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A practical model for predicting road traffic carbon dioxide emissions using Inductive Loop Detector data

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ABSTRACT

Local Government Authorities (LGAs) are typically responsible for roads outside a country's strategic road network. LGAs play a key role therefore in facilitating the reduction of emissions from road traffic in urban areas, and must engage in emissions modelling to assess the impact(s) of transport interventions. Previous research has identified a requirement for road traffic Emissions Models (EMs) that balance capturing the impact on emissions of vehicle dynamics (e.g. due to congestion) against in-use practicality. This study developed such an EM through investigating the prediction of network-level carbon dioxide (CO_2) emissions based on readily available data generated by Inductive Loop Detectors (ILDs) installed as part of Urban Traffic Control (UTC) systems.

Using Southampton, UK as a testbed, 514 GPS driving patterns (1 Hz speed-time profiles) were collected from 49 drivers of different vehicle types and used as inputs to an Instantaneous EM to calculate accurate vehicle emissions. In parallel, concurrent data were collected from ILDs crossed by vehicles during their journeys. Statistical analysis was used to examine relationships between traffic variables derived from the ILD data (predictor variables) and accurate emissions (outcome variable). Results showed that ILD data (when used in conjunction with categorisation of vehicle types) can form the basis for a practical road traffic CO_2 EM that outperforms the next-best alternative EM available to LGAs, with mean predictions found to be 2% greater than proxy real-world values.

1. Introduction

The world's population is increasingly urbanised (UNFPA, 2007). One impact of these shifting demographics is greater congestion on urban road networks, resulting in larger volumes of tailpipe emissions from road traffic. Typically, Local Government Authorities (LGAs) administer roads outside a country's strategic road network (i.e. a LGA is responsible for all local roads inside its area of administration), and are therefore responsible for facilitating the reduction of emissions from traffic in urban areas. To discharge this responsibility properly, LGAs must quantify the emissions impact(s) of any changes to the transport system. At the network-level, measurement of real-world emissions is impractical (Smit, 2006; Smit et al., 2010), which means LGAs must engage in emissions modelling. However, LGAs' resources are scarce (Lowndes and McCaughie, 2013). A brief review of the involvement of LGAs in the emissions modelling process is provided in the remainder of this section. For a more detailed review of this subject the reader is directed to work published by Grote et al. (2016a).

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List of abbreviations

AF	Accuracy Factor
AIRE	Analysis of Instantaneous Road Emissions
ALOTPV	Average Loop Occupancy Time Per Vehicle
APE	Absolute Percentage Error
CAN bus	Controller Area Network bus
cc	cubic centimetre
CO_2	Carbon Dioxide
COPERT	Computer Programme to calculate Emissions from Road Transport
CV	Cross Validation
DfT	UK government's Department for Transport
DV	Dummy Variable
EF	Emission Factor
EM	Emissions Model
HBEFA	Handbook of Emission Factors for Road Transport
HCSE	Heteroscedastic-Consistent Standard Error
HDV	Heavy Duty Vehicle
HGV	Heavy Goods Vehicle (a sub-category of HDV)
IEM	Instantaneous Emissions Model
ILD	Inductive Loop Detector
ITS	Intelligent Transport Systems
IV	Interaction Variable
LDV	Light Duty Vehicle
LGA	Local Government Authority
LGV	Light Goods Vehicle (a sub-category of LDV)
LOOCV	Leave-One-Out Cross Validation
MAF	Mean Accuracy Factor
MAPE	Mean Absolute Percentage Error
MLP	Multilayer Perceptron neural network
MLR	Multiple Linear Regression
MOVES	Motor Vehicle Emission Simulator
NAEI	UK's National Atmospheric Emissions Inventory
PEMLA	Practical Emissions Model for Local Authorities
PEMS	Portable Emissions Measurement System
PHEM	Passenger car and Heavy duty Emissions Model
r	Pearson linear correlation coefficient
R^2	Coefficient of determination
RTM	Road Traffic Model
SAF	Speed-specific Adjustment Factor
SCOOT	Split, Cycle and Offset Optimization Technique
SD	Standard Deviation
SDR	Speed Detection Radar
TEE-KCF	Traffic Energy and Emissions – Kinematic Correction Factor
TRL	UK's Transport Research Laboratory
TRL EFs 2009	TRL Emission Factors 2009 average speed emissions model
TRL/NAEI EM	TRL EFs 2009, with average speed emission functions weighted by each vehicle category's fraction of national VKMs in UK urban areas according to the NAEI national fleet model
U07	SCOOT system message
UTC	Urban Traffic Control
VERSIT+	Verkeers Situatie
VKM	Vehicle-Kilometre

Emissions Models (EMs) used by LGAs must strike a balance between being so simple that they fail to capture the extent of a transport intervention's impact, and being so complex that the resources required to use the model are prohibitive (Grote et al., 2016a). In general, more complex models are more accurate representations of the real-world than less complex models (Smit et al., 2006). However, more complex models require more detailed input data (Smit et al., 2010), which are more susceptible to errors. Optimal model complexity occurs at the point beyond which the decreasing accuracy of input data begins to offset any accuracy gains through increasing model complexity (Alonso, 1968; Ramos et al., 2011; Smit et al., 2010).

EMs range in complexity, and are (briefly) reviewed here in accordance with the classification framework published in Grote et al. (2016a) and Smit et al. (2010). Specific examples of EMs (abbreviated titles are expanded in the List of Abbreviations section provided at the beginning of the article) are included to illustrate each EM type. Aggregate EMs are the simplest, and typically use a fixed Emission Factor (EF, e.g. gCO_2/km) for each vehicle category travelling on a particular road type, often classified as urban, rural or motorway (e.g. the UK national Greenhouse Gas Inventory EFs). Average Speed EMs calculate vehicle category-specific EFs as a function of traffic average speed (e.g. COPERT, TRL EFs 2009). Traffic Situation EMs correlate vehicle category-specific EFs with a range of defined traffic situations characterised by road type and a qualitative description of traffic conditions (e.g. HBEFA). Traffic Variable EMs calculate vehicle category-specific EFs as a function of variables that describe the traffic as a whole, such as traffic average speed or traffic density (e.g. TEE-KCF). Cycle Variable EMs calculate EFs for individual vehicles based on variables derived from driving patterns (fine-grained time series of speed points), such as number of stops per km or maximum acceleration (e.g. VERSIT+ [1]). Modal EMs calculate EFs for individual vehicles based on vehicle or engine operating modes, with the latest generation performing at temporal resolutions of 1 Hz typically termed Instantaneous EMs (IEMs) (e.g. MOVES, PHEM).

Aggregate, Average Speed, Traffic Situation and Traffic Variable EMs all require inputs that can be broadly described as traffic variables; whereas both Cycle Variable and Modal EMs require an individual vehicle's driving pattern as input. Traffic variables are typically readily available from sources such as Urban Traffic Control (UTC) systems, Road Traffic Model[2] (RTM) outputs, Speed Detection Radar (SDR) traffic classifier systems, or vehicle telematics data available from Intelligent Transport Systems (ITS) (Grote et al., 2016a). UTC systems are particularly appealing because their operation is based on vehicle detection by Inductive Loop

[1] VERSIT+ was originally a Cycle Variable EM, but following major changes in 2009 is now better described as a Modal EM (Ligterink and De Lange, 2009).

[2] The term Road Traffic Model (RTM) is used to describe any software application that models the movement of vehicles on road networks. RTMs can be classified according to scale, ranging from macro-RTMs which consider the movement of traffic as an aggregated whole, through to micro-RTMs which simulate the detailed movements of individual vehicles (Grote et al., 2016a).