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A near-road modeling system for community-scale assessments of traffic-related air pollution in the United States

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ABSTRACT

The Community Line Source (C-LINE) modeling system estimates emissions and dispersion of toxic air pollutants for roadways within the continental United States. It accesses publicly available traffic and meteorological datasets, and is optimized for use on community-sized areas (100–1000 km^2). The user is not required to provide input data, but can provide their own if desired. C-LINE is a modeling and visualization system that access inputs, performs calculations, visualizes results, provides options to manipulate input variables, and performs basic data analysis. C-LINE was applied to an area in Detroit, Michigan to demonstrate its use in an urban environment. It was developed in ArcGIS, but a prototype web version is in development for wide-scale use. C-LINE is not intended for regulatory applications. Its local-scale focus and ability to quickly (run time < 5 min) compare different roadway pollution scenarios supports community-based applications and help to identify areas for further research.

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1. Introduction

Living, working, and going to school near roadways has been associated with a number of adverse health effects, including asthma exacerbation, cardiovascular impairment, and respiratory symptoms (see HEI, 2007 for a comprehensive review). In the United States, 30%–45% of urban populations live or work in the near-road environment, with a greater percentage of blacks, Hispanics, and low-income residents than whites living in areas of highly-trafficked roadways (Tian et al., 2012). Near-road studies typically use surrogates of exposure to evaluate potential causality of health effects (Lipfert and Wyzga, 2008). Surrogates include proximity, traffic counts, or total length of roads within a given radius around the impacted location (HEI, 2010; Ryan et al., 2007).

In the United States, modeling efforts related to a state or federal policy initiative (EPA, 2008) require detailed analyses using specific datasets and highly-structured models to produce the most accurate estimates possible of actual pollutant concentrations. Typical modeling efforts for these applications require the use of separate emissions and dispersion models, with subsequent visualization being performed separately as needed. Applications are often related to specific projects and regions, such as highway expansions or traffic re-routing for an urban area. Therefore, users might require modeling expertise to run the models and collect the local input datasets necessary for their performance, and then to subsequently interpret results (Cook et al., 2006).

Community groups are becoming increasingly active in local initiatives that seek to mitigate potentially harmful environmental conditions. Community-based participatory research is an example where community residents work directly with the scientific community to identify these situations. Studies are typically independent, locally-based, and solution-oriented. As such, they are not required to follow regulatory procedures to collect information and make decisions, but instead utilize information sources relevant to their defined objectives. While these sources may not be adequate to meet regulatory requirements, they can meet the goal of informing local decision making. For example, an integrated modeling system that includes an activity-based

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transport demand model, a traffic emission model, a dispersion model and a concentration measurement interpolation model has been developed and applied in Europe, in the regions of Flanders and Brussels, Belgium (Lefebvre et al., 2013). Another example of using models to inform local decision making is the CARBOTRAF system implemented and evaluated in Graz, Austria and Glasgow, UK with the purpose to reduce BC and CO_2 emissions and improve air quality by optimizing the traffic flows (Lefebvre et al., 2014). In community-scale modeling in support of local decision making, an accurate assessment of relative conditions (e.g., one area compared to another, or what-if scenarios that elucidate differences in two or more sets of conditions) can be sufficient for the user's needs. In these cases, simplified modeling systems can provide valuable insights to assist with the decision-making process.

Simplified models provide an opportunity to examine how changes in input parameters, such as vehicle counts or speeds, can affect results (Batterman et al., 2010). The structure of these models can vary depending on the developers or application. Typically, they maintain the same or similar algorithms most responsible for characterizing model uncertainty. Components that are not as influential in model performance or the desired outputs, or structured for a specific model function, could be omitted or parameterized (Batterman et al., 2010). Simplified modeling systems like C-LINE allow users to ask what-if questions, such as, “What will happen if diesel traffic doubles on this roadway?” or “How is near-road air quality affected by a traffic jam?” and then to assess the relative changes in near-road air toxics concentrations that could occur (Batterman et al., 2010; Mejia et al., 2011; Vette et al., 2013). For C-LINE, the user is not required to provide any input datasets, and they can manipulate the existing ones or upload their own if desired.

This paper describes the input parameters, analytical procedures, visualization routines, and software considerations for C-LINE, including a discussion of the dispersion algorithm and an example application for an area of Detroit, Michigan. C-LINE is being developed by the United States Environmental Protection Agency (US EPA, or EPA) Office of Research and Development (ORD) as part of the Sustainable and Healthy Communities (SHC) research program, which is designed to empower and inform communities by providing decision support tools, models, and metrics that promote efficient, balanced, and equitable sustainability initiatives (see http://www.epa.gov/research/research-programs.htm for more information).

2. Model inputs and outputs

This section describes C-LINE input variables and datasets, and the outputs provided by the modeling system. Potential future additions are described in Section 6 (Discussion). C-LINE automatically accesses publicly available datasets with nationwide coverage and provides results for the user-defined geographic area as both visualized maps and tabular data. Users are also able to upload their own (e.g., locally-derived) datasets on traffic activity and/or meteorology to perform model runs.

2.1. Emissions

C-LINE calculates emissions for each road segment using three inputs: 1) the road network (e.g., roadway types and locations); 2) traffic activity on the network (e.g., traffic counts); and 3) vehicle emission factors (i.e., emitted pollutants based on vehicle type, speed, and outdoor temperature). It currently accesses data from calendar year 2010.

2.1.1. Road network

The first input variable to consider is the road network for a given area. A road network is the system of interconnected roadways, and a description of their types (e.g., principal arterials such as interstates). The roadway files are cross-referenced with traffic activity data in order to determine the number and types of vehicles on each roadway. Road network is also used in the dispersion component of C-LINE in order to distribute receptor locations across the spatial domain (described below) where concentrations are calculated.

Road networks are downloaded as shape files from the Freight Analysis Framework (FAF), available from the U.S. Department of Transportation Federal Highway Administration (DOT-FHWA). Files provide a GIS-based centerline representation of the roadway network in the United States (see http://faf.ornl.gov/fafweb/Default.aspx for more information). The overall network is divided into approximately 171,000 links (or *segments*) representing nearly 448,000 miles of roads. Each road segment is also designated by type: urban or rural; arterials, collectors, and local. Arterials provide the highest level of mobility and highest speed for long uninterrupted travel, and include highways and interstates. Arterials are further classified as principal or minor. Collectors provide lower mobility than arterials, and are designed for lower speeds and shorter distances; they are generally two lane roads that collect traffic from local roads and distribute it to arterials. Collectors in rural areas are further designated as major or minor. Local roads are all public roads below the collector classification.

2.1.2. Traffic activity

Traffic activity describes the number, types, and speeds of vehicles on a given roadway and for a given time period. For example, one might expect a higher number of gasoline cars traveling at lower speeds on an urban highway during the morning commute. Therefore, in order to calculate emissions, one needs to determine the total number of vehicles, distribution of vehicle types, and vehicle speeds for a given time period and road segment.

In addition to the road network data, FAF also provides information on annual average daily traffic (AADT), which is then used to calculate vehicle miles traveled (VMT) for each road segment. VMT is AADT multiplied by the length of the road segment. As the name implies, AADT for a given road segment is the average number of vehicles that travel a road segment in a single day, based on the total volume of vehicular traffic for a year divided by 365 days. AADT is a rate that cannot be summed across all roadways, so VMT is a more useful measure of the total amount of traffic in a given area.

FAF does not include detailed fleet mix data (e.g., number of gas and diesel) for each road segment, but it provides distribution tables that describe the typical fleet mix for a given roadway type based on a classification of the roadway segments for each state (see http://www.fhwa.dot.gov/policyinformation/statistics/2010/vm4.cfm for more information). For example, an urban (rural information in parentheses) interstate for Michigan in 2010 had an estimated distribution of 72% (67%) passenger cars, 18% (19%) light trucks, and 7% (11%) combination trucks. Distributions from these tables are applied to the given VMT for a road segment to determine its fleet mix. Vehicle classes from FAF include passenger vehicles (cars, motorcycles, buses, and light trucks (two-axle, four-tire models)); single-unit trucks having six or more tires; and combination trucks, including trailers and semitrailers.

The fleet distribution tables provide a daily estimate of the number and types of vehicles on a given roadway. That total daily traffic count must then be allocated to different time periods throughout the day. For example, a road segment will experience the majority of its daily VMT on weekday rush hour periods during