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Evaluating the cumulative impacts of a long range regional transportation plan: Particulate matter exposure, greenhouse gas emissions, and transportation system performance

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ABSTRACT

Long range regional transportation plans (LRTPs) are typically evaluated with performance measures calculated for the first and final years of the planning period. We call this the endpoint modeling method. Planning periods span 20–30 or more years, and therefore the endpoint method can overlook important changes that occur during interim years as well as cumulative impacts. For example, the impact of GHG emissions accumulating in the atmosphere and chronic or deadly diseases caused by exposure to high concentrations of toxic vehicle emissions cannot be reversed by plans that only perform well in the distant future. In this study we evaluate the annual performance of a LRTP created for the Albuquerque, New Mexico metropolitan area over a 28-year period by modeling land-use, travel demand, vehicle emissions and emissions exposure using an incremental and highly integrated land-use and travel demand modeling method. We call this the annual modeling method. We find non-linear and sometimes complex changes in annual emission rates, pollution exposure and other performance measures, indicating that end of period performance metrics may not be robust indicators of average and overall plan performance, which we argue are important considerations. Furthermore, we find that the annual modeling method has a large effect on land-use, traffic and emission exposure forecasts. By the plan's final year, the annual modeling method forecasts greater population and employment, and correspondingly greater traffic congestion and air pollutant concentrations in the region's largest activity centers than the endpoint modeling method, which is used by most MPOs.

1. Introduction

In the United States, Metropolitan Planning Organizations (MPOs) are responsible for developing coordinated, long range, regional transportation plans (LRTPs) for urban areas with 50,000 or more people. The plans define long term transportation goals and objectives for each region, a series of performance measures to track progress towards achieving those goals, and they provide fiscally constrained lists of transportation projects to be completed during the planning period. These plans are typically evaluated using regional travel demand models that forecast how a plan will affect traffic and travel behavior such as traffic volume, mode share, travel speed, and congestion. Travel demand modeling output may also be used with vehicle emission models such as the United States Environmental Protection Agency's (US EPA) Motor Vehicle Emission Simulator (MOVES) program or the California Air

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Resources Board's EMFAC model to estimate how much plans will contribute to regional greenhouse gas and criteria air pollutant emission inventories. While not common in practice, it is also possible to evaluate how a long range plan affects population exposure to vehicle emissions using an air dispersion model such as US EPA's AERMOD model (Poorfakhraei et al., 2017; Tayarani et al., 2016).

The typical approach for evaluating a LRTP is to measure the plan's performance against a baseline year and a business-as-usual or trend scenario. The plan is therefore evaluated at two points in time, the baseline year (i.e., the current year) and a planning horizon year that is at least 20 years into the future. This approach evaluates the two endpoints of the planning period, which presents an important limitation for evaluating a LRTP's performance, and particularly its air quality impacts. Under the typical "endpoint" approach, it is implicitly implied that the change in a performance measure between the beginning and end of the planning period is linear. That is, the plan that maximizes total welfare gain is the plan that achieves the greatest improvement in performance as measured at the end of the planning period.

However, changes in performance measures are likely to be non-linear over the planning period given the complexity of the transportation system. This is especially true when considering vehicle emissions and exposure. Not only do factors that affect emission rates and exposure such as traffic volume, speed, mode share, and the location of the population change overtime but so do vehicle technology and emission standards that also affect vehicle emission rates (Poorfakhraei et al., 2017; Tayarani et al., 2016). It is therefore possible that a plan that performs relatively poorly at the end of the planning period may have performed relatively well during the interim years and vice versa. If maximizing welfare is the main goal of regional transportation planning, then evaluating performance measures throughout the planning period of an LRTP should provide a more robust and accurate evaluation.

Measuring air pollutant emissions and changes in air quality over the term of an LRTP is also important because their impacts on the environment and public health are often long lasting and irreversible. First, consider greenhouse gas (GHG) emissions. Most GHGs persist in the atmosphere for a relatively long period of time (e.g., carbon dioxide released today can remain in the atmosphere for thousands of years (Solomon et al., 2009)). Thus, the ability of a plan to reduce the accumulation of GHGs is much more important for mitigating climate change risks than achieving a particular emission rate at a particular point in time. An irreversible and damaging accumulation of GHGs could be released by the time low emission rates are achieved at the end of a planning period. GHG emission rates may also rise in the future beyond the planning period. Toxic vehicle emissions also present an, at least partially, irreversible impact. For example, exposure to particulate matter from vehicle emissions has been associated with a wide range of negative health outcomes (e.g., see reviews by the Health Effects Institute (2010) and Brugge et al. (2007)). The impacts of these negative health outcomes on people's lives are, for the most part, not undone if air quality is improved in the future. On the other hand, other common transportation planning goals, such as reducing traffic congestion and providing greater mobility, do not necessarily impose long term damage and are relatively reversible.

Annual average and cumulative performance measures may be a more robust way to evaluate the overall performance of LRTPs and they can be calculated using models and analytical methods currently available to most transportation planning agencies. A travel demand and land-use model for the region of interest are required. Vehicle emission and air quality models are also required, and they are freely available from the U.S. Environmental Protection Agency. In this paper we demonstrate how these models can be used to evaluate the annual and cumulative impacts of an LRTP and discuss how this information can be used to perform a more robust analysis of LRTPs.

An important component of our modeling approach is the use of an integrated travel demand and land-use model. This model integration is critical for understanding how changes to travel demand and land-use co-evolve over time as population grows and new transportation infrastructure investments are made (Iacono et al., 2008). For example, while it is well established that highway and transit capacity expansion and congestion relief projects can spur induced demand by lowering travel costs (Cervero, 2003; Duranton and Turner, 2011; Noland, 2001), traditional travel demand models only capture induced demand from traffic re-routing and mode shifts (Kitamura, 2010). An integrated transportation and land-use model can capture how a highway capacity project that reduces congestion will increase the likelihood that land along the highway is developed, leading to induced demand and increasing congestion in the future, all else equal. Modeling the evolution of travel demand and land-use also allows us to track year-by-year changes in transportation system performance measures. Furthermore, combining the integrated travel demand and land-use modeling results with vehicle emission and an air dispersion modeling allows us to track changing concentrations of air pollutants across the planning area and the location of the population exposed to these emissions.

While prior studies have used integrated travel demand and land-use models to evaluate a range of transportation planning and policy questions (Abraham and Hunt, 1999; Kakaraparthi and Kockelman, 2011; Kitchen et al., 2011; Waddell et al., 2007), these analyses, like current LRTP practice, have used an "endpoint" perspective. While it is common to model some intermediate years en route to the final year in the planning period, the purpose in most studies is primarily for updating the land-use model with revised accessibility data. In most modeling systems, the land-use model requires travel costs (i.e., logsums) from an external travel demand model (Iacono et al., 2008). This requires the land-use and travel demand models to be iterated periodically, where the travel demand model is updated with revised population and employment data from the land-use model and then run to provide the land-use model with revised travel cost data. While interim year iterations create output that could be used to evaluate changes in the transportation system overtime, this is usually not done. For example, Kitchen et al. (2011) use an integrated land-use and travel demand modeling system to evaluate several regional transportation planning scenarios in the Seattle, WA metropolitan area over the period 2010–2040. They iterate the region's travel demand model with the UrbanSim land-use model every 5–10 years. Each planning scenario is then evaluated based on year 2040 performance metrics; interim year outputs are not discussed.

Many recent studies also demonstrate the value of integrating vehicle emission, air dispersion and travel demand modeling for better understanding the air quality and public health impacts of vehicle traffic and transportation planning strategies and policies (Beckx et al., 2009; Dhondt et al., 2012; Dons et al., 2011; Hatzopoulou et al., 2011; Lefebvre et al., 2011, 2013; Poorfakhraei et al.,