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Assessing the impact of traffic crashes on near freeway air quality

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ABSTRACT

As interest grows in eco-friendly green transportation systems, transportation management agencies have focused on effectively mitigating vehicle emissions. Extensive research has been conducted to enhance the performance of transportation systems in terms of environmental compatibility. A novel feature of this study includes considering crash occurrences when analyzing near-freeway air quality. This study quantifies the impact of traffic crashes on vehicle emissions and the associated near-freeway air quality. Both crash data and vehicle detection systems (VDS) data, which were obtained in 2012 from a Korean freeway located in a densely populated urban area, were used to determine the impact of traffic crashes on near-freeway air quality. MOVES and CALPUFF were adopted to estimate freeway emissions and air dispersion for crash-involved and crash-free traffic conditions. The contributing factors that affect the severity of emission dispersion were identified by regression analyses. Results show a community near freeways within a 1-km radius of crash locations was affected by traffic-related air pollution exposure. The regression analyses also showed crash characteristics, and weather characteristics affect traffic-related air pollution exposure areas. Finally, this study proposed traffic-related public health strategies to mitigate air pollutants generated from crash occurrences on freeways.

1. Introduction

Air pollution has become a major concern in urban areas, and vehicles are one of the main contributors to worsening air quality in these areas. As metropolitan areas expand, the population living and working in close proximity to roads is growing, and residents' concerns regarding air pollution in these areas have grown (Health Effects Institute, 2010). Traffic conditions are strongly associated with vehicle emissions. For example, congested traffic causes stop-and-go conditions and contributes to increasing vehicle emissions. Traffic crashes are important factors that change traffic conditions, often increasing vehicle emissions (Barth and Boriboonsomsin, 2008; Chung et al., 2013; Zhang et al., 2011; Sookun et al., 2014).

Numerous efforts have been made to identify the relationship between road traffic and air quality issues near roads. Previous studies suggested that 'near road' defined the area within 100–500 m of the roadway (Baldauf et al., 2008, 2009). The Korean Ministry of Environment defines near road as the area within 500 m of a roadway (Ministry of Environment, 2013). Traffic-related air quality issues were studied using three approaches; estimating vehicle emissions, measuring concentrations of air pollutants, and estimating concentrations of air pollutant using a simulation model. Some studies assessed traffic strategies using vehicle emissions. Al-Deek et al. (1995) evaluated the impact on air quality of rerouting traffic guided by the Advanced Traveler Information System (ATIS). Bartin et al. (2007) analyzed vehicle emissions to evaluate the impact of electronic toll collection (ETC) using a simulation

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model. Several studies have examined the air pollution concentrations near highways (Baldauf et al., 2013; Isakov et al., 2014). These studies used the observed concentrations of pollutants from monitoring stations for evaluating air quality near highways. However, the data collected from monitoring stations measures pollutant concentrations generated from all types of sources, including roadways. Previous studies attempted to estimate concentrations of traffic-related air pollutant using air dispersion models. Barth and Boriboonsomsin (2008) analyzed carbon dioxide in relation to traffic conditions such as congestion using detector data. Lin and Yu (2008) presented carbon monoxide (CO) hotspots and diesel particulate matter (PM) emissions in open road tolling design scenarios considering an air dispersion model. Rehimi and Landolsi (2013) developed a numerical model that simulates both road traffic and the dispersion of pollutant emissions using a Gaussian plume model. Batterman et al. (2014) estimated air pollutant concentrations using a hybrid modeling framework that included detailed inventories of mobile and stationary sources on local and regional scales. Shekarrizfard et al. (2016) proposed an integrated emission-dispersion model to determine near-road air quality.

Although numerous existing studies have analyzed emissions and dispersion based on changes in traffic conditions such as congestion or traffic management strategies, we are not aware of any study that has examined the relationship between air quality issues and traffic crashes that result in significant changes in traffic conditions. The impact of traffic crashes on air quality near roads is not evident in the literature. To address this issue, this study assesses the impact of traffic crashes on near-freeway air quality based on both crash data and vehicle detection systems (VDS) data obtained from a Korean freeway in 2012.

This study considers two pollutants: nitrogen oxides (NO_x) and particulate matter (PM). These two pollutants are heavily generated by motor vehicles and are associated with public health in local communities (U.S. EPA, 2010). The primary contributor of NO_x is motor vehicles, which generate 55% of NO_x emissions. If a residential area or school zone with a large population of children is located near a freeway or freight vehicle route, the risk of asthma and pulmonary disease increases (Gordian et al., 2006; Lin et al., 2002; Brauer et al., 2002). Brauer et al. (2002) reported that traffic-related NO_x caused asthma, colds, and flu in the Netherlands. Fine particles can enter the lungs and bloodstream and cause serious health problems such as asthma, nonfatal heart attacks, and premature mortality (Rehimi and Landolsi, 2013; Makler, 2004; Shields et al., 2013; Lewis et al., 2013). According to an existing study (Shin, 2007), the total mortality would increase by 4% if $PM_{2.5}$ increases to 10 $\mu g/m^3$. Therefore, both NO_x and PM should be studied because they can have significant negative impacts on public health (Pope et al., 2002; Bae et al., 2010; AirKorea, 2016). Existing studies imply that effective traffic management is fundamental for mitigating vehicle emissions, and efficient countermeasures must be created to promote public health.

This study employs the motor vehicle emission simulator (MOVES) to estimate freeway emissions for crash-involved and crash-free traffic conditions. Additionally, the California Puff Model (CALPUFF) is used to analyze air dispersion caused by crash occurrences. The contributing factors that affect the severity of vehicle emissions are identified via regression analyses, and traffic-related public health enhancement strategies are discussed.

The paper is organized as follows. First, an overview of the analysis framework is described. Then, the methodology section explains the concepts associated with the vehicle emission and dispersion analyses employed in the study, followed by a data section. Results and discussion are provided prior to drawing conclusions. Finally, future research directions are presented with the corresponding limitations of this study.

2. Methodology

2.1. Overall framework

This study evaluated near-road air quality resulting from crash-involved traffic conditions based on freeway VDS data, crash records, and meteorological information. The framework used to assess the impact of traffic crashes on near-freeway air quality consists of four steps. The first step is data set preparation. Traffic volume counts and speed data aggregated in a 1-h period were used to represent prevailing traffic conditions. Then, freeway crash records were matched with corresponding volume counts and speeds. Second, vehicle emissions were estimated in each section of freeway, which were defined as approximately 1-km sections covered by a VDS. MOVES was used to estimate emissions in this step. A lookup table of emission factors was used. Third, the severity of air pollution was identified based on the level of concentration. This study employed CALPUFF to analyze the dispersion of air pollution using emission rates obtained from the second step, meteorological data and geometric data. The dispersion model was used to identify the area exposed to air pollution. Then, estimated emissions and areas of influence for crash-involved and crash-free traffic conditions were compared. The final step identified the contributing factors that affect the concentration of air pollution based on regression analyses. The dependent variable in the regression analysis was the size of the spatial area influenced by air pollution. The results from the proposed analysis framework provided valuable information that was used to propose effective traffic-related public health policies. These policies include strategies for reducing emissions and exposure based on traffic management. Fig. 1 presents the framework of the study. More details about each step are presented in subsequent sections.

2.2. Vehicle emission and dispersion analysis

Air quality is defined in this study as the degree of air pollution based on meteorological conditions such as temperature, wind speed and direction. Unlike vehicle emissions analysis, which assesses the total amount of pollution, air dispersion analysis spatially identifies the locations severely affected by air pollution. Road users and near-road residents in affected areas are potentially at risk for respiratory diseases. The study used MOVES and CALPUFF to assess the impacts of vehicle emissions and dispersion. Details relating to each tool are presented in subsequent sections.