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Integrated indicator to evaluate vehicle performance across: Safety, fuel efficiency and green domains

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ABSTRACT

In general, car manufacturers face trade-offs between safety, efficiency and environmental performance when choosing between mass, length, engine power, and fuel efficiency. Moreover, the information available to the consumers makes difficult to assess all these components at once, especially when aiming to compare vehicles across different categories and/or to compare vehicles in the same category but across different model years. The main objective of this research was to develop an integrated tool able to assess vehicle's performance simultaneously for safety and environmental domains, leading to the research output of a Safety, Fuel Efficiency and Green Emissions (*SEG*) indicator able to evaluate and rank vehicle's performance across those three domains. For this purpose, crash data was gathered in Porto (Portugal) for the period 2006–2010 (N = 1374). The crash database was analyzed and crash severity prediction models were developed using advanced logistic regression models. Following, the methodology for the *SEG* indicator was established combining the vehicle's safety and the environmental evaluation into an integrated analysis. The obtained results for the *SEG* indicator do not show any trade-off between vehicle's safety, fuel consumption and emissions. The best performance was achieved for newer gasoline passenger vehicles (<5year) with a smaller engine size (<1400 cm^3). According to the *SEG* indicator, a vehicle with these characteristics can be recommended for a safety-conscious profile user, as well as for a user more interested in fuel economy and/or in green performance. On the other hand, for larger engine size vehicles (>2000 cm^3) the combined score for safety user profile was in average more satisfactory than for vehicles in the smaller engine size group (<1400 cm^3), which suggests that in general, larger vehicles may offer extra protection. The achieved results demonstrate that the developed *SEG* integrated methodology can be a helpful tool for consumers to evaluate their vehicle selection through different domains (safety, fuel efficiency and green emissions). Furthermore, *SEG* indicator allows the comparison of vehicles across different categories and vehicle model years. Hence, this research is intended to support the decision-making process for transportation policy, safety and sustainable mobility, providing insights not only to policy makers, but also for general public guidance.

1. Introduction

During the last decennia there has been an increase in the amount of consumer interest in the vehicle safety performance and fuel economy. Consumers tend to equate vehicle safety with the presence of specific features or technologies (e.g., advanced braking systems, front passenger airbags) rather than with the outcomes of vehicle crash safety/test or crashworthiness (Koppel et al., 2008). Crash testing is a valuable source for consumer regarding vehicle crash safety and credits a car manufacturer for focusing on safety. Despite the scientific procedures under which crash tests are conducted, these tests have limitations. Under the EuroNCAP procedures tests, the frontal impact takes place at 64 kmh^{-1}, meanwhile

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the car strikes deformable barrier that is offset (EuroNCAP, 2011). It simulates one car having a frontal impact with another car of similar weight. Hence, it can only be compared with vehicles in the same class and within a 113 kg weight range (EuroNCAP, 2011). Therefore in Europe EuroNCAP discourage consumers from comparing ratings of cars from different segments and in real crashes there is obviously no control on the vehicle categories involved. Likewise, in the United States the Institute Insurance for Highway Safety (IIHS) endorse the consumers to not compare ratings across vehicle size groups because size and weight influence occupant protection in serious crashes (IIHS, 2012). "Larger, heavier vehicles generally afford more protection than smaller, lighter ones" (IIHS, 2012). Regarding to crash test limitations, Lie and Tingvall claimed that EuroNCAP is not able to predict crash outcomes because start rakings system does not reflect the mass of the vehicles involved in the collisions, and mass has an important role in the impact severity distribution (Lie and Tingvall, 2002). Newstead et al. (2011) stated that crash tests "do not account for vehicle mass effects in the real world and they only cover a limited range of crash types".

Chen and Ren (2010) claimed that the relationship between vehicle safety ratings and fuel efficiencies seem to have been mostly positive correlated. Wenzel's work suggested that vehicle design, which can be improved by safety regulations, would be more effective on occupant safety than fuel economy standards that are structured to maintain vehicle size and weight (Wenzel, 2016). Tolouei and Titheridge (2009) warned that in vehicle design there is a trade-off between fuel economy and secondary safety performance imposed by mass. Even though mass imposes a trade-off in vehicle design, between safety and fuel use, it does not mean that it imposes a trade-off between safety and environmental goals in the vehicle fleet as a whole (Tolouei and Titheridge, 2009). However other study suggested that there is almost no trade-off between better car safety and CO_2 emission reduction (Zachariadis, 2008). Zachariadis claimed that enhanced safety of modern cars has a very small effect on vehicle mass and does not significantly affect fuel consumption (Zachariadis, 2008).

While the advocates of the new vehicle standards claim for the benefits of energy and environment, opponents argue that vehicle safety will be compromised. The current structure of fuel economy standards could encourage manufacturers to sell more smaller, lighter cars to offset the fuel consumed by their bigger and heavier models (IIHS, 2009). "Automakers even are willing to sell smaller and less safe cars at a loss to ensure compliance with fleetwide requirements" (IIHS, 2009). A more recent study claimed that the two ways to decrease the CO_2 emissions is to decrease the mileage and the emissions per kilometer (Bampatsou and Zervas, 2011). However the study by IIHS (2009) claimed that the main way to reduce CO_2 emissions is by reducing car weight, which means downsizing vehicles. Nevertheless IIHS research also suggested that would cause conflicts with occupants safety goals (IIHS, 2009). The application of lightweight design with thermoplastics offers a possibility to reduce CO_2 emissions and fuel consumption (Park et al., 2013). Substituting reinforced polymers in vehicle body components is a promising approach to weight reduction and fuel savings. Nanotechnology application into the automotive industry leads to lighter car bodies without compromising stiffness and crash resistance and results in less fuel consumption (Coelho et al., 2012).

Thought automakers must comply with emissions regulations, consumers' preferences influence the market share by selecting vehicle attributes, such as car segment, fuel type, mass/size, and engine size. Until 2007, consumer's preferences shifts towards larger and less fuel-efficient car segments and also towards larger, heavier and more powerful cars within the same car segment (Kok, 2013). From 2007 to 2011, consumer's preferences shift toward smaller car segments (Kok, 2013). During the last years, due to the global recession and due to fuel economy and CO_2 emissions targets, manufacturers have increased the sales of smaller, lighter cars to offset the fuel economy by their bigger and heavier models. Smaller cars are more affordable, use less fuel and emit less pollutants.

The previous research work showed that the safety and environmental trade-offs are still not fully explained and they impose a challenge for the transportation and environmental authorities. The few existing studies in the trade-off analysis (Chen and Ren, 2010; Wenzel, 2016; Tolouei and Titheridge, 2009; Zachariadis, 2008) have focused on the relationship between safety and fuel consumption, targeting CO_2 emissions only and discarding local pollutants such as: carbon monoxide (CO), nitrogen oxide (NO_x) and particle matter (PM), that have not been included in the analysis. Therefore, safety trade-offs analysis imposes still a challenge and the following questions can be risen. How would a consumer compare the vehicle's performance among different classes such as: selecting between purchasing a passenger car or a SUV? Why would a consumer have to choose the heaviest vehicle on the market to gain safety benefits? But if it does, the other road users could be at higher risk specially the ones travelling in lighter cars. On the other hand, if all new passenger cars would shift towards larger and heavier vehicles, then what would be the cost in fuel consumption and air emissions? Addressing these questions yield to the main motivation for this research. Thus, the major objectives of this study were:

1. Develop an integrated methodology to evaluate vehicle's safety, fuel efficiency and air emissions.
2. Provide an easier to use tool to consumers for evaluation of vehicle performance applicable to different vehicle categories and/or classes and allowing for user profile preferences

In order to address the above questions, an integrated methodology is presented in this paper focusing the relationship between vehicle's safety and fuel consumption, considering not only CO_2 emissions but also local pollutants as CO, NO_x and PM. Such integrated methodology was conducted in two dimensions. First, for the vehicle safety performance this research has taken into account not only vehicle's crashworthiness when involved in a single-vehicle crash, but also when involved in a two-vehicle collision. Second, for the vehicle environmental performance this research was not limited to vehicle CO_2 emissions only, but also it covered other local pollutants (CO, NO_x and PM), which are relevant in terms of air quality and have a high impact on human health in particular in urban areas (Barros et al., 2013).

This paper is organized as follows. Section 1 presents the previous work findings, highlights research gaps and presents the main objectives of this research. Section 2 presents the modeling framework for the integrated analysis. Section 3 presents and discusses the results obtained for a scenario based analysis considering different user profiles. Last, Section 4 provides the main conclusions.

2. Material and methods

The main steps undertaken to execute the *SEG* integrated methodology to assess vehicle safety, fuel efficiency and air emissions are summarized in Fig. 1. First, real word crash data was collected and an extensive database was developed (see Section 2.1). Second, the effect of vehicle characteristics on safety, fuel economy and air emissions was modeled. As a general methodology overview, Fig. 1 highlights the independent variables that were found important to estimate the response (dependent) variables for each modeldomain targeting vehicle's performance across: