Ground: Defining and Measuring an Elusive Concept.* Housing Policy Debate 12.4: 681- 717, Fannie Mae Foundation. http://content.knowledgeplex.org/kp2/programs/pdf/proc_fairgrowth_galster.pdf.

George Washington University (2001). *Public Policies and Private Decisions Affecting the Redevelopment of Brownfields: An Analysis of Critical Factors, Relative Weights and Areal Differentials*. http://www.gwu.edu/~eem/Brownfields/.

Heimlich, R.E. and Anderson, W.D., 2001: *Development at the Urban Fringe and Beyond: Impacts on Agriculture and Rural Land.* U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 803, Washington, D.C., http://www.ers.usda.gov/publications/aer803/aer803.pdf.

Litman, T. (2009). *Evaluating Transportation Land Use Impacts, Considering the Impacts, Benefits and Costs of Different Land Use Development Patterns*. Victoria Transport Policy Institute.

Litman, T., (2008). *Sustainable Transportation Indicators*. Victoria Transport Policy Institute (www.vtpi.org); http://www.vtpi.org/sustain/sti.pdf.

Litman, T., (1995). *Evaluating Transportation Land Use Impacts*. Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/landuse.pdf.; originally published in World Transport Policy and Practice, Volume 1, No. 4, pages 9-16; http://www.eco-logica.co.uk/worldtransport.html.

Northeast-Midwest Institute (2008). *The Environmental and Economic Impacts of Brownfields Redevelopment*, http://actrees.org/files/Research/nmi_brownfields.pdf.

Robert Burchell, et al. (2002), *The Costs of Sprawl – 2000*. TCRP Report 74, TRB (www.trb.org); at http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_rpt_74-a.pdf; http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_rpt_74-b.pdf; and http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_rpt_74-c.pdf.

Robert W. Burchell, Naveed A. Shad, David Listokin, Hilary Phillips, Anthony Downs, Samuel Seskin, Judy S. Davis, Terry Moore, David Helton, and Michelle Gall. *The Costs of*

Sprawl – Revisited (Transit Cooperative Research Program Report 39, Transportation Research Board, National Research Council 1998), hereinafter The Costs of Sprawl – Revisited. Available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_39-b.pdf.

Schueler, Tom. *Site Planning for Urban Stream Protection.* Center for Watershed Protection, Silver Spring, Maryland: 1995.

State of Delaware, Department of Natural Resources. *Air Quality and Sprawl*, presentation by DNREC's Air Quality Management Section, http://www.dnrec.delaware.gov/landuse/Documents/Air%20Quality%20and%20Sprawl.pdf.

Stone, B. Jr., (2007), *Urban Sprawl and Air Quality in Large U.S. Cities*. Journal of Environmental Management, http://www.coa.gatech.edu/~stone/Publications%20folder/Urbansprawlandairqualityinlargecities.pdf.

U.S. EPA, (1999). *The Transportation and Environmental Impacts of Infill Versus Greenfield Development: A Comparative Case Study Analysis*. EPA 231-R-99-005, http://www.epa.gov/smartgrowth/pdf/protect_water_higher_density.pdf.

U.S. EPA, (1999). *Indicators of the Environmental Impacts of Transportation*. Center for Transportation and the Environment; http://ntl.bts.gov/lib/6000/6300/6333/indicall.pdf.

U.S. EPA, (2006). *Protecting Water Resources with Higher-Density Development*. EPA publication 231-R-06-001, http://www.epa.gov/smartgrowth/pdf/protect_water_higher_density.pdf.

U.S. EPA, Development, Community, and Environment Division, (2001). *Our Built and Natural Environment: A Technical Review of the Interactions between Land Use, Transportation, and Environmental Quality*. Washington, D.C., http://www.smartgrowth.org/pdf/built.pdf.

U.S. EPA, Low-Impact Development Center, (2000). *Low-Impact Development (LID) Literature Review*. EPA-841-B-00-005, EPA, Office of Water: Washington, D.C., October 2000), http://www.epa.gov/owow/nps/lid/lid.pdf.

U.S. EPA. *Using SGI to Evaluate Transit-Oriented Development: Wilmington Area Metropolitan Planning*. http://www.epa.gov/dced/topics/tod_case_study1-ES.htm (accessed April 15, 2010).

Washington Department of Fish and Wildlife, 2009. *Landscape Planning for Washington's Wildlife: Managing for Biodiversity in Developing Areas.* Olympia, Washington. http://www.wdfw.wa.gov/publications/00023/wdfw00023.pdf.

Wildlife Policy Committee. 2005. *Sprawl and Wildlife*. Issues Paper, http://www.fishwildlife.org/pdfs/Sprawl-Wildlife_05.pdf.

Appendix K – Stakeholders Interviewed and Interview Guides

K.1 Contacts for State-of-Practice Survey

Table K.1 lists stakeholders interviewed by organization type. The stakeholders represented 20 separate organizations in total.

Table K.1 Contacts for State-of-Practice Survey

Organization	Name	Title/Position
Transit Agencies		
New York City Metropolitan Transportation Authority (NYCMTA)	Naomi Renek	MTA Grant Management
	Projjal Dutta	MTA Strategic Initiatives
	Thomas Abdullah	NYC Transit Environmental Engineering
	Angelo Elmi	NYC Transit Environmental Engineering
	Emil Dul	NYC Transit Environmental Engineering
	Jack Dean	MTA Planning
Southeastern Pennsylvania Transportation Authority (SEPTA) (Philadelphia)	Marion Coker	Manager, Strategic Business Planning and Sustainability
	Erik Johannson	Senior Planner, Strategic Business Planning and Sustainability
Chicago Regional Transit Authority	Mark Minor	Project Manager, Regional Coordination
Capital Metropolitan Transportation Authority (CMTA) (Austin)	Todd Hemingson	Vice President, Strategic Planning and Development
Sacramento Regional Transit District (SRTA)	Paul Marx	Director, Office of Planning
Santa Clara Valley Transportation Authority (VTA)	Oxo Slayer	Transportation Planner, SVRT Program Office
San Francisco Municipal Transportation Agency (SFMTA)	Timothy Papandreou	Assistant Department Director, Transportation Planning and Development

Table K.1 Contacts for State-of-Practice Survey

Organization	Name	Title/Position
Transit Agencies (continued)		
TriMet	Jessica Tump	Planner (Project Planning), Capital Projects
	Alan Lehto	Director (Project Planning), Capital Projects
	Eric Hesse	Strategic Planning Analyst, Office of the General Manager
American Public Transportation Association (APTA)	Robert Padgette	Director of Policy Development and Research
Federal Transit Administration (FTA) – Office of the Administrator	Richard Steinmann	Senior Advisor to the Administrator
FTA – Office of Budget and Policy	Tina Hodges	Program Analyst
FTA – Office of Planning and Environment	Elizabeth Day	Director, Project Planning
	Dwayne Weeks	Community Planner
	Antoinette Quagliata	Environmental Protection Specialist
	Joe Ossi	Environmental Protection Specialist
Other Government Agency		
Columbia River Crossing (Oregon DOT)	Richard Brandman	Project Manager
Florida DOT, Environmental Management Office	Peter McGilvray	Environmental Resource Manager
Chicago Metropolitan Agency for Planning (CMAP)	Bob Dean	Planning Director
Metropolitan Transportation Commission	Lisa Klein	
Environmental Protection Agency Office of Smart Growth	John Thomas	Transportation – Land Use Expert
	Faith Cole	Environmental Protection Specialist
Advocacy		
Natural Resources Defense Council (NRDC)	Deron Lovaas	Director, Smart Growth Program
	Justin Horner	
	Jennifer Sass	
Chesapeake Bay Foundation	Lee Epstein	Director, Land Programs
Institute for Transport and Development Policy (ITDP)	Michael Replogle	Global Policy Director
Academic		
Simon Fraser University	Anthony Perl	Professor of Urban Studies and Political Science and Director of Urban Studies Program
Oregon State University	Gail Achterman	Director, Institute for Natural Resources
	Jimmy Kagan	Information Program Manager, INR

Note: Environmental Protection Specialist with the FTA Office of Planning and Environment, on rotation to the EPA Smart Growth Office until December 2010.

K.2 Stakeholder Interview Guides

Separate interview guides were developed for transit agencies and for other stakeholders interviewed. These guides were used as a loose topic guide for the interviews, and the actual discussion flow was generally customized to the respondent. In most cases, guides were provided to respondents in advance of the interview.

Transit Agencies

(Interviewer: This survey tool is intended as a topic guide rather than a strict question and answer session. Participants are encouraged to share information about their experience with performance measures at any point and regarding any topic, even if not addressed directly.)

Thank you for your participation in Transit Cooperative Research Program Project H-41, Assessing and Comparing Environmental Performance of Major Transit Investments. Through this project we are identifying measures that could be used in FTA's New Starts process or by project sponsors to evaluate the environmental performance of proposed transit investments.

We are interested in how transit agencies and others have evaluated the *environmental performance* of transit investments. We are interested in situations where you may have gone beyond the basic reporting required for the NEPA process and used environmental performance as a way of justifying a project or making comparisons among various transit and/or highway alternatives.

Do you have experience with environmental performance measures, as opposed to only impacts and mitigation? Are there other staff we should speak with, either in your department or another?

[If needed] Environmental performance, as defined for our project, may include:

- Energy use and GHG emissions;
- Air quality and pollutant emissions;
- Community quality of life (noise, light, aesthetics, etc.);
- Public health;
- Ecology/habitat (including water quality);
- Land use/smart growth/sprawl; and
- Other performance measures as defined by the project sponsor.

[If needed] The results of this interview will be included in our synopsis of current and emerging practices used to measure and compare environmental performance. We would like to discuss:

- Specific measures that you have used or proposed;
- How these measures have been used in planning and evaluation;
- Methodologies;
- Level of effort (data gathering, calculation, etc.) and cost;
- Satisfaction with the measures and lessons learned; and
- Your thoughts on future environmental performance measurement.

Respondent

Name:

Organization/Type of Organization:

Title/Department:

Contact Information:

Experience with FTA/New Starts/Transportation/Performance Measures:

Performance Measures – General

1. Has your agency justified a proposed transit project based in part on its environmental benefits?

   If so, what types of benefits? (If examples are needed: energy, GHG, air quality, public health, ecology/habitat, community benefits, land use.)

2. Has your agency used measures of environmental performance to compare different project or investment alternatives? (Including different transit alternatives, or transit versus highway.)

   If so, which ones? Which did you consider to be the most important or useful measures?

3. Why were these measures or metrics selected? By what process?

4. How were the measures and results used?

   - To satisfy NEPA requirements;
   - To screen alternatives and select a preferred alternative;
   - To document the environmental benefits of transit in order to build or justify support for the project; and
   - Other (explain).

5. Did you use the measures to make comparisons across modes, or just for comparing transit alternatives?

Performance Measures – Detail

6. Did you consider the impacts of construction activities, or just the impacts of the transit project's operations?

7. [If energy/GHG] Did you look at *life-cycle impacts* (e.g., from fuel production and transport) or just vehicle energy use and tailpipe emissions?

8. Did you consider secondary impacts, such as those related to changes in land use and growth patterns? If so, how?

Pre- Versus Post-Project Evaluation

9. In cases where you *projected* environmental performance, have you gone back to assess whether the project performed as expected?

10. Has your agency conducted any assessment of the environmental performance of existing transit projects or services? If so, which projects or services, and what environmental measures were examined?

Methodology

11. What data sources and methodologies did you use to assess each of the metrics you identified above?

12. What was the approximate cost and/or level of effort (hours of staff time) to document particular environmental measures? (If respondent is not sure, ask for a qualitative assessment – little, moderate, a lot of time/effort.)

Satisfaction and Lessons Learned

13. Would you use the same performance measures and/or calculation methods again? What would you change?

14. Are there other performance measures you considered, or would like to use, but don't have the data, methods, or resources to estimate?

15. Are there any other obstacles you face in evaluating environmental performance measures or implementing this type of evaluation (not required, performance measurement is not a familiar/accepted concept at the agency, etc.)?

Other Resources

16. Does your organization have plans to measure the environmental performance of transit projects in the future?

17. What research or information would be most valuable to you in measuring the environmental performance of your transit investments?

18. Given your knowledge of the FTA New Starts evaluation process, are there specific environmental evaluation criteria and metrics you would recommend to be part of the program? Are there any you would recommend not be included?

19. Please provide a copy of any studies that you have performed, or resources you have relied on for information.

Nontransit Agencies

Thank you for your participation in Transit Cooperative Research Program Project H-41, Assessing and Comparing Environmental Performance of Major Transit Investments. Through this project we are identifying measures that could be used in FTA's New Starts process or by project sponsors to evaluate the environmental performance of proposed transit investments.

We are interested in how transit agencies and others have evaluated the *environmental performance* of transit investments. We are interested in situations where you may have gone beyond the basic reporting required for the NEPA process and used environmental performance as a way of justifying a project or making comparisons among various transit and/or highway alternatives.

Do you have experience with environmental performance measures, as opposed to only impacts and mitigation? Are there other staff we should speak with, either in your department or another?

(Note) Environmental performance, as defined for our project, may include:

- Energy use and GHG emissions;
- Air quality and pollutant emissions;
- Community quality of life (noise, light, aesthetics, etc.);
- Public health;
- Ecology/habitat (including water quality);
- Land use/smart growth/sprawl; and
- Other performance measures as defined by the project sponsor.

Respondent

Name:

Organization/Type of Organization:

Title/Department:

Contact Information:

Experience with FTA/New Starts/Transportation/Performance Measures:

Performance Measures – General

1. Have [you, your agency, your organization] evaluated the environmental performance of transit – either in general, or for particular projects?

   If so, what types of performance did you examine? (If examples are needed: energy, GHG, air quality, public health, ecology/habitat, community benefits, land use.)

   What specific measures did you use? Why were these measures developed and how have they been used? What measures have you found most useful?

2. Have [you, your agency, your organization] developed *proposed* measures of the environmental performance of transit? If so, which ones? For what purpose?

Performance Measures – Detail

3. Did you consider life-cycle impacts, including construction, vehicle and fuel production, or other impacts? Or just impacts from vehicle operations?

4. Did you consider secondary impacts, such as those related to changes in land use and growth patterns? If so, how?

Pre- Versus Post-Project Evaluation

5. Have you made any comparisons of *actual* versus *projected* environmental performance of transit projects?

Methodology

6. What data sources and methodologies did you use to assess each of the metrics you identified above?

Satisfaction and Lessons Learned

7. Was information on environmental performance measures shared with or used by other agencies/organizations? In what way? (e.g., transit metrics used by MPO in developing long-range plan, or by advocacy groups to support project).

8. Would you use the same performance measures and/or methods again? What would you change?

9. Are there other performance measures you considered, or would like to use, but don't have the data, methods, or resources to estimate?

10. Are there any other obstacles you face in evaluating environmental performance measures or implementing this type of evaluation? (For example, is the concept of performance measurement endorsed or accepted by the local/regional transit agency/agencies you work with?)

Other Resources

11. Does your organization have plans to measure the environmental performance of transit projects in the future?

12. What do you feel are the most significant environmental benefits and disbenefits of transit investments?

13. What research or information would be most valuable to you in measuring the environmental performance of transit?

14. Given your knowledge of the FTA New Starts evaluation process, are there specific environmental evaluation criteria and metrics you would recommend to be part of the program? Are there any you recommend avoiding? Why?

15. Please provide a copy of any studies that you have performed, or resources you have relied on for information.

16. Is there anyone else we should talk to about environmental performance measurement for transit?