14th International Conference on Meteorology, Climatology and Atmospheric Physics

CONFERENCE PROCEEDINGS

October 15–17, 2018
Alexandroupolis, Greece

«Konstantinos Kourtidis, Panagiotis Nastos, Moustris Kostas, Dimitra Founda, Anastasia Paschalidou (Editors)»

www.comecap2018.gr
Integrated modelling tool for the analysis of traffic-congested roads in urban centers.

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Abstract Traffic-congested roads are one of the main problems in cities due to their influence on air pollution, greenhouse effect and health. The REMEDIO project, co-founded by the Interreg Med Programme, aims to develop an Integrated Modelling Tool (IMT) to analyze the current situation and possible mobility soft actions for a transition to a low-carbon scenario. This tool is implemented through FIWARE platform that allows users to calculate by several modules the traffic effects on emissions, fuel consumption, noise, air pollutant concentrations, health effects and costs from the information of the simulation area. The first steps are the introduction by the user of necessary inputs to define the zone (road definition, special lanes, traffic lights) and traffic data (vehicle technologies, flows). Traffic calculations within the tool are made from the open-source software SUMO, modules are programmed in Python. Within IMT, SUMO is linked with the models ‘Passenger Car and Heavy-Duty Emission Model (Light)’ (PHEmlight), ‘Pollutant dispersion in the atmosphere under variable wind conditions’ (VADIS) and a noise module based on the EU ‘Common Noise Assessment Methods’ methodology (CNOSSOS-EU). After simulation and analysis of results, users can simulate the implementation of soft actions to compare different solutions to reduce the traffic effects.

1 Introduction

A novel Integrated Modelling Tool (IMT) has been developed as a tool for mobility decision making within the REMEDIO project (REgenerating mixed-use MED urban communities congested by traffic through Innovative low carbon mobility sOlutions), co-founded by the Interreg Med Programme. The IMT is composed by 8 individual modules that cover the main impacts of traffic on the city and its inhabitants, namely, energy efficiency, noise, atmospheric pollution emission and carbon footprint, air pollution dispersion, freight streamlining, cost and health impact.
As result, user can simulate the main effects (each one of the individual modules) caused by traffic in congested-road from a common platform, which is developed to facilitate the user interaction with the core models within a step by step process. Fig. 1 shows a global resume of IMT conceptual model. The tool is implemented within FIWARE platform that allows users (i.e. technician responsible for traffic management from a certain city), to calculate by means of several modules the traffic effects on emissions, fuel consumption, noise, air pollutant concentrations, health effects and costs from the information of the area to simulate.

![Fig. 1. Overall conceptual modelling approach](image)

The process is divided in 5 steps. Firstly, the user is asking to define the zone of study. The two first steps consist of the zone and traffic definition. A complete zone definition requires data about road length, number of edges and lanes, coordinates of traffic lights, stop signals and pedestrian crossing, specification of special lanes (i.e. bus lanes, bike lanes), slope, road surface material. In the step 2, vehicles technologies and traffic flows are introduced by the user. Traffic calculations within the IMT are carried out using the open-source software SUMO (Simulation of Urban MOBility). SUMO is developed in C++; it uses only portable libraries; it allows microscopic and multimodal traffic simulation and no artificial limitations in network size and number of simulated vehicles. A more detailed explanation of traffic simulation by using SUMO is showed in the following section.

After traffic calculations, the platform has the inputs needed for run each one of the IMT modules. Each individual module is programmed within the REMEDIO project by using open-source software (i.e. Python). For the pollutant emissions concentrations estimation, specific models are used as: i) the emission model ‘Passenger Car and Heavy Duty Emission Model (Light)’ (PHEMLight) and ii) the model ‘Pollutant dispersion in the atmosphere under variable wind conditions’ (VADIS) (coupling a boundary layer flow module with a Lagrangian dispersion module).

After simulation, results of each module are presented as graphics, figure or tables and the users can simulate a new situation by implementing soft actions to compare different solutions to reduce the impact of traffic effects.
2 IMT Platform

The Integrating Modelling Tool (IMT) is a platform designed to integrate a traffic simulator and a set of executable modules that provide the possibility of analysing the impact of traffic on the population.

The IMT has been developed as a web application based on an architectural pattern known as Model-View-Controller (MVC). This kind of architectural pattern divides an application into three interconnected parts: Model, View and Controller. The components of MVC framework and the programming languages used for their development are presented below:

- **Model**: Contains a representation of data managed by the system. Implementing the logic for the application’s data domain. Often model objects retrieve and store model state in database. Responsible for managing the data of the application. To model the data used, it has been employed MongoDB database. MongoDB is part of the new family of NoSQL database systems. Instead of storing data in tables as is done in relational databases, MongoDB stores data structures in JSON-like documents with a dynamic schema (MongoDB uses a specification called BSON), making data integration in certain applications easier and faster.

- **Views**: Components that display the application’s user interface. Responsible for displaying information. It is the user’s way of interacting with the platform.

- **To manage the view system, it has been employed CSS/PUG languages. PUG is a JADE evolution, it is simpler than HTML but uses the same labels and tags. To modify the information shown in views, has been employed JavaScript and Ajax.**

- **Controller**: Components that handle user interaction, does the operations over the models to deliver the results of the query to the user. Ultimately select a view to render that displays user interface. Responsible for responding to user input and interaction.

A general schema of these steps is showed below:

The resolution process followed by the IMT involves two main steps: first step involves traffic characterization and simulation, and second step, using outputs from traffic simulation, carries out Modules execution. An extra step, under development, will consist in the execution of an action plan where a series of interesting actions in order to improve traffic congestion and its consequences will be studied.

3 IMT modules

3.1 Energy module

The energy module is an application created by using Python code which takes the traffic results as inputs. The aim of the module is to calculate the fuel consumption and emissions caused by
traffic. Energy model results have been validated considering literature models for driving cycles calculations.

3.2 Noise module

Noise problems associated to traffic affect an estimated 125 million people in Europe (European Environmental Agency, 2014) causing neurological and psychiatric diseases, hypertension cases, hearing problems and sleep disturbance (Forouhidian 2017). Due to this strongly relation it is necessary to characterize the noise associated with road traffic.

The noise module is an application created by using Python code which implements a theoretical model based on previous CE projects (IMAGINE2 and CNOSOS2). This module calculates the directional sound power per meter per frequency band of the traffic noise determined by the source line, “The road traffic noise”.

3.3 Atmospheric pollution emission and carbon footprint module

Atmospheric pollutant emissions and carbon footprint are estimated using a simplified version of the vehicle emission model PHEM (Passenger Car and Heavy Duty Emission Model). This simplified version, named PHEMlight, was developed within the COLOMBO project (Hausberger & Krajzewicz 2014) and it is embedded into SUMO. PHEMlight estimates emissions of NOx, HC, CO, PM as well as carbon footprint (CO2) based on vehicle data to be entered for various driving cycles on basis of characteristic emission curves and vehicle longitudinal dynamics.

The main input parameters needed for the emissions computations are emission class, speed, acceleration and slope of the road. The emission class compromises information on the vehicle category and size (passenger cars, light commercial vehicles (including three classes depending on size), heavy duty vehicles (including trucks, trucks and trailer, city buses and coaches)), the technology (diesel, gasoline, hybrid, compressed natural gas, battery electric vehicles) and the emission standard (EU0, EU1 to EU6e).

3.4 Freight streamlining module

The Freight module (FM) simulates the impacts in terms of number and type of vehicles of specific scenarios regarding freight deliveries in the road segment/section to be studied, by maintaining the level of service (m³ of cargo transported). These specific scenarios can include: change in vehicle type; vehicle downsizing; changes in delivery hours; introducing of alternative technologies; and optimization of load factors. The simulation of freight demand in a specific case study requires a detailed characterization of the current situation, based on statistics, traffic counts or surveys.

3.5 Air pollution dispersion module

The VADIS model was selected to be included in the IMT to simulate the dispersion of pollutants based on the traffic and emissions estimation by the previous modules of the tool. The dispersion module outputs can be visualized in the IMT for air quality assessment and/or to evaluate the impacts of emission reduction scenarios.
VADIS model, developed at the University of Aveiro, allows the calculation of urban street-canyon air pollution due to road traffic emissions and the estimation of local hot spots, particularly under unfavorable dispersion condition such as thermal stability and low wind speeds (Borrego et al. 2000). This model supports multiple obstacles and source definition and the characterization of time-varying flow fields and emissions.

VADIS structure is based on two modules, FLOW and DISPER. The first module, FLOW, uses the numerical solution of the three-dimensional (3D) Reynolds averaged Navier–Stokes equations and the k-ε turbulence closure to calculate the wind, turbulent viscosity, pressure, turbulence and temperature 3D fields. The second module, DISPER, applies the Lagrangian approach to the computation of the 3D pollutant concentration field using the wind field estimated by FLOW.

3.6 Health module

The goal of Health Module (HM) is to provide information on the number of health events that can occur given a certain level of concentration of several air pollutants. At the time, four air pollutants are considered in HM: PM$_{2.5}$, PM$_{10}$, NO$_2$, and O$_3$. Given to concentration of these four pollutants, HM is now able to estimate the number of health events related to cardiac, respiratory and cerebrovascular diseases in the short-term exposure, i.e., mean exposure in a range of 3 days maximum. Furthermore, HM can also inform the user on the occurrence of lung cancer given the long-term exposure, i.e., the yearly average exposure.

To provide such information to IMT users, additional information on seasonal trends, holidays, temperature and barometric pressure are taken into account, due to the known effects that previously mentioned variables could have on health outcomes. (Michelozzi et al. 2005, Stafoggia et al. 2006) HM embeds all this information using Generalized Additive Models (GAMs), statistical models able to flexibly relate air pollution, temperature, seasonal trends, the barometric pressure to the health events. Using GAMs, HM can provide an estimation of a daily number of health events for all the time simulated by IMT.

3.7 Cost module

An individual cost is associated to each health outcome. Individual cost can be decomposed in two parts: a part related to medical costs and a part related to indirect costs, i.e. all the costs that do not cover health care procedures. The module is able to use default costs stored into it or take a set of customized costs for each health outcome.

At the moment, default costs are available for two type of health outcomes: hospitalizations for cardiac diseases and hospitalizations for respiratory diseases. Costs associated to cardiac hospitalizations are those related to Costs for Coronary Heart Disease (CHD) and stroke, while cost associated to respiratory hospitalizations are those related to Chronic obstructive pulmonary disease (COPD).

Costs for Coronary Heart Disease (CHD) and stroke were derived from the report of the American Heart Association (Khavjou et al., 2016) (which reported data on costs derived from the Medical Expenditure Panel Survey (MEPS) of the U.S. Agency for Healthcare Research and Quality), considering 2015 data. Costs for COPD were derived from the paper of Fen et al (Ford et al. 2015), they were represented only by medical costs and referred to the year 2010. Medical costs of the US were used for developing of the module, users can upload their outcome-specific costs about their interest and the situation simulated under study.
4 Conclusions

A novel Integrated Modelling Tool (IMT) has been developed as a tool for mobility decision making within the REMEDIO. The IMT is composed by 8 individual modules that cover the main impacts of traffic on the city and its inhabitants, namely, energy efficiency, noise, atmospheric pollution emission, carbon footprint, air pollution dispersion, freight streamlining, cost and health impact. The IMT provides to users (i.e. technician responsible for traffic management) the possibility of analyze the main effects of traffic over congested roads in the current situation, as well as analyzing the effects of applying potential soft-actions to mitigate the road-congestion problems.

Acknowledgment This work has been supported by the Interreg Med Programme under grant agreement No. 862, project REMEDIO, project co-financed by the European Regional Development Fund.

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