Applied Energy 111 (2013) 921–929

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Assessment of heavy-duty vehicle activities, fuel consumption and exhaust emissions in port areas

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HIGHLIGHTS

- Evaluation of HDV flows from highway exits to Genoa urban areas and port terminals.
- Assessment of HDV activities and operating conditions in port areas.
- Experimental definition of HDVs driving characteristics in urban and port zones.
- Calculation of emissions and fuel consumption in real world speed patterns with PHEM.
- Comparison of Euro 3 and Euro 5 HDV emissions estimated by PHEM, Copert and HBEFA.

ARTICLE INFO

Article history:
Received 18 March 2013
Received in revised form 16 May 2013
Accepted 19 June 2013
Available online 18 July 2013

Keywords:
Heavy duty vehicles
Port activities
Urban driving mode
Speed patterns
Exhaust emissions
Fuel consumption

ABSTRACT

An experimental and theoretical investigation is being performed to evaluate exhaust emissions and fuel consumption of Heavy Duty Vehicles (HDVs) circulating in urban areas and involved in commercial shipping activities.

The study is focused on the city of Genoa, whose urban road network is influenced by highway connections and shipping activities, as seven motorway exits and more than twenty accesses to port area are located within the urban area.

In a first step, the HDV flows crossing highway exits, urban zones and port areas were evaluated, as well as the relevant vehicle classes. The typical urban trips linking highway exits to port gates and the HDV mission profiles within the port area were then defined, whose validation was performed through an experimental campaign for HDV instantaneous speed measurements on urban trips and in port zones. The availability of speed patterns enabled the application of Passenger Car and Heavy Duty Emission Model (PHEM) for the estimation of fuel consumption and emission factors for selected HDV classes.

The main results of the different investigation steps are presented and discussed in the paper, outlining the specific activities of HDVs in port area and the relevant emissive behaviour.

1. Introduction

Estimation of road transport emissions from inventory models, considering different geographical scales [1–3], shows a growing contribution from vehicle categories such as heavy-duty vehicles (HDVs) or powered two-wheelers (PTWs). Passenger cars (PC) still represent the most important category for fleet extension and travelled mileage, but their real-world emission factors have been forced to strong reductions by the development of the relevant legislation [4,5], even if on-road emissions may be different from expected values included in inventory models [6] and a careful evaluation of available methods for emission factors definition is requested [7]. Comparisons with HDVs and PTWs are therefore generally advantageous for PCs, when taking into account equivalent emission classes [2,8,9].

Different considerations can be developed when referring to carbon dioxide emissions, which are focused by the 2009/443/EC Regulation, having passenger cars as the specific target. A range of technical solutions are available and continuously developed for spark ignition (SI) and diesel engines, but alternative powertrain concepts and fuels will also play a major role. Referring to SI engines, the joint application of downsizing concept, direct injection and turbocharging systems has already achieved an important market penetration, complying with technical challenges, related to control strategies optimisation, knock avoidance

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http://dx.doi.org/10.1016/j.apenergy.2013.06.037

Nomenclature

AT	articulated truck
CO_2	carbon dioxide
FT	ferry terminal
GPS	global positioning system
GT	goods terminal
HDV	heavy duty vehicle
NO_X	nitrogen oxides
NO_2	nitrogen dioxide
O–D	origin–destination
PC	passenger car
PHEM	passenger car and Heavy duty Emission Model
PM	particulate matter
PTW	powered two-wheeler
RT	rigid truck
SI	spark ignition
TT	truck trailer

[10–12] and to the proper matching of engine and turbocharger, which requires to deal with the unsteady flow operating conditions, both for compressors [13–15] and turbines [16–19]. Sustainable bio-fuels are considered one of the most important options to limit the fossil fuels dependence and to cut CO_2 emissions [20–23], while hybrid and electric vehicles are further solutions [24–27], even if different technical problems and cost issues are preventing them to reach a significant diffusion [28].

When dealing with air quality problems, especially in urban areas, particular attention is focused on light and heavy-duty diesel engines, due to their extended use [29,30]. Significant reduction in NO_X emission limits are coming into force for all the vehicle categories, leading to the adoption of a wide range of technical solutions related to deNO_X catalysts and advanced exhaust gas recirculation systems [28,31,32], even if their benefits in real world behaviour must be verified [33–36]. With reference to impact on urban areas and public health, even specific fleet (such as vehicles involved in public transport or waste collection [37,38]) may represent a significant contribution to air pollution [39,40]. Attention must be focused on HDVs, especially when industrial, commercial and shipping activities are deeply linked to the urban territory, also due to the road network development.

Starting from these considerations, an investigation referred to the city of Genoa is being developed jointly by the Internal Combustion Engines Group (ICEG) of the University of Genoa and the Transports and Environmental Laboratory (LTE) of IFSTTAR, aiming at the definition of specific information on HDV activities in urban environment, in terms of circulating fleet, mileage and speed patterns, thus allowing the evaluation of their influence on pollutant emissions and energy consumption.

Within this study, different issues were considered:

- The assessment of HDV flows entering and leaving the urban area at the different highway exits and the relevant share involved in port operations.
- The identification of the typical trips connecting the highway exits to the port gates and the relevant HDV mission profile within the port area.
- The acquisition of instantaneous speed related to these trips and the selection of the most representative speed patterns.
- The application of Passenger car and Heavy duty Emission Model (PHEM) to the experimental speed profiles to estimate fuel consumption and emission factors for selected HDV classes.

The theoretical and experimental tools applied for the development of the different investigation steps are presented in detail, as the proposed methodologies for the assessment of environmental impact of HDVs in port and urban areas are not specific of the case study considered, but can be of general use. The main results are then discussed, focusing on the most critical and innovative aspects, concerning HDV mission profiles and the evaluation of emissive and energetic behaviour at the very low speed typical of port activities, comparing calculated levels with those derived from inventory emission models (Copert/Artemis, HBEFA).

2. Methodologies

The key aspects of the study are introduced in this section. The major features of highway network and port gates in the urban area are firstly summarised. HDV activities within the port are then presented, aiming at the definition of the relevant mission profiles, followed by their experimental characterisation through the associated speed patterns. Details of PHEM are then given, introducing the evaluation of fuel consumption and exhaust emissions for selected HDV classes performing measured speed curves.

2.1. Genoa highway network

Genoa is an important node of the northern Italy highway network, as four different motorways (A7, A10, A12 and A26) start to link northern, central regions and France (Fig. 1). Seven exits are located in the urban area, reflecting the city structure, which covers a 30 km narrow coastal plain and two valleys with a perpendicular orientation to the coastline. The urban area is densely populated, at least from a European perspective, while residential and industrial/commercial zones are generally separate, even if the relevant traffic flows can be mixed, especially in the central zone.

In a first phase, vehicle flows entering and leaving the urban area using the seven motorway exits were evaluated, starting from data of the Highway Society, referred to average daily flows calculated on a yearly period from 2000 to 2010. Flows are related to the five different categories considered in the toll collection system; 2-axle vehicles are included in A and B classes, which are characterised by different heights on the front axle. The other categories are identified by the number of axles (3, 4 and $\geqslant$5) and are mostly made of heavy duty vehicles, with a minority share of specific vehicles, such as cars with trailers and coaches.

2.2. Port accesses

More than twenty accesses to the port area and its terminals are located in Genoa urban area, covering about 15 km of its coastal zone. Data from the Genoa Port Authority allowed to associate the main vehicle flows to five gates. Goods Terminal 1 (GT1, Fig. 2) is located in the western part of the city and is only involved in HDVs traffic, being connected to the highway network through Exit 1, which can be considered as mainly dedicated to their activities [41].

Other four port gates are located near the city centre and are linked to the highway network by Exit 4. Different characteristics are associated to these gates: while Goods Terminal 2 and 3 (Fig. 3) are interested by HDV flows, GT4 is an intermodal gate