Environmental Modelling & Software 64 (2015) 102–123

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Review

Modelling chain for the effect of road traffic on air and water quality: Techniques, current status and future prospects

Masoud Fallah Shorshani [a, b, c, *], Michel André [a], Céline Bonhomme [c], Christian Seigneur [b]

[a] IFSTTAR Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux, 69675, Bron Cedex, France
[b] CEREA, Joint Laboratory École des Ponts ParisTech/EDF R&D, Université Paris-Est, 77455 Marne-la-Vallée Cedex 2, France
[c] LEESU, École des Ponts ParisTech, Université Paris-Est, 77455 Marne-la-Vallée Cedex 2, France

ARTICLE INFO

Article history:
Received 18 June 2014
Received in revised form
30 October 2014
Accepted 17 November 2014
Available online 11 December 2014

Keywords:
Integrated modelling
Traffic
Emission
Air pollution
Water pollution

ABSTRACT

Modelling approaches for simulating air and stormwater pollution due to on-road vehicles are reviewed and discussed. Models for traffic, emissions, atmospheric dispersion, and stormwater contamination are studied with particular emphasis on their couplings to create a modelling chain. The models must be carefully selected according to the requirements and level of detail of the integrated modelling chain. Although a fair amount of research has been conducted to link air pollution and road traffic, many questions related to spatio-temporal scales, domains of validity, consistency among models, uncertainties of model simulation results, and interfaces between models remain open. The aim of this work is to review the current status of the relationships between traffic, emissions, air quality, and water quality models, to recommend modelling approaches and to propose some directions for improving the state of the science. The difficulties and challenges associated with model coupling are illustrated with specific examples.

1. Introduction

It is expected that in 2050 more than 70 percent of the world's population will live in urban areas. The large amount of vehicles in densely populated areas leads to traffic congestion and contributes to the deterioration of air (e.g., Zmirou et al., 2004) and stormwater quality (e.g., Obropta and Kardos, 2007). Thus, traffic is a major source of pollution in cities. Currently, traffic models can predict the position and kinematic parameters of the vehicles and emission models can estimate the amount of different types of pollutants emitted by vehicles, albeit with some uncertainty. Then, the dispersion and transformation of pollutants in the atmosphere can be modelled using atmospheric dispersion models and/or chemical-transport models. A fraction of the air pollutants deposits to surfaces by dry and wet processes. These pollutants may be entrained by the water runoff during rainfall events, which can be simulated by stormwater models. They may also be resuspended in the atmosphere due to mechanical disturbance (e.g., traffic, wind). Various models have been designed to simulate each of these phenomena; however, little work has been done to develop integrated modelling systems that can simulate the impact of traffic on both the air and water environments in urban areas. It is essential that such capabilities be developed and evaluated as their needs are primordial for the planning of the sustainable cities of the future. Thus, there is a need for a global and systemic approach of pollutant mitigation policies in urban areas in order to decrease globally their impact on the environment and human health.

Traffic pollutants are emitted by the internal combustion engine of the vehicles, tyre, clutch and brake wear, fuel evaporation, and road wear. Exhaust emissions consist mostly of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x:NO and NO_2), volatile organic compounds (VOC), particulate matter (PM), nitrous oxide (N_2O), ammonia (NH_3), persistent organic pollutants (POP) including polycyclic aromatic hydrocarbons (PAH), and metals. VOC are also emitted by evaporation. Non-exhaust emissions such as brake and tyre wear are also sources of PM. PM includes inorganic species, trace metals, and carbonaceous compounds. Emission factors are available only for the major air pollutants and large uncertainties exist for many air pollutant emissions.

---

* Corresponding author. CEREA, Joint Laboratory École des Ponts ParisTech/EDF R&D, Université Paris-Est, 77455 Marne-la-Vallée Cedex 2, France. Tel.: +33 637118758.

E-mail addresses: fallah.massoud@gmail.com (M. Fallah Shorshani), michel.andre@ifsttar.fr (M. André), celineb@leesu.enpc.fr (C. Bonhomme), seigneur@cerea.enpc.fr (C. Seigneur).

http://dx.doi.org/10.1016/j.envsoft.2014.11.020
1364-8152/© 2014 Elsevier Ltd. All rights reserved.

First, we present and classify the models for each phenomenon (traffic, emissions, air quality, and water quality) according to their input data and scales of application. Next, we discuss the strengths and weaknesses of these models and the major sources of uncertainties are identified. The level of confidence that one has in the various model inputs and components is qualified using the following classification: high (H), medium (M) and low (L) confidence. Then, we address the development of modelling chains and various approaches to link these models. Finally, we recommend further model development and suggest specific categories of models to build integrated modelling systems. Specific issues such as differences in PM size ranges relevant to air and water quality are identified and actions to resolve those issues are proposed. This work provides the basis to improve the integrated modelling approach to relate traffic to air and water pollution, which today is typically limited to spatially or temporally averaged conditions (average fleet composition, average traffic speed, stationary atmospheric conditions) and separate media (i.e., either air or water).

2. Model description

2.1. Traffic models

The simulation of traffic flow and speed can be conducted using a variety of traffic models that differ in terms of input requirements and detail in terms of output information (Treiber and Kesting, 2013). Three major classes of models can represent the behaviour of vehicles for various applications to an urban network:

2.1.1. Static models

Static models rely on the spatial distribution of population and calculate average traffic volumes in different areas of a network. Such models (e.g., VISUM, Fellendorf et al., 2000) are typically divided into four steps: trip generation, trip distribution, modal split, and assignment. The numbers of trips in each area of the network are estimated based on housing, office density, and their locations. These trips are used to construct an origin-destination (OD) matrix. The OD matrix, in combination with information regarding the availability of the different transport modes, user preferences, and speed flow curves, is used to assign travel according to modes and itineraries, assign traffic and vehicle flow to each link of the road network, and calculate travel times. These models offer a macroscopic description of traffic, but they are useful to provide a static description of the road traffic in terms of flow and speed over large spatial scales (e.g., city scales).

2.1.2. Dynamic models

Dynamic models describe the temporal variations of traffic conditions and how they affect vehicle movement. These models use an explicit representation of congestion and operate at a smaller spatio-temporal scale than the static models. They calculate the location and kinematic parameters of vehicles, which can subsequently be used to predict pollutant emissions and traffic noise as a function of space and time. They are discussed in greater detail below.

2.1.3. Aggregated dynamic models

Aggregated dynamic models (e.g., Daganzo, 2007) provide also an explicit representation of congestion by describing the temporal evolution of traffic states of a simplified road network (spatial aggregation). These models divide the city into neighbourhood-sized reservoirs (commensurate with a trip length) and shift the modelling emphasis from microscopic predictions to macroscopic monitoring. Upon the assumption of a homogeneous distribution of the traffic, it is possible to estimate the average speed and the congestion level as a function of time. These models are based on relationships between the amount of displacement per unit of time (generation) and the number of vehicles on the network (accumulation), which are denoted MFD (Macroscopic Fundamental Diagram), and traffic demand (OD-matrix) among different neighbourhoods. The typical application of such models is the evaluation of the level of congestion to reduce traffic.

We are interested here in dynamic models that should provide an appropriate description of the traffic conditions for an estimation of air pollution at a local scale. Dynamic models can be classified into three subcategories according to different aspects of traffic flow operations: macroscopic, microscopic, and mesoscopic.

(1) The macroscopic models (e.g., METACOR, Diakaki and Papageorgiou, 1996) use an aggregate representation of vehicles (vehicles are not followed individually) and the assumption of a continuous traffic flow based on a “homogeneous behaviour” of the vehicles. Thus, these models use variables such as traffic flow and vehicle density and the point of view is rather that of a continuum. That limits their ability to predict congestion that is mainly due to the interactions between vehicles. The Euler and Navier–Stokes equation of fluid dynamics describing the flow of fluids may also describe the motion of cars along a road. The three main variables of traffic (flow, vehicle density, and average speed) are connected by two fluid laws proposed by Lighthill and Whitham (1955) and Richards (1956) (LWR). This model can be adapted to represent the diversity of urban traffic situations (e.g., Leclercq and Bécarie, 2012). This system must be supplemented by an independent third equation (fundamental diagram (FD) of traffic flow) which describes a relationship between traffic flow and traffic density. Two classes of macroscopic models can be identified. The first class uses the sole mass conservation equation supplemented by suitable closure relationships that represent equilibrium states (first-order models). The second class uses a coupled system of mass conservation and momentum balance equations that represent equilibrium states or the behaviour of the flow acceleration (relaxation flow velocity) (second-order models). These models have been initially proposed by Aw and Rascle (2000) and Zhang (2002); i.e., they are often referred to as ARZ models. The main parameters for the implementation of macroscopic models include the fundamental diagram of traffic flow, OD-matrices, and the traffic control devices (e.g., traffic lights). The simulation outputs are traffic density for each road network segment as a function of time as well as the traffic flows simulated for those road network segments.

(2) The microscopic models (e.g., VISSIM, Fellendorf and Vortisch, 2010) take into account the time-space behaviour of individual vehicles under the influence of other vehicles in their proximity and their interactions with the road network. These models determine vehicle location, speed, and acceleration. There are two main classes of microscopic models: (1) microscopic models with macroscopic law, which in fact correspond to a Lagrangian representation of macroscopic models, and (2) microscopic models that are built up using submodels that control specific tasks in the simulation process. The car-following model is one of the most important submodels. A car-following model controls the driver's behaviour with respect to the interactions between two successive vehicles. Other typical submodels simulate the effect of overtaking as a function of vehicle categories and incoming traffic or the response of vehicles to the control systems such as traffic lights. An intersection submodel