Incorporating Climate Change Considerations Into Transportation Planning

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ABSTRACT

Transportation emissions are a significant contributor to climate change. Transportation plans and related documentation of metropolitan planning organizations and international cities were reviewed to ascertain whether climate change considerations are being incorporated into the transportation planning process. The review revealed that climate change considerations have not yet been included in a majority of cases in the transportation planning process, especially with regard to adapting transportation systems to the potential effects of climate change. Where such consideration did occur, the focus was on greenhouse gas emission mitigation where data collection techniques and analysis tools are better developed and already in place within many planning organizations. A conceptual framework for transportation planning is presented and used to illustrate how some agencies have considered climate change in each step of the planning process. Recommendations are provided on how greenhouse gas emission mitigation and climate adaptation strategies can be incorporated into the transportation planning process.

Key Words: Climate Change, Greenhouse Gas Mitigation Strategies, Transportation Adaptation Strategies
INTRODUCTION

Most climate scientists agree that climate change has been occurring in scientifically measured ways ever since the first stages of industrialization and that it will become even more pronounced if not addressed on a global scale. The transportation sector is one of the major sources of greenhouse gases that contribute to climate change. As such, there are two linkages between surface transportation and climate change that are important from a policy and transportation planning perspective: 1) global transportation is responsible for a significant portion of climate change through the emission of vehicular greenhouse gases (GHG), and 2) a changing climate could have serious consequences on the resiliency and performance of surface transportation systems in response to environmental conditions. In the parlance of today’s policy and planning language, the first issue leads to strategies to mitigate the impact of transportation-related GHG emissions, whereas the second issue leads to strategies to adapt the transportation system to changes in environmental conditions. Although most of the policy discussion in the transportation profession has focused on GHG mitigation, the hazards of a changing climate, such as warmer climate, changes in precipitation patterns, higher severity storms, increasing risk of flooding and larger storm surge, expedited melting of vital snow and permafrost, and more frequent erosion, could have serious implications on a wide variety of natural and human systems, including surface transportation.

As noted above, worldwide, the transportation sector is one of the largest emitters of greenhouse gases. In the United States, transportation accounts for approximately 28% of all GHG emissions. Due to the disproportional energy consumption of the United States as compared to the rest of the world, this translates to roughly 6% of global CO$_2$ emissions (1, 2, 3). In addition, transportation-related CO$_2$ emissions have begun rising dramatically throughout the U.S. in recent years because of rapidly growing vehicle miles traveled (VMT) and a national average fuel economy that has not improved significantly (4, 5, 6).

Most scientists agree that the continuing growth in both the rate and total amount of GHG emissions will likely increase the magnitude of climate change effects and thus the exposure of the transportation system to corresponding environmental threats. The nature of these climate threats will vary from region to region, generally depending upon an area’s geographic layout, typical climate conditions, and latitude, among other factors. In response, there is now discussion among the transportation community about the need to develop adaptive strategies to increase the resilience of the transportation system to likely climate change threats (7, 8).

Given that the relationship between greenhouse gas emissions and the operation of transportation systems is well-known, one could surmise that there is a real need for the transportation planning process to consider surface transportation’s influence on and response to a changing climate. This is especially true given that many participants in the climate change debate view a reduction in vehicle miles traveled (VMT) as one of the major strategies for reducing GHG emissions. And it is transportation planning agencies that focus on investment programs and operations strategies that will affect VMT in any given jurisdiction. Although it is difficult to predict with certainty how the transportation policy environment in the United States will address climate change and greenhouse gas
emissions in future years, it seems likely that at some point in the near future the federal government will require state and metropolitan planning organizations (MPOs) to examine and assess the consequences of different transportation plans and investment programs from the perspective of their impact on GHG emissions. This would be similar in concept to the air quality provisions of previous federal transportation legislation. This paper investigates current metropolitan planning organization (MPO) and municipal efforts to incorporate greenhouse gas emission considerations into the transportation planning process, and recommends actions that will make the linkage between transportation planning and GHG analysis/climate change adaptation more substantive.

A PERSPECTIVE ON STRATEGIES FOR DEALING WITH GHG EMISSIONS

Very little research has been conducted on how MPOs and local governments are addressing GHG emissions and climate change in the transportation planning process. This section offers a framework for identifying the different types of GHG reduction strategies that could be included in a transportation planning process. This framework is then used to determine which strategies may be of use specifically at the metropolitan and local levels. Two types of strategies are discussed, actions aimed at transportation system adaptation and strategies to mitigate GHG emissions originating from the surface transportation system.

Adaptation Strategies

Even if greenhouse gases were no longer emitted at current levels, global temperatures are predicted to rise over several centuries “due to the time scales associated with climate processes and feedbacks” (1). Such temperature increases will likely intensify weather events such as rainfall, flooding, wind, storm surge, as well as expedite coastal erosion and permafrost degradation rates (8, 9). Adapting transportation infrastructure and operations to such damaging effects of climate change should become an increasingly important planning concern. For example, several states have either completed, are working on, or have recommended climate adaptation plans (10 - 14).

Creating an adaptation plan is certainly no simple task, especially considering the uncertainties involved in pinpointing specific climate risks. The U.S. Climate Change Science Program’s (USCCSP) recent report, Gulf Cost Study, Phase I, advocates that a risk management methodology, rather than current deterministic methods, should be used to provide better information on climate-related risks (7). Figure 1 illustrates such a risk management conceptual framework, which is adapted from the USCCSP report. The purpose of such a risk management framework is to develop adaptive strategies in response to any and all identified climate risk. The strategies should consider the resilience of the transportation system, which includes infrastructure, operations, and maintenance, as well as other concerns such as planning horizons and budget constraints.

The risk management framework begins with defining an area’s risk, which is the product of exposure likelihood and damage or disruption costs characterized by transportation facility vulnerability (7). Estimating the level of projected exposure to climate hazards is the most ambiguous of all conceptual factors due to the inherent
uncertainties of climate science, especially at the metropolitan and local level. Some scientists have suggested that the precision of small scale climate analyses is improving, but variability even within regions (such as local elevation changes) generates further difficulty in assessing true climate risks (8). Subsequently, a qualitative assessment of likely effects may be the best option until regional analysis tools become more precise and widely available. Vulnerability, a function of location and integrity of infrastructure and the ability of transportation operations to withstand disturbance, is the second component of risk and would ideally be determined through a repeatable asset management process (7).

Resilience, a concept that defines more than just physical strength, helps define the true costs associated with potential risk. According to the USCSSP report, transportation resilience is generally a function of repair/replacement issues, social and economic resources, and network connectivity and redundancy (7). In other words, the transportation system’s resilience is defined by its ability to recover from an incident or crisis. The “point where a stimulus leads to a significant response,” otherwise known as a threshold, can be identified once risk and resilience have been defined. Thresholds, when considered within the umbrella of planning goals and objectives and organizational characteristics, leads to adaptation strategies. The three adaptive strategies included in the framework and consistent with the USCCSP report are to protect, accommodate, or retreat (7):

![FIGURE 1 Conceptual Risk Management Framework](source)

Source: Adapted from (7)
Protecting facilities would most likely be reserved for infrastructure that is of critical importance or expensive to replace or repair, or transportation operations that are vital to the well being of an area.

Accommodating means to accept the risk and live with it as best as possible (e.g. coastal evacuation plan).

Retreating, considered a last resort, involves terminating the use of a facility. Once abandoned, replacement infrastructure may be built in a location that is less vulnerable, a practice recommended by Meyer (9).

The risk management conceptual framework represents an iterative process because the adaptive strategies will ultimately redefine a region’s vulnerability (e.g. developing more durable facilities) as well as aspects of its resilience both at the facility level (e.g. longer replacement timeframes) and the systems level (e.g. new operational plans or increased network redundancy). A review of the sparse literature on transportation system adaptation to climate change indicates that adapting transportation infrastructure and operations to climate change will be difficult, but not impossible. The authors of the USCCSP report point out that addressing such uncertainty is within the current ability of transportation planners. As noted by these authors, “Transportation decision makers are well accustomed to planning and designing systems under conditions of uncertainty on a range of factors – such as future travel demand, vehicle emissions, revenue forecasts, and seismic risks” (7).

Mitigation Strategies

The Kyoto Protocol, the most well-known international effort to reduce future GHG emissions, became active for many countries in 2005. Although the U.S. government has yet to sign the Protocol, many states and cities have launched initiatives to reduce GHG emissions in their jurisdiction. These include such efforts as the Western Climate Initiative (15) and The U.S. Mayors’ Climate Protection Agreement (16). A common component of these regional initiatives is a cap and trade system where GHG emissions are capped and permits that reflect the unique emissions of private companies or other organizations are distributed and traded, thus providing a monetary incentive to pollute less.

Cap and trade systems are often mostly concerned with mitigating power generation and industry emissions rather than transportation sources. This is not to say that the transportation sector would not have an important role in any national cap and trade program, but simply that there are additional mitigation strategies available in the transportation sector, which generally include the improvement of vehicle and network efficiency, lowering carbon intensity of fuels, enacting other governmental policies and programs, and reducing vehicle miles traveled (VMT) (17-19).

Regulating vehicle technology and fuels, strategies that arguably could have the greatest impact on GHG emission reductions, would most likely occur at the federal or state levels. Current federal examples of such mitigation strategies include the recent changes to the Corporate Average Fuel Economy (CAFE) standards and the national
biofuel production targets, both of which are part of the *Energy Independence and Security Act of 2007* (EISA) (20). It should be noted that life cycle GHG emissions from biofuels may be higher than gasoline based upon a variety of factors such as land use changes, manufacturing processes, and the amount of energy input required (21). Other governmental mitigation policies include CO₂-based vehicle taxation reform, fuel taxes, better vehicle component standards supported by tax incentives, and driver training programs (22).

A review of state and metropolitan transportation plans conducted for this study showed that, for those plans that addressed climate change, reducing VMT was the most often stated road-related objective in slowing GHG emissions. Metropolitan and local level governments are best suited for developing VMT reduction strategies by providing alternative transportation, developing pricing and incentive schemes, and coordinating land use and transportation planning. Examples of pricing and incentive schemes included congestion charges, higher parking rates, pay-as-you-drive insurance, high occupancy toll (HOT) lanes, parking cash out, commuter benefits, and ridesharing services.

In the long run, influencing urban form and land use patterns could be an important strategy for decreasing the rate of VMT increase; yet, such an approach might be the most difficult to implement. The means of implementing such a strategy would be to modify local land use ordinances to encourage compact development patterns (i.e. smart growth), which, over time, would be expected to result in less driving and fewer GHG emissions. There is some evidence to support this observation. A recent comparison between the ten most sprawling and compact metropolitan areas showed that, on average, VMT per capita was 22% less in compact metropolitan areas (22). However, coordinating the agencies having responsibility for transportation planning (state governments and MPOs) with those in charge of land use planning (local governments) remains a difficult challenge.

**LINKING TRANSPORTATION PLANNING AND GREENHOUSE GAS EMISSIONS REDUCTION: A CONCEPTUAL FRAMEWORK**

Given the importance of the transportation system to greenhouse gas emissions, climate adaptation and GHG mitigation strategies need to be considered within a broad transportation planning framework that examines all the different factors and variables that influence system performance. The conceptual transportation-planning framework shown in Figure 2 has been used for considering how a variety of policy issues and topics can be considered by the transportation planning process (23-25). This paper uses this same conceptual framework as an organizing concept for examining key components of the planning process with respect to how climate change considerations could be incorporated into each step of the process, with a focus on metropolitan and local level applications. For a general discussion of each of the framework’s steps, refer to NCHRP Report 541, *Considerations of Environmental Factors in Transportation System Planning* (23).
In order to investigate current efforts to incorporate climate change considerations into transportation planning, a review of available online material (such as long-range plans, transportation improvement programs, other relevant documentation) was conducted for a set of MPOs and domestic and international cities. The 60 most populous MPOs were targeted, in addition to 13 domestic and 27 international cities selected from an internet search for their climate change preparedness. The cities (not MPOs) in the U.S. were selected based on the fact that they had an adopted climate action plan, which included transportation strategies (not surprisingly, the cities were those most known for progressive planning—Berkeley, Boston, Boulder, Cambridge (MA), Denver, Madison (WI), Minneapolis-St. Paul, New York City, Portland, Sacramento, San Francisco, and Seattle). The researchers realize that this sample is a biased sample, however, the cities were selected simply to see what types of approaches and strategies could be incorporated into Figure 2. For international cities, a language translation software was used when international information was not in English.

Material from this search process that illustrates how climate change and/or GHG emission reductions have been considered in the transportation planning process is used in the following sections. Not all of the examples found from this international search are presented in this paper; simply those that best illustrate that particular planning step. A more detailed explanation of the methodology and characteristics of the case study cities is found in (26).

It should be noted that, in general, many of the transportation plans and much of the technical documentation, especially for U.S. metropolitan areas, did not provide a detailed examination of GHG emission or climate adaptation strategies. Thus, the following illustrations used for each step in the transportation planning process are not intended to describe the state-of-practice, but simply illustrate how GHG emission...
strategies and/or climate change can be incorporated into that planning step. In some sense then, the following description provides a composite planning process consisting of different "best practices" from jurisdictions around the world.

Vision

The initial step in the transportation planning process is developing a vision of what the community wants with respect to its quality of life or for transportation system performance. The internet search found only a few MPOs and cities that included climate change considerations into their visioning process. For example, the Boston Region Metropolitan Planning Organization (BMPO) explicitly mentioned CO\(_2\) reduction and strategic mitigation policies within its environmental vision, while the climate vision of the Chicago Metropolitan Agency for Planning’s (CMAP) long range plan was more general and open ended (27, 28). Both the BMPO and the CMAP featured public outreach campaigns as portions of their vision development, with the CMAP going one step further by holding a visioning event where attendees could electronically vote and express their opinions in response to alternative visions of the region’s upcoming long range growth plan.

The search also found that the source of a climate change vision could vary from one location to another. The New York Metropolitan Transportation Council (NYMTC) compiled a list of overarching trends and issues that could influence its long range plan, and mentioned that the driving force behind its climate change considerations was the New York State Energy Plan (29). The City of Boston’s climate change vision was based on an executive order from the mayor (30). It seems likely that agreements such as the U.S. Mayors’ Climate Protection Agreement (16) will foster additional climate change visions that will be incorporated into local planning initiatives.

Goals, Objectives, and Performance Measures

Many of the MPOs and cities that discussed climate change in their plans included goals and objectives pertinent to mitigation or adaptation, though mitigation goals and objectives were far more frequent. Many of these plans identified GHG emission reduction targets. These reduction targets varied greatly, but were usually not lower than the targets established by the Kyoto Protocol. In some cases, the targets were greater than those established by the Kyoto Protocol, with the most often stated reason being the jurisdiction’s or organization’s desire to become a leader in environmental stewardship. In a few cases, the targets were adopted because of national government (for international cities) or state mandates. The most aggressive GHG reduction target encountered in the search process was from Rotterdam, The Netherlands, where a target was set of achieving a 50% reduction in CO\(_2\) emissions below 1990 levels by 2025 (31). However, like most reduction targets, this included more than just the transportation sector -- 83% of Rotterdam’s total CO\(_2\) reduction is expected to come from industry, with the remaining 17% attributable to the transportation and water sectors. The mitigation of CO\(_2\) emissions was found in every case to come from a variety of sectors, including transportation, industrial, residential, agricultural and energy.
The review of plans that did include GHG emission reduction goals and objectives found that the common objectives to meet GHG mitigation targets included improving vehicle fleet efficiency through technological and fuel alternatives in addition to actions aimed in reducing VMT. Coordinated land use and transportation investment decisions were usually included within goals and objectives, but were often not framed by the issue of GHG emission mitigation.

Transportation system adaptation to climate change was not a topic found in the goals and objectives very many of the documents reviewed. The lack of available information and the reliability of climate science were usually cited as impediments to including adaptation considerations. Nevertheless, several organizations were found to have begun identifying adaptation goals and objectives. The City of Berkeley’s Climate Action Plan identified the need to assess the city’s vulnerability to climate change impacts and create an adaptation plan (32), while the Puget Sound Regional Council (PSRC) and Toronto’s Metrolinx discussed aspirations for adaptive planning that would reduce uncertainty over time and eventually result in more resilient infrastructure (33, 34). Other organizations, such as Portland’s Metro, included goals to reduce the vulnerability from natural disasters and terrorist events (35). Such goals could most likely accommodate climate change adaptation quite well.

Given the discussion above, it is no surprise that the search found that performance measures relevant to climate change were exclusively related to mitigation objectives. The most common mitigation performance measures were defined as change in GHG emissions relating to changes in such things as VMT, number of trips, trip length, and modal split. More direct performance measures included total GHG emissions per year and energy efficiency and use.

Analysis

The review found that those organizations analyzing the GHG emissions impact of different strategies did so primarily with models and tools that have been part of the analysis foundation of transportation planning for several years. For example, the Atlanta Regional Commission (ARC), the MPO for the Atlanta metropolitan area, recently completed a greenhouse gas analysis for a planning horizon year of 2030 (36). The ARC used fleet characteristics and average regional fuel economy in conjunction with the EPA’s Mobile6 emission modeling software to calculate emissions factors. The ARC then utilized its travel demand model and a variety of land use scenarios to estimate future travel growth and VMT in the metropolitan region. GHG emissions over the planning timeframe were then estimated using both the VMT figure and emission rate factors. The New York Metropolitan Transportation Council (NYMTC) conducted a similar analysis, but instead of using Mobile6, the NYMTC opted to calculate energy use using the travel demand model outputs of VMT and speed (37). The NYMTC then converted energy use into GHG emissions.

While the mitigation analysis approach for those metropolitan areas or cities examining GHG emissions and climate change was common among the transportation planning organizations examined, adaptation analysis was difficult to find. Perhaps this is not too surprising given that the agencies most concerned with adaptation strategies
would be those that own and operate the transportation system (that is, state departments of transportation) and thus this topic might not be of interest to planning organizations. The several instances of what could be considered adaptive climate change analysis were primarily concerned with assessing exposure to flooding. The Brisbane City Council (Australia) borrowed a report by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) that investigated the exposure to the effects of climate change in the State of Queensland, Australia (38). The report discussed the projections of Queensland’s future climate and produced flood maps of the Brisbane area. In London, United Kingdom, the London Climate Change Partnership qualitatively investigated the effects of climate change on London’s transportation systems (39). The report looked into several case studies concerned with excessive heat and flooding and presented qualitative conclusions coupled with recommended actions. None of these analysis methods were definitive in assessing transportation system risks, but did represent a step in the direction for adaptation planning.

**Strategies Identification**

A common approach for assessing potential mitigation strategies was the development of alternative scenarios, each with its own unique combination of projects, land use configurations and alternative improvement strategies. Each strategy was then analyzed with respect to relative GHG emissions. No process was found were alternative scenarios were solely focused on lowering GHG emissions. However, some organizations noted that reducing GHG gases were more predominate in one scenario over another due to the differing strategies and transportation projects included. Toronto’s Metrolinx utilized this alternative scenario approach for analyzing different strategies, and found that one of its three growth scenarios was predicted to meet Ontario’s GHG emission reduction target of 20% below 1990 levels by 2020 (40). Other organizations (e.g. the NYMTC and the San Joaquin Council of Governments or SJCOG) identified alternative transportation strategies that were supportive of their respective state reduction targets as well (41, 42).

Identifying strategies can also be an iterative process, as demonstrated by the efforts of Transport for London (TfL) (43). For its Transport 2025 plan, the TfL initially conducted a GHG analysis of one scenario, known as the Reference Scenario, and concluded that this scenario would not come close to realizing the mayor’s GHG reduction goal. In response, TfL identified six strategies that would exceed emissions reductions relative to the Reference Scenario. One of these strategies focused on providing new capacity primarily in the form of public transportation, which resulted in the TfL analyzing three capacity expansion scenarios. The agency found that the scenario that included the most expansion of public transportation came closest to meeting the mayor’s GHG emission reduction goal.

With respect to climate change adaptation strategies, very few metropolitan or local plans identified such strategies. In its sustainability document, PlaNYC in New York City identified three general adaptation strategies that incorporated considerations for the transportation system (44). Based on one of the adaptation strategies, New York City created a Climate Change Advisory Board with the purpose of producing an adaptation planning framework for the Office of Long-Term Planning and Sustainability.
The framework is be centered on a risk management and cost-benefit analysis through the use of explicit performance measures, but first will require a scoping study to define a planning methodology. Additionally, the New York State Energy Plan includes language that suggests adaptation strategies for transportation infrastructure could possibly appear in future NYMTC plans.

Evaluation

The evaluation process assesses the relative merits of one alternative or strategy over another. This process is based on evaluation criteria or measures of effectiveness that form the basis for the comparison. For those planning efforts that reached a formal evaluation of scenarios or GHG emission reduction strategies, the most used criterion was the change in CO\textsubscript{2} emission levels among the considered alternatives. The BMPO and the PSRC offered good examples of how GHG mitigation strategies were incorporated into the evaluation process (27, 45). The BMPO evaluated all of its highway and transit projects before they were included in the final recommended transportation plan using different highway and transit criteria. Highway projects were evaluated with 18 different evaluation categories, including air quality (which included CO\textsubscript{2}), with each category receiving a score ranging from -3 to 3. Transit projects, on the other hand, were not assigned scores, but were instead evaluated qualitatively over seven categories (which included air quality), meaning that CO\textsubscript{2} emissions reductions were given a larger weight for transit projects than highway projects. The PSRC assessed four growth alternatives based upon several evaluation approaches. Evaluation criteria included the mitigation of GHG emissions in addition to other supportive measures such as changes in travel demand characteristics, energy use, and land use.

Other MPOs that identified climate change as a transportation challenge compared and contrasted projects and alternatives with more general environmental, air quality, and land use evaluation criteria. While many of these metrics were related to GHG emissions, it was often the case that explicit changes in CO\textsubscript{2} emission levels were not estimated.

In contrast to MPO plans, municipal climate action plans explicitly identified strategies that were to form the basis for meeting the plan’s objectives. In these cases, where the identification of the strategies was not discussed from the perspective of any evaluation process that preceded their selection, the criteria used to describe the strategies included such factors as implementation feasibility, cost-effectiveness, and viability, as demonstrated by the City of Denver Climate Action Plan (46).

FORMING A CLOSER LINK BETWEEN TRANSPORTATION PLANNING AND GHG EMISSION REDUCTION AND CLIMATE CHANGE CONSIDERATIONS

This paper has presented the results of a search of transportation planning efforts in a large number of U.S. metropolitan areas and U.S. and international cities with the aim of identifying best practice examples of how GHG emission reductions and climate change considerations can be incorporated into the transportation planning process. As such, the search represents a snapshot in time of what metropolitan areas and cities are
considering with respect to mitigation and adaptation strategies, at least as they are reporting them in their literature. It is likely that many planning studies are examining the GHG reduction potential of different strategies, but have not yet reported them (although this is not likely the case for adaptation strategies, which seem to be of less concern to most planning agencies). Thus, this paper cannot be conclusive with respect to the state-of-practice concerning GHG emission and climate change strategies as they relate to transportation planning. However, the use of the conceptual planning framework does lead one to suggest, based on what was found in the search process, efforts that can be undertaken to assess more systematically a concern for transportation’s role in reducing GHG emissions and preparing for climate change impacts on transportation system performance.

Several recommendations can be made in terms of encouraging a more focused consideration of GHG emissions and climate change in the transportation planning process. It should be noted that the following recommendations are made with a generic planning process in mind, and do not consider the implementation feasibility with respect to individual agencies or organizations. Thus, it is likely that for smaller MPOs and jurisdictions, many of these recommendations would be beyond the agency’s ability to implement given limited resources.

**Vision**

- Incorporate climate change considerations and the role of the transportation sector in the visioning process for transportation planning. This effort should not only examine transportation’s role in GHG emission mitigation, but should also include climate change adaptation.

- This participation in the visioning process should be informed by the best scientific information available to the transportation profession. It is thus probably necessary for the transportation planning agency to prepare materials on the “facts” associated with climate change.

**Goals, Objectives and Performance Measures**

- Identify current goals and objectives whose ultimate attainment reinforces the desired achievement of GHG emission reduction. Articulate what supportive role each such objective has with respect to this desired reduction.

- If approved by policy makers, include GHG emission mitigation as one of the planning study’s goals and objectives.

- If approved by policy makers, include the likely effects of climate change into existing goals and objectives pertaining to natural disasters, security threats, and preservation of existing transportation infrastructure.

- For those planning processes that occur within a broader climate change context (e.g., the state government has established a policy on GHG emission reductions), establish GHG emission reduction targets for the metropolitan area.
• Include performance measures for both GHG emission mitigation and climate change adaptation that influence and track progress towards meeting related goals and objectives (e.g. land use and transportation integration, parking supply and ratios, resilience of transportation system, and percentage of facilities built outside flood or high risk areas).

**Analysis**

• Incorporate GHG analysis into the planning analysis process. If the U.S. EPA establishes GHG emissions targets or standards, such an analysis would include the degree to which such standards are met in the study area.

• For longer term consideration, analyze the effects of urban form and land use patterns on GHG emissions and the consequences of climate change.

• Collect data concerning exposure to the effects of climate change and the vulnerability of the transportation system, which could lessen uncertainties over time.

• One of the important challenges in the analysis process will be identifying the cost effectiveness of different mitigation strategies. It is likely, however, that such information will be critical for informing decision makers on what strategies would make most sense for their jurisdiction. The transportation planning agency should provide such information (to the best of its ability to estimate it) so that decision makers are aware of the costs and levels of effectiveness associated with different strategies.

• Introduce a risk management planning process into transportation systems planning, as illustrated in Figure 1 (in this instance, such an approach would be considered for the larger metropolitan planning organizations in areas more prone to climate change effects).

**Strategies Identification**

• Identify potential adaptation strategies as part of a risk management analysis process, as illustrated in Figure 1.

• Include a climate change alternative in scenario planning to achieve a better understanding of how transportation investment decisions affect and respond to climate change, assuming the study has access to valid analysis tools and data.

• Incorporate GHG emission reduction strategies within the scope existing planning processes and procedures where appropriate. For example, in the United States, the federally required Congestion Management Process for areas over 200,000 population could include such strategies given that it already examines strategies that focus on reducing all types of vehicle emissions.
Evaluation

- Include the GHG emissions mitigation as part of the air quality, transportation alternatives, and land use evaluation criteria.
- Include adaptation to the effects of climate change as part of the safety, security, and preservation evaluation criteria.
- Through the policy making process, assign weights to the evaluation criteria so that projects and strategies that help reduce GHG emissions or respond to climate change adaptation are more likely to result from the evaluation process.

This paper has been primarily concerned with the consideration of climate factors in the development of transportation plans. As shown in Figure 2, however, there are additional steps that follow the creation of such plans: programming (project prioritization), project development, and system monitoring. These three steps of the more broadly defined planning process were not examined in the search process with the same depth as the prior planning steps, but several general recommendations can be made concerning these activities as well.

Programming

- Include climate change adaptation as a component of system preservation so that it may receive higher priority.
- Assign weights to the prioritization factors so that projects and strategies that address the serious and probable threats of climate change are more likely to be implemented.
- Create a prioritization category that evaluates consistency with other climate change plans and initiatives.

Project Development

- Incorporate actions that reduce GHG emissions during project development and implementation, such as using recycled materials, incorporating low carbon cement mixtures, utilizing alternatively fueled vehicles, and purchasing locally or regionally manufactured materials.
- Incorporate adaptive design considerations during project development and implementation as discussed in (9).
System Monitoring

- Monitor the effects of efforts to reduce GHG emissions.
- Monitor and redefine the exposure to the effects of climate change as well as the vulnerability and resilience of the transportation system through a risk management process.

CONCLUSION

There is a common agreement among most scientists that climate change is real, has already begun, and can have serious implications on a wide variety of natural and human systems. Given the linkage between transportation and GHG emissions, the relationship between climate change and transportation is particularly important and thus the need for considering transportation-related GHG emission reduction and climate adaptation strategies in the transportation planning process. Incorporating climate change considerations into the planning process would provide the opportunity for transportation planners and decision makers to best develop the most cost effective strategies in the context of all the other goals that are guiding the planning process.

The review of readily available transportation plans and documentation of 100 transportation planning organizations revealed that climate change considerations are not yet incorporated into the transportation planning process in any significant numbers, especially with regard to climate adaptation policies. Only a few organizations have begun to develop adaptation methodologies and plans. On the other hand, GHG mitigation is more frequently included in the planning process, using existing data and analysis tools.

There is much room for improvement in terms of incorporating climate change into transportation planning. The above recommendations are initial steps for integrating GHG emission mitigation and climate change adaptation strategies into the planning process at the metropolitan and local level. It seems likely that as climate change continues to receive attention from both the public and policy makers that the transportation planning process will have to provide a platform for examining the most cost effective strategies that could be adopted by individual jurisdictions. The planning framework shown in Figure 2 provides a starting point for determining how the planning process can do this.

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