Automation in Construction 72 (2016) 338–346

Contents lists available at ScienceDirect

Automation in Construction

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

Operational level emissions modelling of on-road construction equipment through field data analysis

Khalegh Barati, Xuesong Shen *

School of Civil and Environmental Engineering, The University of New South Wales (UNSW), Sydney, Australia

ARTICLE INFO

Article history:
Received 21 October 2015
Received in revised form 25 June 2016
Accepted 13 August 2016
Available online 9 September 2016

Keywords:
Construction industry
Emissions
Data collection
On-road equipment
Regulations
Data analysis

ABSTRACT

The construction industry is considered to be one of the largest contributors to greenhouse gas (GHG) emissions globally. Emissions from construction equipment are normally estimated through simulation or conducting emission tests in the laboratory, which may not represent real-world situations. Field data measurement is essential to quantify the emissions of equipment in use. This paper aims to develop an operational level model to estimate the emission rates of carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC) and nitrogen oxides (NO_x) of on-road construction equipment. The data collection procedure included instrumentation, laboratory testing and field measurements. Three types of instruments, including a portable emission measurement system (PEMS), a global positioning system-aided inertial navigation system (GPS-INS) and an engine data logger, were used to collect emissions rates, operational parameters and engine data, respectively. The raw data collected from the three channels were then synchronized and validated. Further, the operational level emission model was developed by performing ordinary least square (OLS) and multivariable linear regression (MLR) analyses of the field data. The emission model considers engine specifications, operational factors and environmental parameters as affecting variables. The statistical analysis results verify the high correlation between emission rates and affecting parameters. The developed model is finally validated by comparing the estimated results with the real data collected by the PEMS and the engine data logger in the field experiments.

1. Introduction

In recent decades, global warming and climate change resulting from greenhouse gas (GHG) emissions are becoming pressing concerns worldwide [1]. GHGs are mainly composed of contaminants such as CO, CO_2, HC, NO_x, sulfur dioxides (SO_2) and general particulate matters (PM). These pollutants can pose serious health threats, such as cardiovascular and respiratory diseases, to human beings. Recently, many restrictions and regulations have been imposed by international agencies like the United Nations Framework Convention on Climate Change (UNFCCC) and the United States (US) Environmental Protection Agency (EPA) to minimize GHG emissions.

The construction sector plays a significant role in GHG emission production, being placed as the third highest emitted pollution industry, just behind the oil and gas and chemical manufacturing sectors [2]. The construction industry contributes around 5% of CO_2 global emissions and is ranked as the third highest CO_2 emitter per used unit of energy after the cement and steel production sectors [3,4]. According to the UNFCCC, GHG emissions from construction operations account for around 6.8% of total emissions produced by all industrial sectors. Similarly, the US Clean Air Act Advisory Committee (CAAAC) [5] estimates that construction and mining equipment emit 32% of nitrogen oxide (NO_x) and 37% of the PM in industrial-related GHGs. The EPA [6] predicts that if the fuel consumed by the construction sector is reduced by 10%, CO_2 emissions will decrease by 6700 tonnes per year. In construction projects, equipment operations and material transportation account for the majority of emissions. Lewis et al. [7] claimed that the type, age and size of engine, and the kind of fuel used are the most significant parameters affecting equipment emission rates. To illustrate the effect of equipment operation on emissions, the EPA [6] predicts that if the idle time of construction equipment could be reduced by 10 h per month, CO_2 emissions would fall by approximately 650,000 tonnes per year.

However, GHG emissions of construction equipment have not yet been comprehensively investigated. It is technically challenging to measure the exact amount of emissions from each type of equipment or operation. Two emission models, NONROAD and OFFROAD, were used to obtain a rough estimation of different construction equipment groups' emission rates at national and state levels. Many parameters affecting emission rate and fuel consumption have also not been fully investigated, even though in previous studies, the effects of selected factors such as engine size, engine mode and fuel type on emissions and fuel consumption have been considered.

* Corresponding author.
E-mail address: x.shen@unsw.edu.au (X. Shen).

http://dx.doi.org/10.1016/j.autcon.2016.08.010
0926-5805/

This research aims to develop a quantitative model to estimate more accurately the different pollutant emission rates of on-road construction equipment at operational level by analyzing field data. To do so, a comprehensive research framework was developed to collect and analyze real-world data. State-of-the-art data collection instruments were then employed to measure the required parameters of on-road construction equipment as it is used on site. Finally, the operational level emission model was developed and validated. The research methodology thus developed holds substantial application potential for the construction industry, such as emission tax calculation and machinery management.

This paper starts with an extensive review of current models and approaches that can be used for estimating the emissions of non-road and on-road construction equipment. The parameters affecting such emissions are then investigated so as the required instruments for collecting field data. In the next step, we model the emissions of the on-road construction equipment through MLR analysis of the collected data. The validation process is conducted by comparing the predicted results of the model against the field data measured by the PEMS.

2. Literature review

Regulations are the main incentive for reducing pollution emissions, though each country may have its own requirement on emissions. In recent years, there have also been many efforts spent in developing models and approaches to estimate the GHGs emitted from construction equipment.

2.1. Emissions regulations

Emissions regulations can be classified into two broad categories of emissions and air quality standards. The aim of the former is to restrict engine emissions, while the latter restricts the level of pollutants emitted into the atmosphere. These regulations impose restrictions on emissions by focusing on the specifications of engines, fuel and the combustion process [7].

There are two main types of on-road and non-road emission standards. On-road regulations are applied for vehicles that can be driven on normal roads, and are significantly more stringent. The European Union (EU) has the best known on-road standard, which was introduced in the early 1970s and over the years, the EU standard has become more stringent. Currently, most countries around the world adopt and implement the EU in their own regulations. The first non-road emission regulation was introduced in 1994 by the EPA. This was implemented in 1998 as a Tier 1 regulation to restrict the emission of main GHGs from engines with power >56 kW. The power and model year of the equipment's engine were taken into consideration when making the tier classification. In 2001 and 2006, the EPA implemented two more, and more stringent, regulations Tiers 2 and 3, for manufactured engines. The most stringent regulation so far, Tier 4, was released from 2008 in transitional and final phases.

In regards to air quality standards, the EPA established the first National Ambient Air Quality Standard (NAAQS) to control the concentration of GHGs in the atmosphere and their effects on human health and the environment. The NAAQS is reviewed periodically and is becoming more stringent over time. The NAAQS includes primary and secondary emission regulations. The primary standards are more stringent, and focus on public health, including people with respiratory problems [8]. The secondary standards limit pollutant concentrations to protect public welfare, such as visibility and preventing damage to the environment. Currently, the EPA imposes restrictions on CO, NO_x, PM, SO_2, Ozone (O_3) and lead pollutants, which are known as criteria pollutants. Equipment engines are the main contributors of CO, NO_x, PM pollutants that are considered in this research. Hexane is also considered a major source of HC emitted from equipment contributing to O_3 formation.

2.2. Emission modelling

Emission modelling approaches can be classified into four main categories, namely aggregated, instantaneous parametrized, modal and simulation-based studies. In the aggregated approach, the model is developed at the simplest level and emissions are estimated roughly, based on the general specifications of the vehicle [9]. The NONROAD, OFFROAD and the national atmospheric emissions inventory (NAEI) models are examples of this approach. Instantaneous-parametrized approaches, like MODEM and digitized graz (DGV), estimate emissions more accurately through considering driving pattern every second. These models are used mostly for estimating the emissions of light-duty vehicles in urban areas [10,11]. Modal models predict machinery emissions in different operational modes. These models are relatively detailed and take into account the effects of engine size and engine power on exhaust emission rates. For instance, the model developed by Lewis [12] and the comprehensive modal emission model (CMEM) estimate emission rates of different equipment in idle, moving, dumping and scooping modes [7]. Simulation-based models such as the motor vehicle emission simulator (MOVES) and the advanced vehicle simulator (ADVISOR) map different parameters, including emission rates and fuel consumption of vehicles according to driving pattern, fuel type and general engine specifications [5,9].

2.2.1. Emission models for off-road equipment

The EPA developed the NONROAD model to gain a rough estimation of the GHG emission rates of all equipment types by considering work volume, equipment population, emission factors, activity hours and deterioration parameters [12–14]. Table 1 ranks the contribution of non-road construction equipment types to GHG emissions in terms of NO_x, CO and PM_{10} [13]. The California Air Research Board (CARB) [12,15] developed the OFFROAD model to estimate emission rates of construction equipment in California. The OFFROAD model takes into account the effects on emissions of such parameters as technology type, regulations and seasonal conditions, which were not considered in the NONROAD model [15]. The main limitation of both the NONROAD and OFFROAD

Table 1
EPA construction equipment ranking and contribution of NO_x, CO, PM_{10}.

	NOx		CO		PM_{10}	
Equipment	Contribution	Ranking	Contribution	Ranking	Contribution	Ranking
Front-end loaders	14.5%	1	11.5%	3	11.2%	3
Bulldozers	12.5%	2	9.3%	4	9.1%	4
Excavators	11.4%	3	7.4%	5	8.6%	5
Trucks	11.0%	4	7.3%	6	6.6%	6
Backhoes	9.2%	5	16%	1	15.1%	1
Skid-steer loaders	6.2%	6	14.5%	2	13.6%	2
Generators	4.7%	7	5.1%	7	6.0%	7
Forklifts	3.9%	8	4.9%	8	4.6%	8
Scrapers	3.4%	9	2.7%	11	2.3%	12
Cranes	3.2%	10	1.5%	15	1.9%	14