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Multi-objective optimization for short distance trips in an urban area: choosing between motor vehicle or cycling mobility for a safe, smooth and less polluted route

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Abstract

Mobility in urban areas is highly complex because of the variety of possible facilities and routes, the multitude of origins and destinations, the increase of population density and traffic. Furthermore, people are willing to use more environmentally friendly transportation modes, such as cycling, to do short-distance trips in urban areas.

This paper develops a multi-objective model for passengers in urban transportation network for short trips using bicycle or motor vehicle. The main objective of this paper is to improve the urban network mobility in order to decrease traffic congestion, road conflicts between road users and pollution. Furthermore, optimization objectives could comprehensively reflect expectations of passengers from the dimension of traffic and emissions as criteria and use a motor vehicle or a bicycle as an alternative.

The methodology of this study was applied based on the real world case study in the city of Aveiro, Portugal. The present work uses a microscopic simulation platform of traffic (VISSIM), road safety (SSAM) and emissions (Vehicle Specific Power – VSP) to analyze traffic operations, road conflicts and to estimate carbon dioxide (CO_2) and nitrogen oxide (NO_X) emissions. Three-dimensional Pareto Fronts, which were expressed through traffic performance, road conflicts between motor vehicles and bicycles and emissions, were optimized using the fast Non-Dominated Genetic Algorithm (NSGA-II).

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Keywords: Microscale modeling, Multi-objective optimization, Traffic, Safety, Emissions

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1. Introduction and objectives

Cycling brings the following advantages: health issues improvement, environmental preservation, and lower traffic congestion. Hence, the demand for cycling increases day after day especially in high density areas (Pucher and Buehler, 2008; Twaddle et al., 2014; Coelho and Almeida, 2015). Because of complexity and congestion characteristics of urban road networks, to cycle can be defined as the best and fast alternative to use in a group of multiple roads. The short distance variety of routes between origin and destination gives more alternative to the cyclist when compared to the user of a motor vehicle; under a considerable variety of options, bicycle users may choose the optimal route according to their personal preference such as travel time, emissions and safety concerns.

Considering safety, in case of urban areas, number of conflicts has a significant relationship with the number of crashes (Van Hout et al., 2008). Moreover, traffic safety concerns could be of high importance for cyclists due to the fact that a bicycle has more vulnerable potential and exposed to damage of a collision than a motor vehicle (Van Hout et al., 2008; Götschi et al., 2016).

The problem of air pollution in urban areas is aggravated and becoming a critical issue in terms of increased emissions. European Environment Agency (EEA) estimates that air pollution causes 467,000 premature deaths a year in Europe (EEA, 2016).

Due to these reasons it appears that not only traffic performance but also vehicle emissions and safety concerns appear simultaneously as key challenges in urban road networks. In this way the role of bicycle can be more important because increasing the modal share of cycling significantly reduces transportation emissions and traffic congestion as well. According to a case study in New Zealand (Lindsay et al., 2011), the results showed that by shifting only 5% of motor vehicle kilometers to cycling lead to a reduction of almost 223 million kilometers per each year, saving about 22 million liters of fuel and reducing 0.4% of greenhouse emissions.

Several studies have been carried out about multi-objective optimization problems involving safety concerns, traffic performance and emissions in urban areas for motor vehicle purposes (Wisemans et al., 2010; Chen and Zhang, 2013). However, there is a lack of research using multi-objective analysis in order to find the balanced solutions regarding traffic performance, safety and emissions in an integrated way for both of cyclists and motor vehicle drivers. For instance, Ehrgott et al. (2012) have applied a two criteria analyses for this purpose but this work considers three criteria with multiplying safety analysis which gives more complete work. Thus, the main objective of this paper is to optimize the choices of the routes that are carried out using the individual transport (motor vehicle) or the bicycle considering in this choice traffic performance, environmental and safety aspects. The final outcome of this work is ultimately to increase the use of more sustainable modes, namely the bicycle, by creating a methodology that can assist users and decision makers in their decision. This paper addressed the above concerns in a real-world urban network (with no of cycle paths) by evaluating the safety, traffic performance and global/local pollutant emissions.

This paper is divided into four sections. Section one details background and objectives while section two establishes the methodology framework and methods. Then, section three explains the results and discussions. Finally, section four summarize the paper and concludes the findings and limitations.

2. Methodology

The methodology of this study was applied based on the real world case study in an urban road network in the city of Aveiro, Portugal. The present work uses a microscopic simulation platform of traffic (VISSIM) (PTV, 2011) and emissions (Vehicle Specific Power – VSP) (Frey et al., 2002) to analyze traffic operations and to estimate carbon dioxide (CO_2) and nitrogen oxide (NOx) emissions generated by vehicles in the selected routes of the network. Furthermore, the Surrogate Safety Assessment Methodology (SSAM) (Gettman et al., 2008) was applied to assess road safety. Traffic movements were videotaped and second-by-second speed data and acceleration-deceleration rates were collected on-board a test-equipped vehicle and a bicycle. Subsequently, the collected data were coded in the VISSIM after calibration and validation. The flowchart of methodology was illustrated in Fig. 1.