SHORT PAPER TEMPLATE GET2020

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IMPACT OF MOTOR VEHICLES-BICYCLES INTERACTION ON ROUTE SELECTION, TRAFFIC PERFORMANCE, EMISSIONS AND SAFETY

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Keywords: Microscale modelling, Multi-objective analysis, Traffic, Emissions, Safety, Driving volatility, Bicycle.

Subject area: Sustainable mobility; Safety for cyclists

1.INTRODUCTION

Mobility in urban areas is highly complex because of the variety of possible facilities and routes, the increase of population and traffic. Increased use of active modes, such as cycling, presents economic and environmental benefits, and contributes to health improvement. However, it can lead to safety concerns such as bicycles sudden or unexpected movements mainly when circulating together with motor vehicles (MVs) or when there is an overtaking situation between MVs and bicycles. The main goal of this doctoral thesis is to quantify and assess the impact of the interaction MV-bicycle on traffic performance, road safety and emissions. The thesis was focused on three main topics: (*i*) to perform a multi-objective analysis in an integrated manner of the traffic performance, pollutant emissions and road conflicts between bicycles and MVs at a signalized intersection; (*ii*) to assess the driving volatility in MV-bicycle interactions at two-lane roundabouts and its impacts on safety, pollutant emissions and traffic performance; and (*iii*) to analyze the impacts of the overtaking lateral distance between a bicycle and a MV on road safety and energy consumption at two-lane urban roads. This PhD Thesis was concluded and defended in November 2019.

2. METHODOLOGY

The methodology developed in this thesis (Figure 1) was applied based on real world case studies at different urban roads in the city of Aveiro, Portugal.

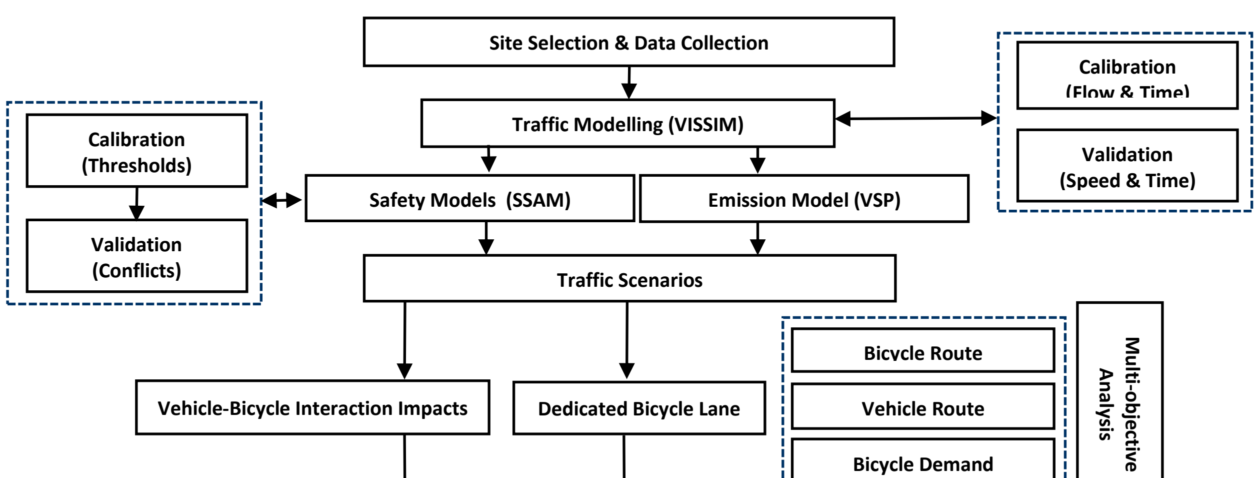


Figure 1: Methodology framework.

The present work uses a microscopic simulation platform of traffic (VISSIM), road safety (Surrogate Safety Assessment Methodology – SSAM) and emissions (Vehicle Specific Power – VSP) to analyze traffic operations, road safety concerns and to estimate carbon dioxide (CO_2), nitrogen oxide (NO_X), carbon monoxide (CO), and hydrocarbons (HC) pollutant emissions. Furthermore, the Fast Non-Dominated Sorting Genetic Algorithm (NSGA-II) was used in order to address the multi-objective analysis of traffic performance, road conflicts between MVs and bicycles, and emissions. Bicycle Specific Power (BSP) and VSP concepts were used in order to analyze the cyclist and vehicle energy consumption respectively.

3. RESULTS / DISCUSSIONS

3.1. Cycling at intersections: Multi-objective view

This thesis chapter (Bahmankhah, Fernandes & Coelho, 2019a) addressed the impact of bicycle demand at a three-leg signalized intersection on traffic performance, vehicular emissions and safety. Also, this research proposed a roundabout for the intersection and compare with the existing situation subjected to increments in the number of bicycle users (and decrease in the number of MVs based on occupancy ratio). Lastly, the research improved site-specific operations by searching the optimal number of bicycle users to minimize global and local pollutants and call to optimize surrogate safety measures criteria. The analysis results showed a reduction in emissions (6-9%, depending on the pollutant) by increasing the number of bicycle users from 9 to 270 for signalized intersection, while bicycles' travel time increased from 94.1 s to 105.5 s. It was also found that the roundabouts outperformed signalized intersection as CO_2, NO_X and HC criteria regardless of the bicycle demand scenario. The proposed layout also improved the number of MV stops and number of traffic conflicts, but this was not hold for surrogate measures (more severe conflicts in roundabout solution and not clear trend for potential severe crashes). Based on multi-objective analysis bicycle demand lower than 165 bph dictated a good compromise between global and local pollutants, and the inverse of TTC and MaxS safety variables. CO_2, NO_X, HC and CO emissions decreased in all the represented optimal solutions for the proposed alternative scenario.

3.2. Bicycle-MV route selection in an urban area: Multi-objective view

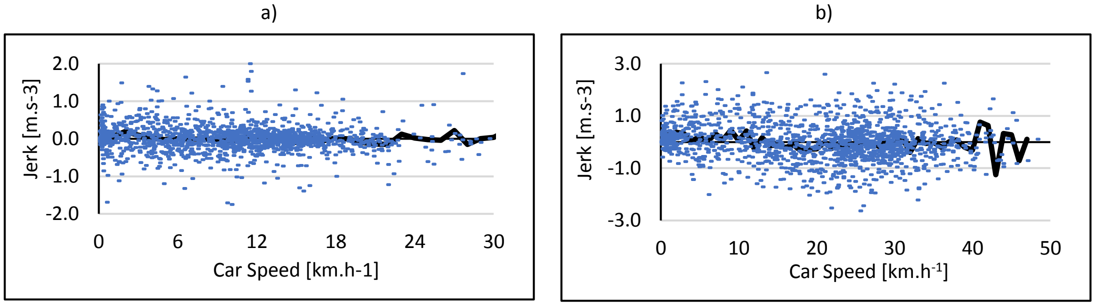
This research (Bahmankhah & Coelho, 2017) proposed a multi-objective scenario for bicycle and MV route optimization in order to improve traffic performance, emissions and safety. The analysis was based on a microscopic approach using VISSIM traffic model together with VSP methodology and SSAM model. Average travel time, CO_2 and NO_X vehicular emissions and number of conflicts were the outputs analyzed in this research. As a solution algorithm for the models the NSGA-II was used to search the optimal solutions for the suggested alternatives. The results classified the selected alternative routes based on the each traffic performance, safety level and emissions rate separately and these results can be useful for users to choose the optimum route based on individual preferences. In this way, route D represents the worst performance regarding travel time, conflicts and emissions. Route C requires more travel time than route A (fastest alternative) for MV and bicycle users, with 106 s and 177 s respectively, but represents the best performance regarding safety and emissions. Furthermore, each point of optimum solutions from

Pareto front based on its travel time, safety and emissions value can be defined in one or more selected routes. The results of multi-objective analysis represent route C as the best option for both bicycle and motor vehicle users. Sensitivity analysis of road users' criteria for each specific transportation network can be useful for urban network designers and planners in order to improve traffic performance besides the environmental and safety concerns. Regarding the results of dedicated lane for bicycle, in general the results showed that presence of dedicated lane can improve traffic performance, safety and emissions for both cyclists and MVs. In this way, route D represents the worst performance regarding travel time, conflicts and emissions. Route C represents the best performance regarding safety concerns and rate of emissions while route A represents the best performance regarding travel time with 404 s and 388 s for MV and bicycle respectively. Furthermore, route A and B represent less travel time for bicycle than MV. Since this study carried out based on the role of bicycle and MV in route selection, further studies are needed considering the role of pedestrians, adverse weather conditions in different urban areas.

3.3. Bicycle-MV interaction impacts at two-lane roundabouts: Driving volatility analysis

The results of this research (Bahmankhah, Fernandes, Teixeira & Coelho, 2019b) were promising since speed variation and subsequently, acceleration-deceleration variation were showed to have influence on driving volatility for both bicycles and MVs at conventional two-lane roundabouts. However, MVs yielded higher acceleration-deceleration variation than bicycles. It was also demonstrated that the frequency of MV-bicycle and MV-MV conflicts (up to 9 times), emissions per unit distance (9-15%, depending on the pollutant) and number of stop-and-go cycles (up to 8 times for bicycles and 90% for MVs) were higher at the roundabout with high traffic volumes and low cyclist activity. It is well known that emissions and acceleration-deceleration rates are intrinsically associated, but this paper takes a step forward and extends the analysis to the acceleration-deceleration variation (jerk) in different speed ranges (Figure 2) and volatility impacts at multi-lane roundabouts. The potential applications of this research can include the development of quantitative surrogate measures for interaction between MV and cyclists at different roundabout layouts. This research also supplied relevant information for transportation experts to better understand how MV-bicycle interactions can influence traffic performance, safety, and emissions at two-lane roundabouts. It must be outlined that this type of roundabout represents specific problems for cyclists, since it allows vehicles to approach and negotiate at high speeds and enabling lane changing and weaving maneuvers at the circulating and exit areas.

a) b)



c) d)

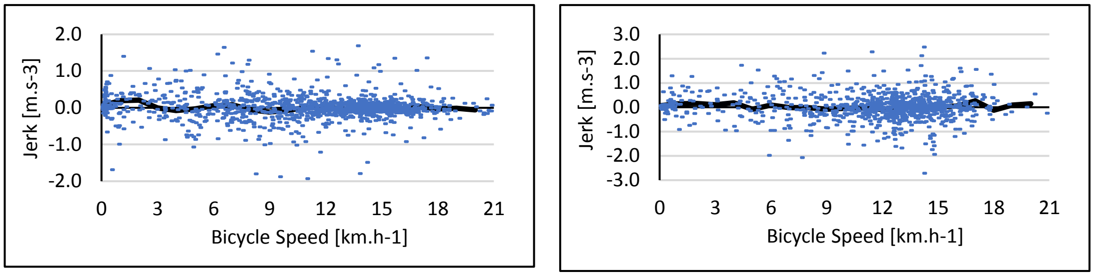


Figure 2: Traffic performance: a, b) Speed-based volatility of MV at R1 and R2; c, d) Speed-based volatility of bicycle at R1 and R2.

3.4. Assessing the bicycle-MV overtaking lateral distance: Impacts on energy and road safety

This research (Bahmankhah et al., 2020) represents an evaluation of the impacts of the bicycle-MV overtaking lateral distance on driver and cyclist behaviours, safety and BSP/VSP mode distributions. Field measurements were conducted in a real-world corridor with traffic lights and an urban network with four alternative routes. The analysis was based on overtaking lateral distance measurements extracted from a platform of sensors installed on a conventional bicycle. Measurements were carried out in daily peak hours. Bicycle and MV GPS data were also used to characterize road user behaviours. More than 75% of the total overtaking lateral distances were lower than 1 m, and 50% were lower than 0.5 m, thus confirming some issues regarding the cyclist safety. It was found that lowest overtaking lateral distances (<0.5 m) occurred in the segments with high traffic volumes with resulting lack of road space during the interaction between MVs and cyclists. The analysis of acceleration/deceleration profiles confirmed that bicycles and MVs had similar behaviour in both periods, but the trend of acceleration-deceleration for MVs was higher than bicycles regardless the case studies. The analysis of relationship for traffic volumes and overtaking lateral distances showed good fit between these variables ($R^2 > 0.67$). In contrast, no correlation was observed between overtaking lateral distance and bicycle-MV overtaking lateral distance.

4. CONCLUSIONS

Although extensive research was carried out about interaction of MV-bicycle in different type of roads and traffic conditions, few studies were found about impacts of MV-bicycle interaction on the traffic performance (such as travel time, speed, traffic flow and number of stop-and-go), pollutant emissions (CO_2, CO, NO_X, and HC), and safety concerns (such as number of traffic conflicts and TTC). The main contribution of this PhD thesis focused on the assessment of the driving volatility and the impacts of the MV-bicycle interactions at urban areas considering multi-objective criteria. The thesis developed a multi-objective model for bicycle and MV users to choose the proper route based on traffic performance, emissions and safety concerns. The parameters concerning the MV and bicycle activity data (speed, acceleration-deceleration), traffic volume, energy consumption and overtaking lateral distance were characterized in detail. The candidate studied locations were located in an urban areas and they included different traffic control treatments such as traffic lights, stop-controlled intersections and conventional roundabouts.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the projects: **TEMA**, Centre for Mechanical Technology and Automation Strategic Project UID/EMS/00481/2019-FCT and CENTRO-01-0145-FEDER-022083; **@CRUiSE** Project, funded under Project 9471 - Strengthening Research, Technological Development and Innovation (Project 9471 - RIDTI) and supported by the European Community Fund ERDF; **MobiWise** Project (P2020 SAICTPAC/0011/2015, co-funded by COMPETE2020, Portugal2020 - Operational Programme for

Competitiveness and Internationalization, European Union ERDF and FCT) and **DICA-VE** - Driving Information in a Connected and Autonomous Vehicle Environment: Impacts on Safety and Emissions (POCI-01-0145-FEDER-029463), funded by FEDER, through COMPETE2020-Portuguese Operational Program Competitividade e Internacionalização (POCI), and by National funds (OE), through FCT/MCTES.

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