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1 **Reducing vehicle fuel consumption and exhaust emissions from**
2 **the application of a green-safety device under real driving**

3
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15

16 **Abstract**

17 Vehicle emissions have a significantly negative impact on climate change, air quality and
18 human health. Drivers of vehicles are the last major and often overlooked factor that determines
19 vehicle performance. Eco-driving is a relatively low-cost and immediate measure to reduce
20 fuel consumption and emissions significantly. This paper reports investigation of the effects of
21 an on-board green-safety device on fuel consumption and emissions for both experienced and
22 inexperienced drivers. A portable emissions measurement system (PEMS) was installed on a
23 diesel light goods vehicle (LGV) to measure real-driving emissions (RDE), including total
24 hydrocarbons (THC), CO CO₂, NO, NO₂ and particulate matter (PM). In addition, driving
25 parameters (e.g. vehicle speed and acceleration) and environmental parameters (e.g. ambient
26 temperature, humidity and pressure) were recorded in the experiments. The experimental
27 results were evaluated using the Vehicle Specific Power (VSP) methodology to understand the
28 effects of driving behavior on fuel consumption and emissions. The results indicated that
29 driving behavior was improved for both experienced and inexperienced drivers after activation
30 of the on-board green-safety device. In addition, the average time spent was shifted from higher
31 to lower VSP modes by reducing excessive speed, and aggressive accelerations and
32 decelerations. For experienced drivers, the average fuel consumption and NO, NO₂ and soot
33 emissions were reduced by 5%, 56%, 39% and 35%, respectively, with the on-board green-
34 safety device. For inexperienced drivers, the average reductions were 6%, 65%, 50% and 19%,
35 respectively. Moreover, the long-term formed habits of experienced drivers are harder to be
36 changed to accept the assistance of the green-safety device, whereas inexperienced drivers are
37 likely to be more receptive to change and improve their driving behaviors.

38 **Keywords:** Green-safety device; Eco-driving; PEMS; VSP; Fuel consumption; Gaseous
39 and particulate emissions

40

41 **Highlights**

- 42 • Eco-driving is a cost-effective method for reducing fuel consumption and emissions
- 43 • RDE tests were performed with different driver ages, experience and offense points
- 44 • Green-safety device increased from 31% to 35% of time spent in lower VSP modes
- 45 • Fuel consumption reduced 5%-6% with the green-safety device installed
- 46 • Emissions reduced 19%-35% for PM and 56%-65% for NO with the device installed

47

48 **Abbreviations:**

49 CO: Carbon monoxide

50 CO₂: Carbon dioxide

51 DOC: Diesel Oxidation Catalyst

52 DPF: Diesel Particulate Filter

53 EGR: Exhaust Gas Recirculation

54 FID: Flame Ionization Detector

55 GPS: Global positioning system

56 HKEPD: Hong Kong Environmental Protection Department

57 LGV: Light goods vehicle

58 NO: Nitric oxide

59 NO₂: Nitrogen dioxide

60 PEMS: Portable emissions measurement system

61 PM: Particulate matter

62 RDE: Real-driving emissions

63 THC: Total hydrocarbons

64 VSP: Vehicle Specific Power

65

66 **1. Introduction**

67 Road transport is a major source of atmospheric pollutants, including hydrocarbons (HC),
68 carbon monoxide (CO), carbon dioxide (CO₂), nitric oxide (NO), nitrogen dioxide (NO₂) and
69 particulate matter (PM). Greenhouse and pollutant emissions of on-road vehicles have negative
70 impacts on climate change (Sausen, 2010) and human health (Ren et al., 2016; World Health
71 Organization, 2013). According to the fifth assessment report of the Intergovernmental Panel
72 on Climate Change (IPCC), the CO₂ emissions from road transport increased by 45% since
73 1990 (IPCC, 2014). An increasing amount of CO₂ emissions and other greenhouse gases such
74 as methane (CH₄) and nitrous oxide (N₂O) has received considerable attention from policy
75 makers and environmental groups. In addition, the European Union has set out ambitious
76 targets for 2030, to reduce greenhouse emissions gas by 40% compared to 1990 levels (Rogner,
77 2007). Although significant progress has been made to limit the pollutant emissions from the
78 transport sector, emissions of diesel vehicles are still one of the main contributors to urban air
79 pollutants as diesel vehicles produce significant percentages (40-60%) of the total NO_x and PM
80 emissions (Pui et al., 2014; Ramlan et al., 2016). In Hong Kong, numerous policies and
81 measures have been adopted by the Hong Kong Environmental Protection Department
82 (HKEPD) to improve roadside air quality and greenhouse gas emissions from motor vehicles
83 (Ning et al., 2012). In order to protect the environment and public health, the Hong Kong SAR
84 Government has carried out air quality impact assessments and published an emissions
85 inventory report of local air pollutant emissions (HKEPD, 2018). It was reported that CO
86 emissions were decreased by 37% between 1997 and 2016 (HKEPD, 2018), which was mainly
87 attributed to a series of vehicle emission control programmes, including the tightening of
88 vehicle emission standards from Euro IV to Euro V in 2012, deploying roadside remote sensing
89 equipment to detect excessive emissions from petrol and LPG vehicles and progressively
90 phasing out some 82,000 pre-Euro IV diesel commercial vehicles by 2019. During the same

91 period, respirable suspended particulates (RSP) and NO_x emissions were greatly reduced by
92 69% and 39% respectively (HKEPD, 2018).

93 Air pollution control policies and technologies have been promoted to improve fuel
94 economy and vehicle emissions all over the world, including initiation of the Paris Agreement
95 within the United Nations Framework Convention on Climate Change (UNFCCC) (United
96 Nations, 2015), the tightening of automotive emission standards from Euro 5/V to Euro 6/VI
97 (European Parliament and the Council, 2012), electric and hybrid electric vehicles (Huang et
98 al., 2019), better fuel quality and renewable fuels (Zhen and Wang, 2015) and stricter
99 enforcement for high-emitting vehicles (Huang et al., 2018b). Among these typical measures,
100 another important but often overlooked factor to reduce vehicle emissions and to improve fuel
101 economy (hence reducing the negative impact to environment) is eco-driving technology. Eco-
102 driving is a driving behavior based method and is an immediate measure to reduce vehicle
103 emissions and fuel consumption. Although many strategies have been undertaken to improve
104 vehicle fuel economy and roadside air quality (e.g. promoting new vehicle technologies and
105 fuels), the implementation of eco-driving appears to be more cost effective, immediate,
106 relatively simple and can lead to an improvement in fuel efficiency by up to 45% (Sivak and
107 Schoettle, 2012; Xu et al., 2017).

108 Eco-driving technology was first introduced and discussed in the Driver Energy
109 Conservation Awareness Training (DECAT) program by the United States Department of
110 Energy (U.S. DOE) in 1976 (Alam and McNabola, 2014; Greene, 1986). Eco-driving
111 technology involves a number of factors and strategies to improve the driving behavior hence
112 reducing vehicle emissions and fuel consumption (Huang et al., 2018a; Lee and Son, 2011; Xu
113 et al., 2017). Zhou et al. (2016) identified six groups of eco-driving factors that affected the
114 fuel consumption of a vehicle, including travel-related, weather-related, vehicle-related,
115 roadway-related, traffic-related and driver-related factors. Vahidi and Sciarretta (2018)

116 reported that the connectivity to other vehicles and infrastructure allows better anticipation of
117 upcoming events, such as real-time traffic and signal status information. This can avoid
118 unnecessary acceleration/deceleration and reduce the number of stop and go driving. The
119 results showed that connected and automated vehicles could increase energy efficiency and
120 lead to additional energy savings for neighboring vehicles. Amini et al. (2021) presented the
121 benefits of eco-driving strategies of connected and automated vehicles. The results showed that
122 speed profile optimized by the eco-driving strategy would provide 14.5% average fuel saving
123 for driving on a hybrid electric vehicle. Gao et al. (2019) investigated the sensitivities of fuel
124 economy and exhaust emissions to eco-driving factors using simulation method. The results
125 showed that higher velocity and lower road grade were recommended for eco-driving. The
126 emissions of gaseous nitrogen oxides (NO_x) and soot particles were positively correlated with
127 fuel consumption rate, which was dominated by vehicle acceleration whose effect was
128 aggravated by road grade (Gao et al., 2020). Sivak and Schoettle (2012) defined eco-driving as
129 driver decisions that improved vehicle fuel economy, including strategic decisions (vehicle
130 selection and maintenance), tactical decisions (route planning and weight) and operational
131 decisions (driver behavior). Of those factors identified, changing driving behavior is the most
132 common, useful and effective eco-driving skill that every driver can implement in practice
133 every day (Alam and McNabola, 2014; Huang et al., 2018a). The methods used to positively
134 change driving behavior include eco-driving training programs, in-vehicle eco-driving
135 feedback devices, regulations, incentives and social marketing. Eco-driving training programs
136 are widely used for changing the driver's inefficient driving behaviors. It can achieve
137 immediate and obvious fuel savings, while the main limitation is that the effect is
138 heterogeneous between individuals and can attenuate over time (Andrieu and Pierre, 2012;
139 Strömberg and Karlsson, 2013). On the other hand, in-vehicle eco-driving devices are an
140 important complement to the training programs.

141 As reviewed above, existing studies on driving behavior only concerned on fuel
142 consumption or specific emissions. In addition, previous studies usually used less accurate
143 methods in the measurements, such as OBD data and simulations. Therefore, the aim of this
144 study is to achieve a thorough understanding of eco-driving technology applied under real
145 driving. To realize this goal, an on-board green-safety device was installed on a diesel light
146 goods vehicle (LGV) to provide real-time feedback to the driver. Real-time warnings were
147 provided to alert the driver so as to improve driving behavior, such as excessive speed, hard
148 acceleration and braking (Alzaman, 2016; Gonder et al., 2012; Vaezipour et al., 2015). A
149 portable emissions measurement system (PEMS) was installed on a diesel vehicle to measure
150 real-driving emissions (RDE), including both gaseous and particulate emissions. In addition,
151 the driving parameters (i.e. vehicle speed and acceleration) and environmental parameters (i.e.
152 ambient temperature, humidity and pressure) were also recorded by an OBD logger.
153 Experimental data was used to evaluate the relationship between driving behavior and fuel
154 consumption for both experienced and inexperienced drivers. The fuel economy and emissions
155 data of diesel LGV were analyzed using the Vehicle Specific Power (VSP) model (Boroujeni
156 and Frey, 2014; Jiménez-Palacios, 1999; Zhang et al., 2014). The current study provides a
157 thorough evaluation of green-safety device effect and supports the development of eco-driving
158 technology in Hong Kong.

159 **2. Experimental setup and analytical methods**

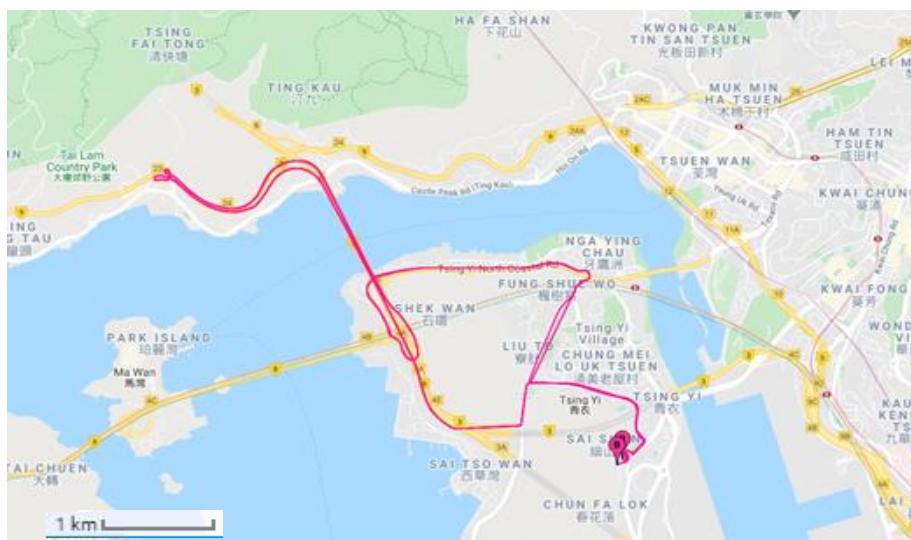
160 To investigate eco-driving technology for reducing emissions and fuel consumption of
161 diesel commercial vehicles in Hong Kong, a Euro 5 diesel 3.3 tonnes LGV (Toyota HiAce)
162 with an on-board green-safety device (Green Safety Advanced Driver Assistant System) was
163 selected to conduct experiments in this study. The device consisted of a driver assistance system,
164 a movement detection sensor, a video camera and a data collection box. Artificial intelligence
165 image processing was used to detect the distance from the object precisely and provides

166 instantaneous auditory warning to the driver when the vehicle acceleration, deceleration and
167 turning speed exceed the safety limit. A total number of 30 drivers were recruited to perform
168 on-road emission tests, including 15 experienced and 15 inexperienced drivers. The on-road
169 emissions experiments were conducted in stage 1 without the green-safety device activated and
170 stage 2 with the green-safety device activated. The hypothesis is that the activation of the green-
171 safety device in stage 2 will positively influence fuel consumption and emission relative to
172 tests in stage 1 without the green-safety activated. Gaseous and particulate emissions
173 measurements were conducted in a real-world driving route by using a PEMS, which integrates
174 an AVL M.O.V.E Gas PEMS 493 and AVL M.O.V.E PM PEMS 494. It was installed on the test
175 vehicle to obtain RDE data, driving parameters and environmental parameters.

176 *2.1 Tested vehicle and driving route*

177 The Toyota HiAce LGV was chosen because it is the dominant diesel vehicle type in Hong
178 Kong. In December 2020, the total number of registered diesel vehicles in Hong Kong
179 increased by 12.3% to around 150,000 vehicles within ten years, including private cars, buses,
180 light buses, LGVs, medium goods vehicles, heavy goods vehicles and special purpose vehicles.
181 In 2020, diesel LGVs account for 50.4% of the total registered diesel vehicles in Hong Kong
182 (Hong Kong Transport Department, 2020). Thus, a diesel LGV representative of the Hong
183 Kong market was selected to perform the on-road emissions measurement. The 3.3 tonnes LGV
184 equips an in-line four cylinder, 3.0 L displacement, turbocharged diesel engine with a combined
185 diesel particulate filter (DPF), exhaust gas recirculation (EGR) and diesel oxidation catalyst
186 (DOC) after treatment system. The installed DPF is a ceramic filter consisting of honeycomb-
187 shaped openings that trap the soot onto the channel walls and prevent the particulate matter
188 from exiting out the tail pipe. The honeycomb substrate is coated with a platinum group metal
189 catalyst and packaged in a stainless steel container. EGR recirculates a controllable proportion
190 of the engine exhaust gas which is mixed with the intake air to reduce NO_x emissions. DOC is

191 a modern catalytic converter consisting of a monolith honeycomb substrate coated with a
192 platinum group metal catalyst and packaged in a stainless steel container. A DOC was used to
193 oxidize CO and HC into CO₂ and H₂O. Furthermore, the DOC was equipped in front of the
194 DPF in the after treatment system. The vehicle was type approved to the Euro 5 standard and
195 was registered in January 2014. It has an automatic four-speed transmission and the mileage
196 was 53,050 km at the beginning of the test. A RDE test route that is representative of daily
197 driving in Hong Kong has been designed, as shown in Figure 1. The testing route has a total
198 distance of 19 kilometers, including 5 kilometers of urban driving, 6 kilometers of rural driving
199 and 8 kilometers of highway driving conditions. One RDE trip took between 25 and 30 minutes
200 to complete. The characteristics of the testing route are described in Table 1. For the
201 environmental conditions during RDE testing, the range of temperature and humidity was
202 between 27.7°C to 29.1°C and 63.2% to 63.9% respectively. The testing days were mainly
203 sunny. It can be noted that the weather conditions were similar in the experiments. In addition,
204 the air-conditioning system was turned on during the experiments to minimize variation of
205 energy consumption between both monitoring stages (Wang et al., 2020).



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Figure 1: PEMS test routes for on-road data collection.

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Table 1: Characteristics of PEMS testing routes.

Road type	Lanes (single direction)	Speed limit (km/h)	Traffic conditions
Urban road	1-2	50	High traffic volume; Traffic lights; Roundabouts; Pedestrian crossings.
Rural road	2-3	70	Moderate traffic volume; Traffic lights; Roundabouts.
Highway	3-4	80	Moderate traffic volume; No traffic light; No pedestrian crossings.

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2.2 Test drivers

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In this study, a total number of 30 drivers were recruited to conduct the on-road emission experiments, including 15 experienced and 15 inexperienced drivers. As shown in Table 2, the 15 experienced drivers recruited were full time drivers and they had at least 15 years of driving experience, with an age range of 40-72 years old. For the 15 inexperienced drivers, they had 3-5 years of driving experience and were aged between 21-40 years old. The average age of all inexperienced drivers is younger than the experienced drivers. In addition, all drivers recruited to perform on-road emission tests were male to minimize bias attributable to sample heterogeneity. The on-road emission test experiments were conducted in two stages. In the first stage of experiments, the driver was requested to drive along the route normally that follow his own driving style. In the second stage of experiments, an on-board green-safety device was activated to provide the driver with information and guidance on how to improve their driving behavior. In the experiments, each driver is responsible for four trips over the same route. One set of experiments (first stage and second stage) were conducted during 11:00 a.m. to 01:00 p.m. and the second set were repeated during 02:00 p.m. to 04:00 p.m. on the same day, to avoid peak hours and maintain relatively low traffic density which allowed the driver to drive

225 according to their own driving style. The details of on-road emission test experiments are show
 226 in Table 3.

227 **Table 2:** Details of experienced and inexperienced drivers recruited in the on-road
 228 emission tests.

	Gender	Age	Driving experience	Driving Offense points ^[1]
Driver 1	Male	60-70	More than 25 years	0
Driver 2	Male	>70	More than 25 years	5 - 10 points
Driver 3	Male	60-70	More than 25 years	5 - 10 points
Driver 4	Male	18-30	Less than 5 years	5 - 10 points
Driver 5	Male	30-40	Less than 5 years	0
Driver 6	Male	50-60	More than 25 years	0
Driver 7	Male	>70	More than 25 years	0
Driver 8	Male	30-40	Less than 5 years	0
Driver 9	Male	18-30	Less than 5 years	5 - 10 points
Driver 10	Male	30-40	Less than 5 years	0
Driver 11	Male	30-40	Less than 5 years	0
Driver 12	Male	40-50	15 - 25 years	0
Driver 13	Male	40-50	More than 25 years	0
Driver 14	Male	30-40	Less than 5 years	0
Driver 15	Male	30-40	Less than 5 years	0
Driver 16	Male	30-40	Less than 5 years	5 - 10 points
Driver 17	Male	30-40	Less than 5 years	0
Driver 18	Male	50-60	More than 25 years	0
Driver 19	Male	30-40	Less than 5 years	0
Driver 20	Male	60-70	More than 25 years	0
Driver 21	Male	30-40	Less than 5 years	0
Driver 22	Male	>70	More than 25 years	0
Driver 23	Male	50-60	More than 25 years	0
Driver 24	Male	30-40	Less than 5 years	5 - 10 points
Driver 25	Male	30-40	Less than 5 years	More than 10 points
Driver 26	Male	>70	More than 25 years	0

Driver 27	Male	30-40	Less than 5 years	0
Driver 28	Male	50-60	More than 25 years	0
Driver 29	Male	60-70	More than 25 years	0
Driver 30	Male	50-60	More than 25 years	0

229 (^[1]In Hong Kong, if the driver has incurred 15 or more points in respect of offences committed
230 within a period of 2 years, the driver can be disqualified by a Court from holding or obtaining
231 a driving license (Hong Kong Transport Department, 25 August 1984).)

232 **Table 3:** The driving pattern of on-road emission test experiments.

Test No.	Testing period	Status of on-board green-safety device
1	11:00 a.m. – 12:00 p.m.	un-activated
2	12:00 p.m. – 01:00 p.m.	Activated
3	02:00 p.m. – 03:00 p.m.	un-activated
4	03:00 p.m. – 04:00 p.m.	Activated

233 *2.3 Portable emissions measurement system*

234 In the on-road emission test experiments, a PEMS was installed on the test vehicle to obtain
235 RDE data, driving parameters and environmental parameters. PEMS integrates advanced gas
236 analysers, a PM measurement device, an exhaust flow meter, a weather station, a wheel speed
237 sensor and a global positioning system (GPS). The on-road emissions experiments were
238 conducted using an AVL M.O.V.E Gas PEMS 493 and AVL M.O.V.E PM PEMS 494. The gas
239 PEMS uses a non-dispersive infra-red (NDIR) analyzer for CO and CO₂ measurement, a non-
240 dispersive ultra-violet (NDUV) analyzer to measure NO and NO₂ separately and
241 simultaneously, a heated flame ionization detector (FID) to analyze total hydrocarbons (THC)
242 and an electrochemical sensor to measure oxygen (O₂). The PM PEMS is a portable soot
243 measurement device by using the micro soot sensor and a particle filter for gravimetric PM
244 measurement. The PM emissions are calculated by using the mass of the particle filter, the
245 time-resolved soot signal and the exhaust mass flow as inputs. The particulate filters were
246 conditioned in an open dish for three hours before the test in an air-conditioned chamber. After
247 this conditioning, the particulate filters weighed and stored until they were used. After the on-

248 road emission test experiments, the particulate filters were taken to the weighing chamber and
249 conditioned for three hours and then weighed. The particulate filters were weighed by the
250 Sartorius air quality microbalance. The microbalance is designed for weighing 47 mm filters
251 specified in the EPA regulation. It is based on gravimetric analysis and provided a resolution
252 from one microgram to six grams.

253 To assure the accuracy of the test results, the AVL gas PEMS was set to zero with pure
254 nitrogen before each test and was calibrated with standard gases (US EPA Bar 97) before and
255 after the tests on each day. Zero calibration was performed so that the baseline concentration
256 could be established and prevent a drift in measurements. An audit calibration as carried out
257 before and after the road tests by comparing the measured concentrations of mixed gases with
258 the values stated on the gas bottles. A linearity check of the instruments took place
259 approximately once every five weeks to ensure instrument precision. In addition, a 2.5-inch
260 EFM-2 was used to measure instantaneous exhaust mass flow rates and temperature from the
261 test vehicle. A weather station was mounted on the roof of the test vehicle to measure ambient
262 temperature, relative humidity and atmospheric pressure during on-road testing. As shown in
263 Figure 2, the emission gas sample line and exhaust flow measurement system are directly
264 connected to the exhaust pipe. The exhaust emissions flow rate and temperature can be
265 monitored in real-time together with ambient meteorological parameters. A Peiseler MT pulse
266 transducer was employed to measure the wheel speed during the on-road emissions
267 measurement. In addition, a Garmin International Inc. GPS receiver was mounted on the roof
268 of the test vehicle to track the route, elevation and ground speed of the LGV under test. The
269 PEMS was installed in the trunk of the test vehicle and the sampling line was connected to the
270 tailpipe to measure gaseous and PM emissions. The sampling line was heated to a temperature
271 of 190 °C in order to avoid condensation of THC. A Honda EU 30is generator and a battery
272 pack consisting of three lead acid batteries with a capacity of 150 Ah were mounted inside the

273 test vehicle to supply power for the instruments. In the present study, all the data were logged
274 at a sample rate of 10 Hz and sent to the internal storage of a notebook computer using an
275 Ethernet cable. Furthermore, engine control unit (ECU) data were recorded via the OBD system.
276 The data included vehicle speed, engine speed, engine coolant temperature and throttle pedal
277 position.

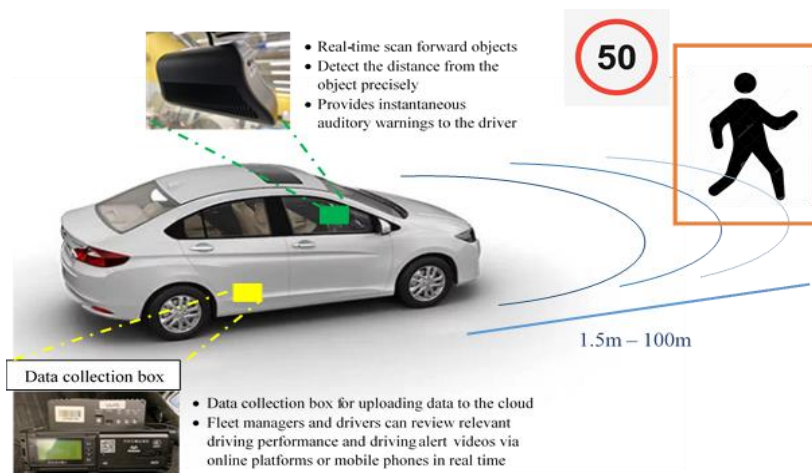


278
279 **Figure 2:** Diesel 3.3 tonnes LGV connected with the emission gas sample line and exhaust
280 flow measurement system.

281 *2.4 On-board green-safety device*

282 An in-vehicle device is required to provide the driver feedback instantaneously and
283 monitor driving behavior under real traffic conditions. Eco-driving devices can meet the above
284 requirements (Strömberg et al., 2015; Young et al., 2011). They monitor driving performance
285 including speed, acceleration, deceleration, gear shifting, idling time, fuel consumption, road
286 information and traffic conditions. The feedback may be given by a dashboard display,
287 smartphone applications, a GPS navigation system and dedicated aftermarket feedback systems
288 (Jamson et al., 2015). In this study, the on-board green-safety device installed on the test vehicle
289 was used to record the numbers of brake, tailgating and speeding warnings during stage 2 of
290 the on-road emissions experiments. The device is not activated in the first stage of experiments.
291 Figure 3 shows the main components and working principle of the green-safety device used in

292 the present study. As shown in Figure 3, the green-safety device was designed for safety and
 293 consisted of a driver assistance system, a movement detection sensor, a video camera and a
 294 data collection box. The driver assistance system uses artificial intelligence image processing
 295 to identify vehicles, pedestrian and objects with analyses of on-road conditions. In addition,
 296 dual cameras detect the distance from the object precisely and the driver assistance system can
 297 instantly alert drivers to prevent collisions. The data collection box was used to collect and
 298 upload data to the server. Drivers and fleet managers can download and analyze relevant
 299 driving performance and driving alert videos via online platforms or mobile phones in real-
 300 time. Furthermore, the driver assistance system also provides instantaneous auditory warnings
 301 to the driver when the vehicle acceleration, deceleration and turning speed exceeds the safety
 302 limit. The warning will not disappear until the drivers make the corresponding changes or the
 303 potential hazard disappears. As show in Table 4, those warnings include forward collision
 304 warning, lane departure warning, headway monitor warning, speed limit warning and
 305 aggressive acceleration, deceleration and turning warning.



306

307 **Figure 3:** Working principle of on-board green-safety device.

308 **Table 4:** Types of warnings provided by the on-board green safety device.

Types of warnings	Alert mechanism
Forward collision warning	When a possible collision will occur with the vehicle

	and other general objects in front.
Lane departure warning	When the vehicle departs from the driving lane.
Headway monitor warning,	When the time gap from the vehicle ahead is less than or equal to 1.0 second.
Aggressive acceleration warning	When the vehicle speed accelerates higher than 10 km/h in one second.
Aggressive deceleration warning	When the vehicle speed decelerates higher than 12 km/h in one second.
Aggressive turning warning	When the turning acceleration of the vehicle is higher than 3.0 m/s ² .

309 *2.5 Data analysis using VSP methodology*

310 VSP is defined as the instantaneous power output of the engine per unit mass of the vehicle
311 (Jiménez-Palacios, 1999). In recent years, emission models have been widely applied to
312 quantify emission rates and fuel consumption over VSP (Jiménez-Palacios, 1999). VSP
313 represents vehicle operating conditions and is calculated with the information of vehicle speed,
314 vehicle acceleration and road grade which are highly correlated with the fuel consumption and
315 gaseous emissions (Song and Yu, 2011; USEPA, 2002). In this study, the VSP methodology
316 was adopted to fulfill the objectives of the present study by calculating the percentage of time
317 spent in different driving patterns, including deceleration, idling, acceleration and hard
318 acceleration. In addition, calculating VSP involves aerodynamic drag and tire rolling resistance
319 of the vehicle. Thus, the formulae were developed for calculating the VSP values of different
320 types of vehicles. Road grade is calculated with the road surface altitude recorded by the GPS.
321 Based on the second-by-second recorded data, the distance traveled along the route is divided
322 into segments of 80 to 100 m. The elevation for each run along the segment is calculated. Thus,
323 the average road grade is calculated for each segment. In this study, equation (1) was applied
324 for calculating the VSP_{LGV} (W/kg) (Jiménez-Palacios, 1999; Zhai et al., 2008).

325
$$VSP_{LGV} = v \cdot (1.1 \cdot a + g \cdot \sin(\phi) + \phi_{LGV}) + \delta_{LGV} \cdot v^3 \quad (1)$$

326 where v (m/s) is the instantaneous vehicle velocity, a (m²/s) is the instantaneous vehicle
327 acceleration, g (m/s²) is the acceleration due to gravity, \emptyset is the road grade, φ is the coefficient
328 of rolling resistance term (0.132 for LGV) (Jiménez-Palacios, 1999; Zhai et al., 2008) and δ_{LGV}
329 is the coefficient of drag term (3.02×10^{-4} for LGVs) (Jiménez-Palacios, 1999; Zhai et al.,
330 2008).

331 Based on the recorded data, VSP values were calculated and grouped into 14 modes and
332 four driving conditions (Rolim et al., 2014). The negative values of VSP in modes 1 and 2 are
333 grouped into one, as they represent the vehicle's deceleration. Idling is represented in mode 3,
334 including the vehicle's acceleration when it started to move. VSP modes 4-7 and 8-14 are
335 grouped as mild driving and heavy acceleration, respectively. Having a larger number of VSP
336 modes represents the higher power demand of the engine.

337 **3. Results and discussion**

338 Results will be presented and discussed in three sub-sections. Sub-section 3.1 will report
339 the effect of the on-board green-safety device on driving behavior. In 3.2 the driving time
340 distribution for different VSP modes will be analysed. The effect of driving behavior on fuel
341 consumption and exhaust gas emissions will be reported in 3.3.

342 *3.1 Effect of on-board green-safety device on driving performance*

343 To understand the effect of on-board green-safety device on driving performance, driver
344 behavior will be analysed by comparing the driving parameters with and without activation of
345 the green-safety device. Table 5 shows the driving parameters of 30 experienced and
346 inexperienced drivers on a 3.3 tonnes diesel LGV. To understand the effect of the green-safety
347 device on driving performance, the percentages of individual driving parameter will be
348 presented and analysed.

Table 5: Driving parameters of tested 30 drivers on a 3.3 tonnes diesel LGV.

		Experienced driver		Inexperienced driver	
		Stage 1	Stage 2	Stage 1	Stage 2
Vehicle speed (km/h)	Average	44.6	41.4	46.5	42.1
		(39 - 54)	(35 - 46)	(40 - 53)	(25 - 48)
	Max	95.9	74.5	85.0	77.4
	Stdev	23.5	20.8	25.6	21.9
Engine speed (rpm)	Average	1,378	1,314	1,432	1,324
	Max	3,789	3,027	3,748	3,333
	Stdev	497	412	542	419
Acceleration (m/s ²)	Max	2.9	1.8	2.2	1.3
	Stdev	0.1	0.1	0.1	0.1
Accelerator pedal position (%)	Average	22.8	21.6	23.4	21.6
	Max	48.0	39.6	53.3	38.3
	Stdev	7.5	5.6	8.4	5.7
Travelling time (minutes)		25	27	24	27

350 As shown in Table 5, the average vehicle speed of the experienced and inexperienced
351 driver was reduced by 8% and 10% from the first to the second stage respectively. The
352 maximum vehicle speed of the experienced and inexperienced driver was reduced by 22% and
353 9% from the first to the second stage respectively. The average and maximum engine speed of
354 the experienced driver was reduced by 5% and 20% while that the inexperienced driver was
355 reduced by 8% and 11% from the first to the second stage respectively. In addition, the average
356 accelerator pedal position of the experienced and inexperienced driver was reduced by 5% and
357 8% from the first to the second stage respectively. The maximum accelerator pedal position of
358 the experienced driver was reduced by 17% while that the inexperienced driver was reduced
359 by 28% from the first to the second stage respectively. From the overall statistics of the driving
360 parameters of 30 drivers, the percentage reduction of average vehicle speed, engine speed and
361 Accelerator pedal position of the inexperienced driver were higher than those of the
362 experienced driver after activation of on-board green-safety device. In contrast, the percentage

363 reduction of maximum vehicle speed and engine speed of the experienced driver were higher
364 than the inexperienced driver from the first stage to the second stage of experiments.

365 According to the driving performance of 30 drivers, the maximum vehicle speed and
366 engine speed of the experienced drivers were higher than the inexperienced drivers. This can
367 be explained as the rich driving experience for the experienced drivers. Therefore, experienced
368 drivers chose a higher speed on highway. In addition, the percentage reduction of average
369 vehicle speed, engine speed and of accelerator pedal position of the inexperienced driver were
370 higher than those of the experienced driver after activation of the on-board green-safety device.
371 This was mainly due to the long-term formed habits of experienced drivers are harder or less
372 willing to be changed to accept the assistance of the on-board green-safety device, whereas
373 inexperienced drivers are likely to be more receptive to change and improve their driving
374 behaviors.

375 From a safety point of view, Table 6 compares the total numbers of warning parameters
376 between both monitoring stages. As shown in Table 6, the number of braking events for the
377 experienced and inexperienced driver was greatly reduced by 62% and 72% from the first to
378 the second stage respectively. The number of forward collision, lane departure and headway
379 monitor warnings were reduced more than 50% after activation of on-board green-safety device.
380 For the numbers of aggressive acceleration, aggressive deceleration and aggressive turning
381 warnings, they were greatly reduced by 48%, 100% and 72% for the experienced drivers and
382 74%, 78% and 60% for the inexperienced driver from the first to the second stage. This
383 indicated a strong impact of on-board green-safety device for both experienced and
384 inexperienced drivers. The number of forward collision, lane departure and headway monitor
385 warning were greatly reduced indicating the green-safety device was effective to improve
386 drivers' understanding of road safety and the reduction of aggressive acceleration, aggressive
387 deceleration and aggressive turning warnings indicating that the green-safety device was also

388 effective to help both experienced and inexperienced drivers to avoid aggressive driving and
 389 enhance understanding for eco-driving. In addition, the total numbers of warnings for the
 390 experienced and inexperienced driver's group were greatly reduced by 71% and 72% from the
 391 first stage to the second stage respectively. This provided an indication that following the
 392 instructions from the safety device led to a smoother driving speed than that without the device
 393 and yielded a more appropriate vehicle speed when driving.

394 **Table 6:** Changes on warning parameters between both monitoring stages.

	Experienced driver		Inexperienced driver	
	Stage 1	Stage 2	Stage 1	Stage 2
Braking number (times)	95	36	177	49
Forward collision warning (times)	10	2	24	5
Lane departure warning (times)	34	15	102	48
Headway monitor warning (times)	109	16	185	28
Aggressive acceleration warning (times)	56	29	57	15
Aggressive deceleration warning (times)	2	0	18	4
Aggressive turning warning (times)	43	12	62	25
Total number of warning (times)	254	74	448	125

395 *3.2 Distribution of travelling time over different VSP mode*

396 Travel time is quite often critical which can affect vehicle emissions and fuel consumption.
 397 Shorter travel times are preferred or required. However, when it comes to real-world conditions,
 398 travel time can be affected by driving performance including time spent on idling, acceleration
 399 and deceleration. Thus, the distributions of VSP modes were calculated to compare the
 400 percentage of time spent in different driving patterns, including deceleration, idling,
 401 acceleration and strong acceleration. As shown in Table 7, the experiments were conducted on
 402 30 days, including 120 trips with a total of 2,244 km being travelled which was evenly
 403 distributed over two stages of experiments both with and without the on-board green-safety

404 device.

405 **Table 7:** Driving data between both monitored stages.

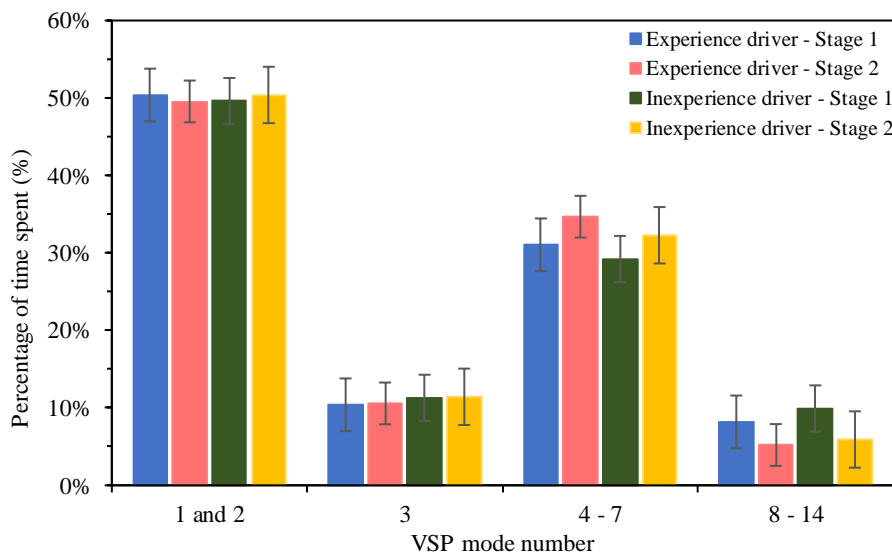
	Stage 1	Stage 2
Total travelling time (hours)	24.8	27.3
Total travelling distance (km)	1,122.8	1,121.4
Number of trips	60	60
Number of days	15	15

406 Figure 3 show the average time spent on different VSP modes without and with the on-
407 board green-safety device for both experienced and inexperienced drivers. As shown in Figure
408 3, the percentage of time spent in modes 1 and 2 of experienced group's driver is reduced from
409 50.4%% to 49.6% from stage 1 to 2. This can be explained as the braking time is reduced by
410 the driver. In contrast, the percentage of time spent in modes 1 and 2 of inexperienced group's
411 driver is increased by 0.8% from stage 1 to 2. These findings may relate to the rich driving
412 experience in experienced driver's group, experienced drivers chose a steadier speed than
413 inexperienced drivers (Wu et al., 2018). Furthermore, the on-board green-safety device
414 improved experienced drivers' ability to maintain a more consistent driving behavior to reduce
415 the number of decelerations. There is no significant difference in time spent in two stages of
416 experiments for in both VSP 1-2 and VSP mode 3.

417 In the medium VSP modes 4 to 7, the percentage of time spent by experienced and
418 inexperienced group's driver is increased by 3.7% and 3.1% from stage 1 to 2 respectively. The
419 increase of average distribution from stage 1 to 2 in modes 4 to 7 can be related to the lower
420 and steady speed of the vehicle as controlled by the on-board green-safety device. It can also
421 be explained that the driver controlled the speed of the vehicle more appropriately. These
422 results can be also supported by the driving parameters for both experienced and inexperienced
423 drivers. After activation of on-board green-safety device, the average vehicle speed and engine

424 speed of experienced driver was lower than inexperienced driver (Stahl et al., 2016).

425 In the higher VSP modes 8 to 14, the percentage of time spent for experienced and
426 inexperienced driver is reduced by 3.0% and 4.0% from stage 1 to stage 2 respectively. This
427 was due to the reduced time spent on speeding and strong acceleration in the heavy acceleration
428 driving modes in stage 2. The on-board green-safety device was effective to improve drivers'
429 ability to perform eco-driving and reduce the time spent on excess speeding and heavy
430 acceleration. These results can be also supported by the driving parameters for both
431 experienced and inexperienced drivers. The percentage reduction of average vehicle speed and
432 the number of aggressive acceleration warnings of inexperienced drivers was higher than that
433 for experienced drivers.



434

435 **Figure 4:** Comparison of average time distribution over VSP modes of experienced driver
436 and inexperienced driver without (stage 1) and with (stage 2) the on-board green-safety
437 device. Error bars are the standard deviation.

438

439 *3.3 Effect of on-board green-safety device on fuel consumption and exhaust gas* 440 *emissions*

441 To assess the effect of driving behavior on fuel consumption and gaseous emissions of
442 LGV under real driving conditions, the exhaust gas emissions and fuel economy in each of the

443 VSP mode were calculated. Table 8 shows the overall fuel consumption and emission rates of
444 the tested diesel 3.3 tonnes LGV for both experienced and inexperienced driver with and
445 without the activation of green-safety device. As shown in Table 8, THC and CO₂ emission
446 rates of the experienced driver were reduced by 3% and 5% respectively from stage 1 to stage
447 2. The results can be explained as the experienced driver drove the LGV more carefully with
448 the reduction of average vehicle speed and engine speed. In addition, with the reduction of the
449 maximum acceleration and engine speed, the NO emission rates of the experienced driver were
450 greatly reduced by 56% from 0.36 g/km without the activation of device to 0.16 g/km with
451 device, and the NO₂ reduced by 39% from 0.49 g/km to 0.30g/km, demonstrating a strong
452 impact of the on-board green-safety device on NO and NO₂ emissions of experienced driver.
453 However, the CO emission rates of the experienced driver was increased from 0.009 g/km to
454 0.014 g/km. This result is consistent with the previous study that the driving behavior did not
455 show distinct difference in the CO emissions (Gallus et al., 2017). With the lower acceleration
456 and average vehicle speed of the test vehicle, the soot mass emission rates and fuel consumption
457 were reduced by 35% and 5% from the first stage to second stage of experiment.

458 For the group of inexperienced drivers, the THC and CO₂ emission rates were reduced by
459 5% and 6% respectively from stage 1 to stage 2. This results can be explained as the percentage
460 of time spent on lower VSP mode is increased and the driver tends to spend more time on
461 steady speed and acceleration. As shown in Table 8, the CO₂ emissions were reduced from
462 286.0 g/km without the activation of device to 268.9 g/km with device. Furthermore, the
463 emission rates of NO and NO₂ were greatly reduced by 65% from 0.44 to 0.15 g/s and 50%
464 from 0.55 to 0.27 g/s respectively in the second stage of the on-road emissions experiment,
465 demonstrating a strong impact of the driving behavior on NO and NO₂ emissions of
466 inexperienced driver. The results can be explained as the inexperienced driver drove the LGV
467 more carefully with the reduction of time spent on excessive speeding, strong acceleration and

468 deceleration. In addition, with the lower acceleration and vehicle speed of the test vehicle, the
 469 soot mass emission rates and fuel consumption were reduced by 19% and 6% respectively from
 470 the first stage to second stage of experiment.

471 **Table 8:** Averaged exhaust gas emission rates and fuel consumption of diesel 3.3 tonnes
 472 LGV.

	Experienced driver			Inexperienced driver		
	Stage 1	Stage 2	Percentage of change	Stage 1	Stage 2	Percentage of change
THC (g/km)	0.0082	0.0079	-3%	0.0081	0.0077	-5%
CO (g/km)	0.009	0.014	49%	0.016	0.017	4%
CO ₂ (g/km)	280.7	266.7	-5%	286.0	268.9	-6%
NO (g/km)	0.36	0.16	-56%	0.44	0.15	-65%
NO ₂ (g/km)	0.49	0.30	-39%	0.55	0.27	-50%
Soot mass (g/km)	0.019	0.013	-35%	0.033	0.027	-19%
Fuel economy (l/100km)	10.6	10.1	-5%	10.8	10.2	-6%

473 To understand the averaged results shown in Table 8, distributions of the emissions and
 474 fuel consumption over the VSP mode will be analysed. Figure 4 shows the distribution of
 475 emissions over the VSP modes. As shown in Figure 4, after activation of the on-board green-
 476 safety device for experienced driver, the emission rates of THC in VSP modes 1 and 2 was
 477 reduced by 4%, CO₂ by 7% NO by 54% and NO₂ by 39%. The results can be explained as the
 478 experienced driver reduce the number of braking events and increased the coasting distance.
 479 However, the CO emission rates was increased after activation of the on-board green-safety
 480 device. It is reasonable to assume that CO emissions were not corresponding to the driving
 481 behavior when the LGV was decelerating in VSP modes 1 and 2. Furthermore, the soot mass
 482 emission rates were greatly reduced by 20% from the first stage to second stage of experiment.

483 For the emission rates of inexperienced driver in VSP modes 1 and 2, THC, CO₂, NO and NO₂
484 emissions were reduced by 6%, 3%, 62% and 46% respectively from stage 1 to stage 2. In
485 addition, the CO emission rates was weakly affected by the driving behavior and remains
486 unchanged in both monitoring stages. The soot mass emission rates were greatly reduced by
487 28% from the first stage to second stage of experiment. As shown in Figure 5, the fuel
488 consumption of experienced and inexperienced driver in VSP modes 1 and 2 were reduced by
489 7% and 3% respectively from stage 1 to stage 2. This indicates a strong impact of the driving
490 style such as reduction of braking events and an increase of the coasting distance on fuel
491 economy as shown in the experimental results.

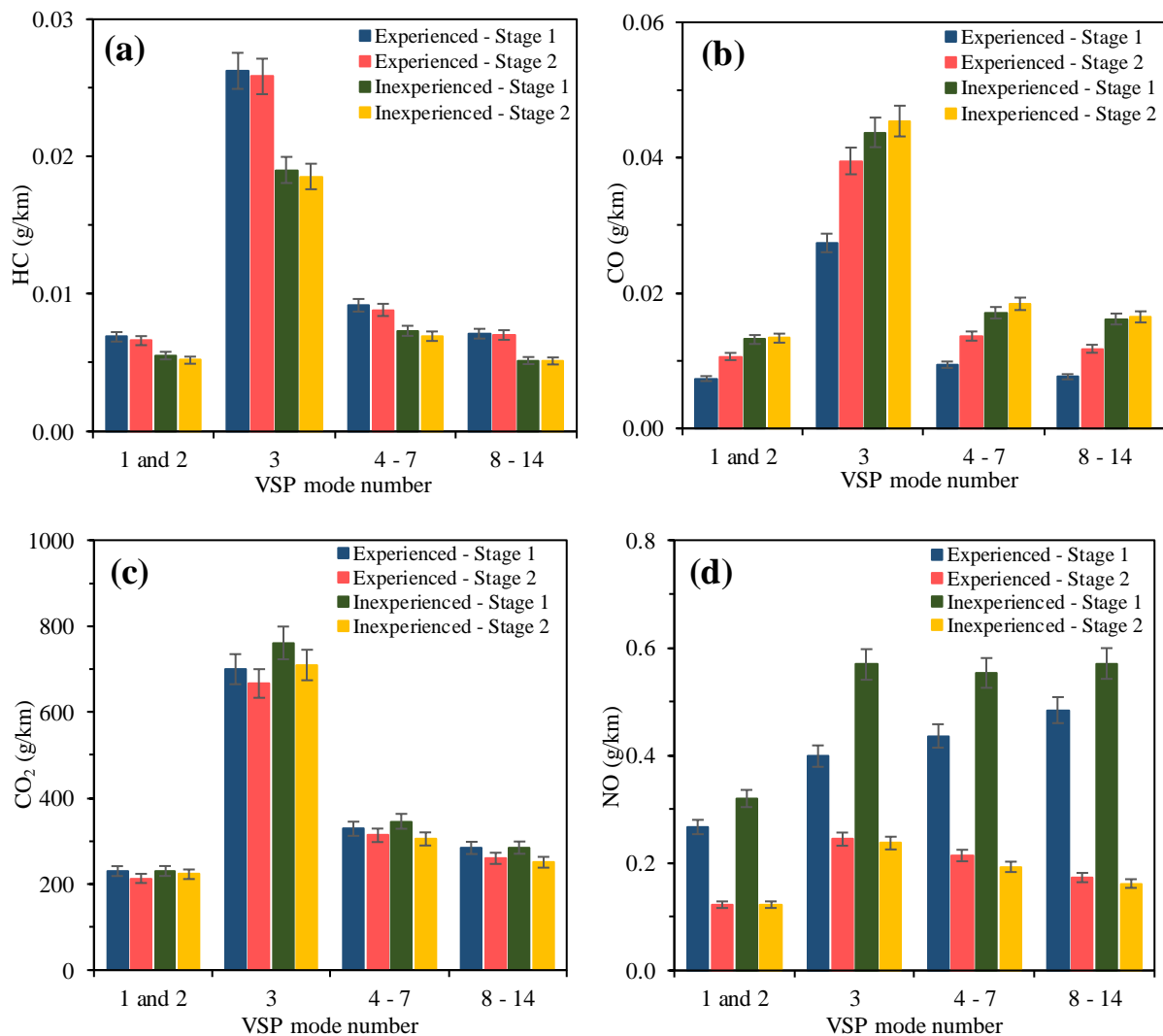
492 For the emission rates of experienced driver in VSP mode 3 which is the idling condition,
493 THC, CO₂, NO and NO₂ emission rates were reduced by 2%, 5%, 39% and 19% respectively
494 from stage 1 to stage 2. However, the emission rates of CO were increased after activation of
495 the on-board green-safety device. For the emission rates of inexperienced driver in VSP mode
496 3, THC, CO₂, NO and NO₂ emission rates were reduced by 2%, 7%, 58% and 33% respectively
497 from stage 1 to stage 2. Furthermore, the soot mass emission rates of experienced and
498 inexperienced driver were reduced by 14% and 16% respectively from the first stage to second
499 stage of experiment. As shown in Figure 5, the fuel consumption of experienced in VSP modes
500 3 was reduced by 5% and inexperienced driver were reduced by 7% from stage 1 to stage 2.

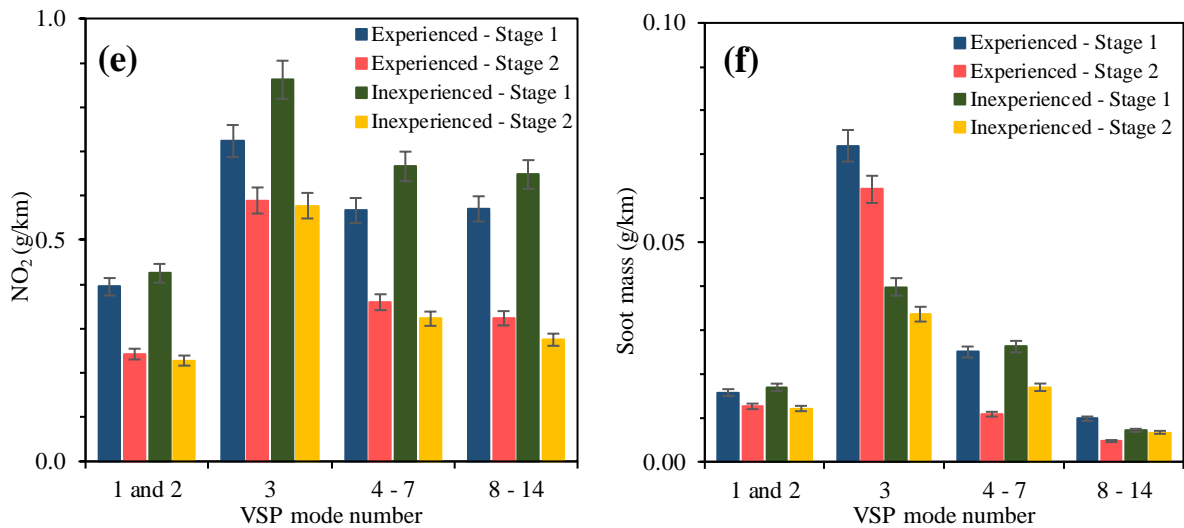
501 For the emission rates for experienced driver in the medium VSP modes 4 to 7 (which is
502 normal driving condition) (Rolim et al., 2014), the emission rates of THC, CO₂, NO and NO₂
503 were reduced 4%, 5%, 51% and 37% respectively from stage 1 to stage 2. With the increase of
504 the percentage of time spent in VSP modes 4 to 7, the THC emissions were reduced from
505 0.0092 g/km without the activation of on-board green-safety device to 0.0088 g/km with the
506 on-board green-safety device. The CO₂ emissions were reduced from 329 g/km to 314 g/km,

507 the NO from 0.44 g/km to 0.21 g/km and the NO₂ from 0.57 g/km to 0.36 g/km. The results
508 indicated that experienced driver controls the speed of the LGV more appropriately and the
509 time spent on steady driving and acceleration was increased in the second stage of experiment.
510 Resulting in the reduction of CO₂, the fuel consumption of experienced driver was reduced by
511 5% from 12.5 l/100km in stage 1 to 11.9 l/100km in stage 2. In addition, the soot mass emission
512 rates of experienced driver were greatly reduced by 57% from stage 1 to stage 2. This provided
513 indication that the fuel economy and soot mass can be influenced by the travelling speed of the
514 vehicle. For the emission rates of inexperienced driver, the THC emissions were reduced by
515 5% from 0.0073 g/km to 0.0069 g/km. The CO₂ emissions were reduced by 12% from 346
516 g/km to 305 g/km, the NO emissions were greatly reduced by 65% from 0.55 g/km to 0.19
517 g/km and NO₂ emissions by 52% from 0.67 g/km to 0.32 g/km. The reduction of CO₂ was
518 mainly due to the fuel consumption which was reduced by 12% from 13.1 l/100km without the
519 activation of device to 11.6 l/100km with the device. These results indicated that inexperienced
520 driver controlled the speed of the LGV more appropriately so that more time was spent on
521 driving slowly and steadily in stage 2 of the on-road experiment. Furthermore, the soot mass
522 emission rates of inexperienced driver were reduced by 35% from stage 1 to stage 2.

523 In higher VSP modes 8 to 14 with heavy acceleration, the emission rates THC, CO₂, NO
524 and NO₂ of the experienced driver were reduced by 1%, 9%, 64% and 43% respectively from
525 stage 1 to stage 2. In the second stage of the experiment, the maximum acceleration of the
526 experienced driver was decreased by 61% from 2.9 m/s² to 1.8 m/s². This indicates a strong
527 impact of the driving style such as reduction of excess speeding and strong acceleration on
528 emission rates of experienced driver as shown in the experimental results. With the lower and
529 steady speeds of the test vehicle, the fuel consumption of experienced driver was reduced by
530 9% from the first stage to the second stage of experiment. In addition, the soot mass emission
531 rates for experienced drivers were greatly reduced by 52% from stage 1 to stage 2. For the

532 emission rates of the inexperienced driver, the emission rates THC, CO₂, NO and NO₂ of the
 533 experienced driver were reduced by 1%, 12%, 72% and 58% respectively from stage 1 to stage
 534 2. After the activation of the on-board green-safety device, the maximum acceleration and
 535 speed of the inexperienced driver was decreased by 69% and 17% respectively. This indicates
 536 a strong impact of the driving style such as reduction of excess speeding and strong acceleration
 537 on emission rates of inexperienced driver as shown in the experimental results. With the lower
 538 and steady speeds of the test vehicle, the fuel consumption and soot mass emission rates were
 539 reduced by 12% and 6% respectively from stage 1 to stage 2.





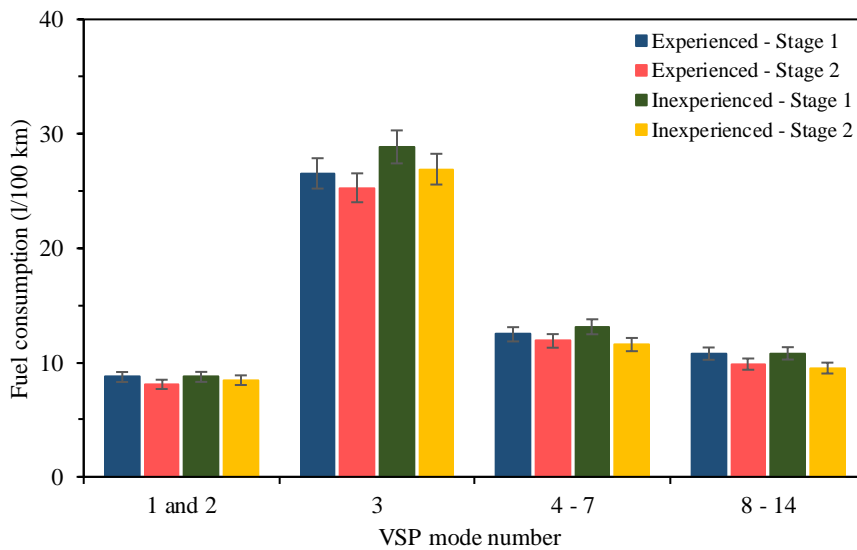
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Figure 5: The THC (a), CO (b), CO₂ (c), NO (d), NO₂ (e) and soot (f) emissions of the LGV for experienced and inexperienced drivers in each group of the VSP modes in both monitoring stages



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547

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Figure 6: The fuel consumption of the LGV for experienced and inexperienced driver in each group of the VSP modes in both monitoring stages.

549 4. Conclusions

550

551

552

On-road emissions experiments have been conducted to investigate the effects of driving behavior on fuel consumption and gaseous and particulate emissions of a diesel 3.3 tonnes LGV. A PEMS was used to measure the emissions data, driving parameters and environmental

553 parameters from a diesel LGV under real-world conditions. A representative driving route that
554 covered urban and highway driving was designed for the experiments. The effectiveness of on-
555 board green-safety device for both experienced and inexperienced drivers and the effect of
556 driving behavior on fuel consumption and emissions were examined. The VSP model was
557 applied to analyse the experimental data. The major results can be summarised as follows.

558 1) The on-board green-safety device improved driving behavior obviously for both
559 experienced and inexperienced drivers. The total number of warnings for the experienced and
560 inexperienced driver was greatly reduced by 71% and 72% respectively.

561 2) The maximum vehicle and engine speeds for the experienced driver (22% and 20%)
562 were reduced more than the inexperienced driver (9% and 11%) by the green-safety device. In
563 contrast, the average vehicle and engine speeds for the inexperienced driver (10% and 8%)
564 were reduced more than the experienced driver (8% and 5%) after activation of on-board green-
565 safety device.

566 3) The VSP results of both experienced and inexperienced drivers showed that the
567 percentage of time spent on lower VSP mode was increased and the time spent on higher VSP
568 mode was decreased after the green-safety device was activated. This was due to the driver's
569 more adequate use of the engine as well as to spend more time on cruising.

570 4) By following the instructions from the on-board green-safety device, the driving
571 behavior had a positive effect on fuel consumption and gaseous emissions of both experienced
572 and inexperienced drivers. For the experienced driver, the average THC was reduced by 3%,
573 CO₂ by 5%, NO by 56%, NO₂ by 39%, soot mass by 35% and fuel consumption by 5% with
574 the on-board green-safety device. For the inexperienced driver, the average reduction was 5%
575 for THC, 6% for CO₂, 65% for NO, 50% for NO₂, 19% for soot mass and 6% for fuel

576 consumption. The experimental results can be explained as the driving behavior improved and
577 the time spent on excessive speeding, strong acceleration and deceleration was reduced.

578 5) Overall, our RDE testing results indicate that the on-board green-safety device can be
579 deployed in vehicles not only to positively influence driving behavior but also to successfully
580 reduce real driving fuel consumption and emissions. In order to further investigate the effects
581 of driving behavior on fuel consumption and emissions, future research should extend to
582 passenger cars and trucks which may show similar or different results from the change of
583 driving behavior.

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715 **Supplementary Material**716 **Table S1:** The specifications of the AVL M.O.V.E Gas PEMS 493 and PM PEMS 494.

Gas	Measurement Range	Zero Drift	Analyzer
THC	0-30,000 ppmC1	< 1.5 ppmC1/8h	FID
NO	0-5000 ppm	2 ppm/8h	NDUV
NO ₂	0-2500 ppm	2 ppm/8h	NDUV
CO	0-5 vol%	20 ppm/8h	NDIR
CO ₂	0-20 vol%	0.1 vol%/8h	NDIR
Dilution ratio		DR=2 to 100 (proportional)	
Filter holder		47 mm, measurement filter	
Soot measuring range		up to 1000 mg/m ³ (at DR=20)	
Soot detection limit		~ 5 µg/m ³	

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718 **Table S2:** Key parameters measured and recorded by PEMS.

Parameter	Unit
Total hydrocarbons	ppm
Carbon monoxide	ppm
Carbon dioxide	%
Nitric oxide	ppm
Nitrogen dioxide	ppm
Soot mass	µg
Ambient temperature	°C
Ambient humidity	%
Ambient pressure	mbar
Exhaust flow rate	l/h
Exhaust flow temperature	°C
Vehicle speed	km/h
Vehicle position	Latitude and longitude
Vehicle altitude	m
Throttle pedal position	%
Engine speed	rpm
Engine coolant temperature	°C

Table S3: The specifications of the on-board green-safety device.

Sensor unit		
Electrical characteristics	Input voltage	9 – 32 volt
	Input current	540 mA @ 12 volt, 270 mA @ 24 volt
	Max power consumption	6.5 W
Movement detection sensor	Sensor model	Foresight binocular camera
	Resolution	720 p
	Scan distance	1.5 m to 100 m
	Horizontal field angle	~ 42 degree
	Time delay	< 3 ms
Driving user interface unit		
Types of warnings	Forward collision warning, lane departure warning, headway monitor warning, aggressive acceleration warning, aggressive deceleration warning, aggressive turning warning	