Integrating Impacts for a Smart and Sustainable Mobility: Connecting the Dots

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Biography of Margarida C. Coelho

Prof. Margarida Coelho (Lisbon, n. 1977) is Assistant Professor with Habilitation ("Agregação") of the Department of Mechanical Engineering of the University of Aveiro (UA), Portugal. She also serves as Vice-Diretor of the Centre for Mechanical Technology and Automation.

Margarida Coelho finished her PhD at Instituto Superior Técnico (IST) - Technical University of Lisbon in 2005, within a partnership between IST and the Institute for Transportation Research and Education, of North Carolina State University, USA. She completed her Habilitation ("Provas de Agregação") on Mechanical Engineering in September 2020. She is the Scientific Coordinator of the research team on Smart mobility at the Department of Mechanical Engineering.

Margarida Coelho created a completely new teaching and research area at UA (mobility, energy and environment). She is the Scientific Coordinator of the research team on Smart mobility. As a researcher, she contributed for the understanding of the trade-off between different transportation impacts (namely, emissions, safety and noise). Her research interests are: impacts of transportation systems (namely, traffic congestion, energy consumption, pollutant emissions and road safety), connected and automated mobility, life cycle assessment and active mobility.

Margarida Coelho has 100 scientific papers in SCI SCOPUS (h-index 20), published in Transportation Research Part A and Part D, Journal on Sustainable Transportation, Applied Energy, Science for Total Environment, Renewable & Sustainable Energy Reviews, Sustainable Cities and Society, etc, besides other publications in books and conferences proceedings.

Margarida Coelho has had extensive participation in transport related projects. She is/was the Principal Investigator of R&D Projects funded by the Portuguese Science and Technology Foundation (FCT) and ERDF. She is also Vice-Coordinator of one Interreg Europe project (CISMOB) and participating member in 2 other projects funded by the EU - Interreg Europe and SUDOE. She was also Principal Investigator of projects funded by the Luso-American Foundation / United States National Science Foundation. In the last 10 years, she was directly responsible (as Lead Investigator, Co-Responsible Researcher or Local Project Coordinator) for more than 2M€ in R&D Projects for UA. The scientific projects outcomes resulted in a combination of scientific impact (in terms of publications and creation of scientific jobs, with the hiring of junior researchers), policy instruments development (required under the Interreg Europe projects) and public outreach (with more than 40 events that she organized for the scientific audience, stakeholders and general public).

Because of the impact of her research on mobility, energy and environment she was invited to be Associate Editor of Transportation Research Part D, Journal of Intelligent Transportation Systems and IEEE Open Journal of Intelligent Transportation Systems. She has been invited for multiple committees (e.g., evaluation of PhD grants for the Portuguese Science and Technology, PhD defense committees) and for more than 30 seminars, both in European and US Universities (e.g, TU Wien, TU Delft, University of Salerno, NY University at Abu Dhabi, Université Gustave Eiffel, North Carolina State University). She already supervised 5 PhD and more than 50 Master students. Right now, she is supervising 6 PhD students and 10 Master students. She was the Chairwoman of EWGT2021 - EURO Working Group on Transportation Annual Meeting. MC is also a recognized Expert on Transportation and Energy by the Portuguese Association of Engineering.

Finally, Margarida Coelho continues to tackle the articulation between research and teaching on smart mobility with the objective of implementing a coherent posture in the set of teaching-research activities. On her perspective, this is the essence to contribute towards rethinking transport for clean, safe, smart and inclusive mobility.

Acknowledgements

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Regarding real-world crashes data, the cooperation of the Portuguese Authority for Road Safety (ANSR) is deeply appreciated.

I would also like to express my sincere appreciation to the successive Boards of the Department of Mechanical Engineering at the University of Aveiro, the Center for Mechanical Technology and Automation (TEMA), for their full cooperation for my professional development.

Research influences teaching and I try to share the enthusiasm of studying such as interesting field as mobility with my students. In the classroom, I often learn as much or more than I taught. I remember, in particular, the teaching that I experience in a multicultural (which brought together students of eight nationalities in the same classroom, from four continents!) and multidisciplinary environment (with students with different backgrounds) and from whom I always derive enormous personal and professional pleasure.

As a final (and personal) note, I dedicate this document to my parents because there is beauty in everything they do, and for having guided me to the bookshelf.

Aveiro, July 2022

Margarida C. Coelho

Chapter 1: Connecting the dots between Safety, Emissions and Noise in a CAV environment - Introduction and Objectives

Road transport will remain a strategic sector in climate change, air pollution and noise (Uherek et al., 2014; EEA, 2019; UN, 2014; EC, 2002). Despite high expectations of new vehicle technologies as a way for reducing transport impacts, the expected contribution of oil products in 2050 will exceed 50% (EC, 2011). In this context, a more efficient use of existing infrastructures has been identified by EU as a key strategy to reduce transport externalities (EC, 2011). In line with this strategic orientation, various authors have demonstrated that a smart traffic allocation across multiple routes may result in significant energy savings (Bandeira et al., 2014; Zhang et al., 2010; Minett et al., 2011).

There is significant potential for emissions/fuel use reduction through intelligent traffic assignment strategies (Bandeira et al., 2016, 2018a, 2018b). However, research has also demonstrated that there is no unique solution that can optimize all traffic externalities (e.g. CO_2 vs. local pollutants or emissions vs. travel time) (Bandeira et al., 2016; Wismans et al., 2013; Ahn et al., 2013; Ahn et al., 2008; Guo et al., 2013). Furthermore, major traffic environmental externalities are seldom calculated in an integrated fashion, neither are adjusted to the local contexts of vulnerability (Wismans et al., 2011), a factor often neglected in network optimization algorithms (Fernandes et al., 2014). Therefore, several inefficiencies may arise when implementing traffic management solutions without a holistic view of consequences across systems, since exposures are not proportional to traffic volumes only and incremental risks depend on site-specific factors (Zhang & Batterman, 2013).

Currently, the increasing availability of floating car data (FCD) as a result of the high market penetration of vehicles equipped with GPS/smartphones is changing the paradigm of traffic flows analysis. Consequently, assessing traffic performance based on FCD is increasingly important for traffic management.

Recent work has demonstrated the capability of microsimulation traffic tools to realistically reproduce vehicles' speed and acceleration patterns on specific routes and the high potential for improvements on air quality modeling with a detailed methodology for emissions estimation (Coelho et al., 2013). Best practices have been established to connect different modeling platforms of traffic/emissions/air quality (Fontes et al., 2015).

Regarding traffic noise prediction, innovative dynamical approach is being developed to include the dependence of noise emission by considering kinematic parameters, such as speed, position and acceleration (Guarnaccia, 2013). However, the interaction between these models with online traffic data in a straightforward way still represents a hot research subject.

In summary, previous research has shown that an efficient traffic management can lead to significant environmental improvements. However, little attention has been paid to the fact that there may be trade-offs in minimizing different externalities. Simultaneously, the generality of traffic management mechanisms ignores the vulnerability indices associated with each network link. In short, there are considerable challenges to integrate new sorts of traffic data into traffic-flow analysis, environmental assessment and network optimization. What has been learned from the literature review is that several studies have addressed the impact of ATMS to reduce pollution impacts. However, few have integrated the development of numerical tools and methodologies for the analysis of the full range of traffic-related impacts based on environmental indicators, and in a context of incising availability of floating car data.

In line with EU agenda for the implementation of sustainable cooperative traffic management systems, this proposal addresses these issues based on a comprehensive systematization of the literature, state-of-the-art modeling tools, data mining techniques, and optimization methods.

References

Ahn KG, Rakha H. The effects of route choice decisions on vehicle energy consumption and emissions. Transp Res Part D-Transport Environ. 2008;13(3):151–167.

Bandeira J, Carvalho D, Khattak A, Rouphail N, Fontes T, Fernandes P, Pereira SR, Coelho MC. Empirical assessment of route choice impact on emissions over different road types, traffic demands, and driving scenarios, International Journal of Sustainable Transportation. 2016;10(3): 271-283.

Bandeira J, Guarnaccia C, Fernandes P, Coelho MC. Advanced impact integration platform for cooperative road use, International Journal of Intelligent Transportation Systems Research, 2018a;16:1-15.

Bandeira J, Fernandes P, Fontes T, Pereira SR, Khattak A. Coelho MC. Exploring Multiple Eco-Routing Guidance Strategies in a Commuting Corridor, International Journal of Sustainable Transportation. 2018b;12(1):53–65.

Carnevale C, Finzi G, Pisoni E, Volta M. Neuro-fuzzy and neural network systems for air quality control. Atmospheric Environment. 2009; 43, 4811-4821.

Coelho MC, Fontes T, Bandeira JM, Pereira SR, Tchepel O, Dias D, et al. Assessment of potential improvements on regional air quality modelling related with implementation of a detailed methodology for traffic emission estimation. Sci Total Environ. 2013;470-471C:127–37.

EEA. European Environment Agency. EMEP/EEA air pollutant emission inventory guidebook. 2019. Available from: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

European Commission. Position paper on dose response relationships between transportation noise and annoyance. 2002. http://ec.europa.eu/environment/noise/pdf/noise_expert_network.pdf

European Commission - EC. EG FTF - 1st Report of the Expert Group: Future Transport Fuels. 2011. http://ec.europa.eu/transport/themes/urban/cts/doc/2011-01-25-future-transport-fuels-report.pdf

European Commission. White paper 2011: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. 2011. http://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.htm

Fernandes P, Bandeira J, Fontes T, Rouphail N, Coelho MC. Traffic restriction policies in an urban avenue: A methodological overview for a trade-off analysis of traffic and emission impacts using microsimulation. Int J Sustain Transp. 2016;10(3):201-215.

Fontes T, Pereira SR, Fernandes P, Bandeira JM, Coelho MC. How to combine different microsimulation tools to assess the environmental impacts of road traffic? Lessons and directions. Transp Res Part D Transp Environ. 2015;34(0):293–306.

Friedrich M, Jehlicka P, Otterstaetter T, Schlaich J. Mobile Phone Data for Telematic Applications. Imeti 2008 Int Multi-Conference Eng Technol Innov Vol I, Proc. 2008;337–42 378.

Graser A, Ponweiser W, Dragaschnig M, Brandle N, Widhalm P. Assessing traffic performance using position density of sparse FCD. 2012 15th International IEEE Conference on Intelligent Transportation Systems (ITSC). 2012. pp. 1001–5.

Guarnaccia C. Advanced Tools for Traffic Noise Modelling and Prediction noise. WSEAS Trans Syst. 2013;12(2):121–30.

Guo L, Huang S, Sadek AW. An Evaluation of Environmental Benefits of Time-Dependent Green Routing in the Greater Buffalo–Niagara Region. J Intell Transp Syst. 2013;17(1):18–30.

Minett C, van Arem B, Kuijpers S. Eco-routing: comparing the fuel consumption of different routes between an origin and destination using field test speed profiles and synthetic speed profiles. IEEE Forum on Integrated and Sustainable Transportation Systems. Vienna; 2011.

Ryu BY, Jung HJ, Bae SH, Choi CU. Estimation of carbon dioxide emissions per urban center link unit using data collected by the Advanced Traffic Information System in Daejeon, Korea. Atmos Environ. 2013;81:433–42.

Uherek E, Halenka T, Borken-Kleefeld J, Balkanski Y, Berntsen T, Borrego C, et al. Transport impacts on atmosphere and climate: Land transport. Atmos Environ. 2010 Dec;44(37):4772–816.

United Nations. United Nations Environment Programme. 2014. http://www.unep.org/urban_environment/issues/urban_air.asp

Wismans L, Van Berkum E, Bliemer M. Modelling Externalities using Dynamic Traffic Assignment Models: A Review. Transp Rev. 2011;31(4):521–45.

Wismans L, Berkum E Van, Bliemer M. Effects of Optimizing Externalities Using Cooperating Dynamic Traffic Management Measures on Network Level. J Intell Transp Syst. 2013;17(1):65–77.

Zhang YL, Lv JP, Ying Q. Traffic assignment considering air quality. Transp Res Part D-Transport Environ. 2010;15(8):497–502.

Zhang K, Batterman S. Air pollution and health risks due to vehicle traffic. Sci Total Environ. 2013;450-451:307–16.

Chapter 2: Literature review

In this chapter, a complete literature review and meta-analysis on methods for assessment of activity patterns recognition, transport externalities valuation, population vulnerability to transport impacts, traffic-data mining, multiobjective optimization and traffic-control techniques, artificial intelligence techniques or determination of emissions and air quality levels was developed. The literature review focused on the impact of technology and environmental information on human behaviour. The experimental design specified the required equipment, tests to be conducted, selection of the case studies and relevant variables such as days, time periods, number of routes, number of drivers, and measurements spots of traffic, noise, air quality. A complete experimental setup for collecting and transmitting data was made.

At the end of the literature review, the research team was fully aware of the existing/new methods to analyse different impacts of road transportation and the first milestone was reached: the functional specification report. This was extremely important to enhance the novelty of the research and to understand the bonds between the current topics within the project.

Also, contacts between the Centre for Mechanical Technology and Automation (TEMA) and other institutions (namely, University of Salerno, North Carolina State University and University of Tenneessee, Knoxville) were made, to enhance faculty/students exchange as well as joint papers within the project. In addition, contacts between TEMA with other institutions: 1) Estradas de Portugal and BRISA, in order to obtain road traffic data; 2) Departments of Mobility and Geographic Information Systems of the Municipality of Aveiro, in order to get traffic volumes and geographic data; 3) Toyota Caetano Portugal, for planning the collaboration during the experimental measurements; 4) Taxis of Aveiro, in order to obtain vehicle dynamics data from the local fleet of taxis; 5) National Authority of Road Safety in order to obtain road crashes data; 6) IDAD, regarding the cooperation during the air quality measurements campaign.

The main conclusions of the literature review are summarized in the following points:

- A sector of society considers environmental issues in route selection decision process, which is related to positive behaviour associated with environmental consciousness.
- The impact of route selection on traffic emission and fuel consumption have been widely studied. However, population exposure to the pollutants, noise, and safety has been neglected in the literature.
- From an individualistic perspective, there is potential for significant reduction of environmental impacts using intelligent Transportations System (ITS) for route choice. This potential is achieved with relatively low penetration rates and without a significant increase in travel time.
- The generality of traffic management mechanisms ignores the vulnerability indices associated with each network link.
- Although several studies have addressed the impact of ATMS to reduce pollution impacts, few have integrated numerical tools and methodologies for the analysis of the full range of traffic-related impacts based on environmental indicator. The team members are not aware of any integration of different externalities in a sustainability indicator.
- Internalizing the external costs of transportation has been an important concern for policy development and transportation research.

The advantages of using Internet such as efficiency, convenience, broader selections, competitive pricing, rich information, and diversity are well known. By increasing teleworking activities most of the work daily travels reduced due to bringing work office to home. So far, advanced technology has changed even the culture and behavior of people in their daily activities. About transportation, more than half of Internet users said they go online while on the move, such as through a mobile device while walking or in transportation, up from 40 percent in 2013. About EU-28 in 2014, the percentage of internet users who ordered goods or service by internet has risen 6% compared with 2012 and reached 50% (EC, 2015).

Road traffic poses negative externalities on society, thereby representing one of the key challenges in sustainable transportation nowadays. In 2016, road transportation accounted for 73% and 83% of transportation greenhouse gases (GHG) emissions in the European Union (EU) (EEA, 2017) and in the United States (US) (EPA, 2018), respectively. Long term-projections for carbon dioxide (CO_2) emissions concerning the passenger transportation in cities of over 300 000 inhabitants show an increase up to 27% in 2050 compared with 2015 levels (Chen and Kauppila, 2017).

Besides GHG emissions, road transportation has long-lasting negative impacts on road safety, human health and wellbeing. Road traffic crashes within EU claimed approximately 25,650 fatalities in 2016 (ERSO, 2018); 54% of these occurred at rural roads (ERSO, 2018). Also, road transportation is one of the major sources of some harmful air pollutants such as particulate matter (PM), nitrogen oxides (NO_X) and carbon monoxide (CO) (EEA, 2018a). Around 39% of total NO_X came from road transportation (EU member states), which represented the highest share of that gas in 2015 (EEA, 2017a). This sector is, by far, the dominant source of traffic noise in Europe, representing almost 90% of total noise emissions (EEA, 2018b). Approximately 29 million livening in main roads outside urban areas in EU-28 were exposed to average day-evening-night noise levels (Lden) exceeding 55 dBA (EEA, 2018b). Traffic noise causes nuisance, stress reactions, sleep disturbance, and it also has negative effects on health, such as cardiovascular diseases (WHO, 2011).

Understanding the most cost-effective strategies to mitigate both congestion and environmental costs in automobile trips have been pointed out as one of the critical issues in transportation for the next 20 years (National Academies of Sciences, 2018). The overall size of transportation external costs is estimated at around 7% of the EU Gross Domestic Product (EC, 2018).

About the effect of environmental information on human behavior, nowadays, consumers' behavior positively associated with environmental consciousness. Regarding the environmental awareness of people, the number of eco-friendly providers is increasing because of consumers willing even to pay more for environmentally sustainable products compared with other similar alternatives (Moon et al., 2016; Tait et al., 2016). It seems that due to have more awareness about environmental issues, even the culture of life can change positively. The people who are called green costumers are willing to change all their behaviors in a more ecofriendly way. For example, the results of research about energy Europe and United States consumer attitudes and their expectations about energy shown that environmental concerns can affect consumer decision making with respect of energy more strongly than economic issues (Karlstrom et al., 2014; DeCicco et al., 2015).

Global Positioning System (GPS) is one of the common traffic sources that can have a strong effect on traffic impacts. Route selection is one of the main advantages of this system can provide useful information for travelers to choose the best route for them based on their preferences such as cost, distance, emissions, safety and others. Bandeira et al. (2013) used GPS data to propose a way to generate travel information about emissions and other route characteristics for drivers faced with a choice of routes. In other similar study (Bandeira et al., 2016) the GPS data used to confirm the significant role of the eco-routes in emission reduction and energy saving specially during the peak hours.

Increasing the awareness of people about the details and results of their decision can be helpful for them to better choose their transport mode and routes based on their criteria and concerns. In fact, drivers have not always enough information to identify among numerous routes, what is best for the economy and the environment (Bandeira, 2013). In many daily situations, where people must make a quick decision, they may use general attributes like environmental concerns, cost of the decision, and safety concerns as a few examples among others but their personality criterion can lead to different results. The existing literature about the assessment of traffic externalities drawn on a standard measure (e.g., sustainability indicator) is scarce (Bandeira et al., 2014; El-Rashidy and Grant-Muller, 2015; Kickhöfer and Nagel, 2016; Sdoukopoulos et al., 2019; Torrao et al, 2016). However, although previous research has shown that efficient traffic management can lead to significant environmental improvements, Little attention has been paid to the fact that there may be trade-offs in minimizing different externalities. Simultaneously, the generality of traffic management ignores the vulnerability indices associated with each network link.

Through Advanced Traffic Management Systems - ATMS, it is possible to provide all the necessary traffic information for drivers about the routes that can be helpful for them in their decision making to choose the best route based on their priorities such as distance, time, environmental concerns and safety concerns. Furthermore, this information can be used as a support tool to identify parking spaces, reducing the number of vehicles within a city (Chen and Cheng, 2010; Ezell, 2010). Although ATMS systems have been studied to reduce pollution impacts, few have integrated the development of numerical tools and methodologies for the analysis of the full range of traffic-related impacts based on environmental indicators, and in a context of increasing availability of floating car data.

Considering this, by integrating road traffic impacts into a single analytic framework for use of advanced traffic management systems (ATMS), @CRUiSE project aims to propose and develop technologies and applications that support a more sustainable relationship between transportation and the environment.

References

Bandeira J, Almeida TG, Khattak AJ, Rouphail NM, Coelho MC. Generating Emissions Information for Route Selection: Experimental Monitoring and Routes Characterization. Journal of Intelligent Transportation Systems. 2013;17:3-17.

Bandeira JM, Pereira SR, Fontes T, Fernandes P, Khattak AJ, Coelho MC. An Eco-Traffic Management Tool. In: de Sousa JF, Rossi R, editors. Computer-based Modelling and Optimization in Transportation. Springer International Publishing, Cham, 2014:41-56.

Bendeira, J.M. Road Traffic Information Platform for Energy and Emissions Savings, PhD Thesis on Mechanical Engineering, University of Aveiro, Aveiro, 2013.

Bandeira J, Fernandes P., Fontes T., Pereira S., Khattak A. J., Coelho M.C. Exploring multiple eco-routing guidance strategies in a commuting corridor. International Journal of Sustainable Transportation. 2018;12(1):53-65.

Chen, B., Cheng, H.H. A review of the applications of agent technology in traffic and transportation systems. IEEE Transactions on Intelligent Transportation Systems. 2010;11:485-497.

Chen G, Kauppila J. Global Urban Passenger Travel Demand and CO2 Emissions to 2050. Transportation Research Record: Journal of the Transportation Research Board. 2017;2671:71-79.

Decicco, J., Yan, T., Keusch, F., Muñoz, D.H., Neidert, L. US consumer attitudes and expectations about energy. Energy Policy. 2015;86:749-758.

EC - European Comission. Digital economy and society statistics - households and individuals, European Statistics Explained, 2018.

EC – European Comission. Multimodal Sustainable Transport: Which role for the internalisation of external costs? European Commission - Directorate-General for Transport and Mobility (DG MOVE), 2018.

EEA. Publications - Transport and Environment Reporting Mechanism (TERM): European Environmental Agency, 2018.

El-Rashidy RAH, Grant-Muller SM. An operational indicator for network mobility using fuzzy logic. Expert Systems with Applications 2015;42: 4582-4594.

EPA. U.S. Transportation Sector Greenhouse Gas Emissions, 1990 –2016: U.S. Environmental Protection Agency, 2018.

ERSO. Annual Accident Report 2018: European Road Safety Observatory, 2019.

EEA. Air quality in Europe — 2018 report: European Environmental Agency, 2018a.

EEA. Population exposure to environmental noise. European Environment Agency, 2018b.

Ezell, S. Explaining international it application leadership: Intelligent transportation systems. Explaining Interational IT Application Leadership: Intelligent Transportation systems, 2010.

Karlstrøm, H. & Ryghaug, M. Public attitudes towards renewable energy technologies in Norway. The role of party preferences. Energy policy. 2014;67:656-663.

Kickhöfer B, Nagel K. Towards High-Resolution First-Best Air Pollution Tolls. Networks and Spatial Economics. 2016;16: 175-198.

Moon, S., Bergey, P.K., Bove, L.L. & Robinson, S. Message framing and individual traits in adopting innovative, sustainable products (ISPs): Evidence from biofuel adoption. Journal of Business Research. 2016;69:3553-3560.

National Academies of Sciences E, and Medicine 2018. Critical Issues in Transportation 2019. Networks and Spatial Economics, 2018, pp. 45.

Sdoukopoulos A, Pitsiava-Latinopoulou M, Basbas S, Papaioannou P. Measuring progress towards transport sustainability through indicators: Analysis and metrics of the main indicator initiatives. Transportation Research Part D: Transport and Environment 2019; 67: 316-333, 2019.

Tait, P., Saunders, C., Guenther, M. & Rutherford, P. Emerging versus developed economy consumer willingness to pay for environmentally sustainable food production: a choice experiment approach comparing Indian, Chinese and United Kingdom lamb consumers. Journal of Cleaner Production. 2016;124:65-72.

Torrao G., Fontes T., Coelho M.C., Rouphail N. Integrated indicator to evaluate vehicle performance across: Safety, fuel efficiency and green domains. Accident Analysis & Prevention. 2016; 92:153-167.

WHO. Burden of disease from environmental noise - Quantification of healthy life years lost in Europe: World Health Organization, 2011.

Chapter 3: Monitoring of Road and Environmental Conditions

The monitoring plan of road and environmental conditions was designed to gather field data with three main purposes: 1) to correlate FCD (link-based individual vehicles dynamic) with varying levels of traffic performance; 2) to correlate several traffic conditions with pollution noise levels; 3) to calibrate and validate an integrated modelling framework.

A good experimental design is essential to perform a correct data collection. This included a complete description of the equipment used, the tests to be conducted, and the applications to be performed. Variables such as days, time periods, number of routes, number of participating drivers, and vehicles used were defined, as well as the material and team members responsible for data collection. This task can be divided into 3 sub-topics:

- Road Traffic Measurements
- Macroscopic measurements of traffic performance
- Environmental conditions monitoring

which were applied to each case study.

1st Case Study

A main avenue of the city of Aveiro, a medium-sized city in Northwest Portugal, called *Avenida 25 de Abril* was selected as a first case study (Figure 1).

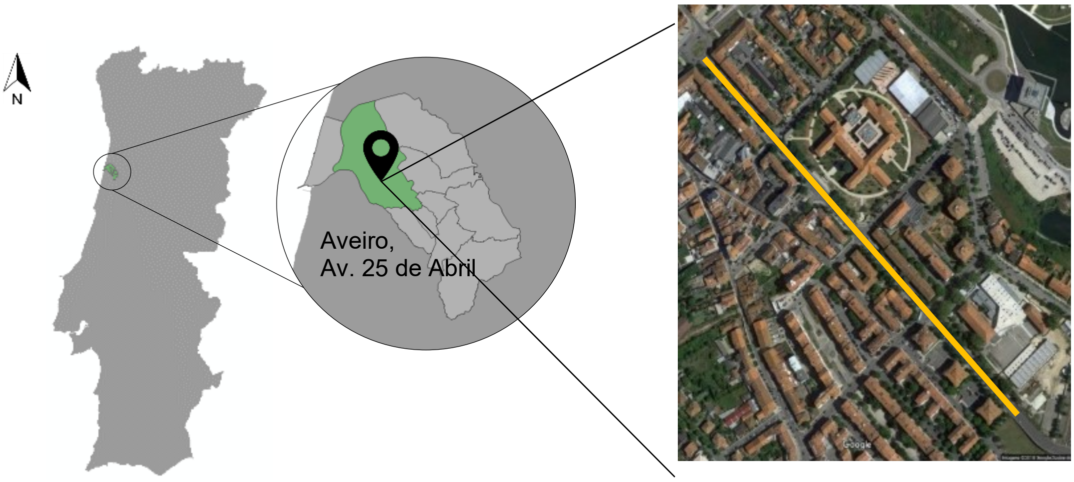


Figure 1 - Location of the 1st case study [Source: Google Maps]

This avenue is located near the city centre, surrounded by residential and two schools. Thus, a significant part of the population can potentially be exposed to traffic-related impacts since the levels of traffic flows are significant, specially in peak hours. An Air Quality Station (AQS), classified as urban traffic according to the type of emission source, is built-in in the middle of the avenue, which enhances the evaluation of pollutants concentrations in this area.

An experimental campaign was performed in 25 de Abril avenue, in Aveiro, to characterize the traffic flow (speed, time and distance) and to count the number of vehicles which use this road on an hourly basis. Furthermore, an air quality station (AQS), classified as urban traffic according to the type of emission source was monitoring the concentration of multiple pollutants.

The experimental campaign (7th of February 2017) was performed with the application of emissions models based on bottom-up approaches. For vehicles dynamic monitoring, three different light-duty vehicles were equipped with Global Navigation Satellite System (GNSS) data loggers to collect second-by-second trajectory data and covering a total of 128km and 160 runs in each direction (Table 1).

Vehicle Name	Type of fuel	Year	Engine Size (L)
Opel Astra	Gasoline	2006	1.3
Renault Scenic	Gasoline	2004	1.5
Toyota Yaris	Diesel	2016	1.0

Table 1 - Data collection vehicles characterisation

For traffic flow monitoring, two static video cameras were used, one located at the beginning, and another located at the end of the road segment. The avenue with 0.7 km was divided into five different links based on the intersection's connections (Figure 2).

Aiming to characterize the daily profile of NOx and PM10 concentrations and to assess the accuracy of numerical simulations for the period of the experimental campaign (see Task 3 description), a monitoring network consisting of two stations (an urban traffic station and a suburban background station) was designed. Both stations belong to the national network QUALAR (http://www.qualar.org), managed by the Portuguese Environmental Agency (APA).

Air quality monitoring equipment with similar technical specifications is used in both stations. The urban traffic station is located within the study domain and so its concentrations are determined predominantly by the emissions from nearby traffic. Data from a suburban background station, located southwest from the study area at approximately 6.5 km, was included in the analysis. This station allows a characterization of the concentrations levels that are not considerably influenced by single (local) sources but by an integrated contribution from all sources. However, background concentration is not a fixed value and vary in that it may be influenced by regional air quality and indirectly by local sources, i.e. background concentration is likely to increase in response to peak traffic emissions or decrease at night in response to minimal traffic emissions (Moreno et al., 2009).

Figure 2 – Monitoring scheme in Av. 25th of April, Aveiro

2nd Case Study

The second case study was developed on a corridor near a commercial mall in the city of Guimarães – Portugal (Figure 3). The monitoring plan included vehicle dynamic (instantaneous speed and acceleration-decelarion cycles), traffic, and noise.

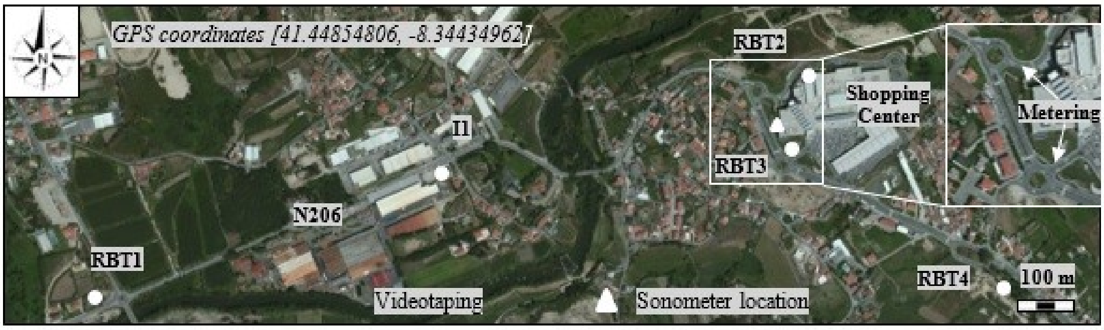


Figure 3 - Location of the 2nd case study - suggested metering legs identification and equipment location [Source: Bing Maps] – RBT: Roundabout; I1: Signalized intersection

This corridor is a stretch along N206 national road (~2.2 km length) that connects Guimarães to Famalicão and is located near major industrial areas. The posted speed limits range from 40 (roundabouts approaches) to 70km/h, and corridor has one lane between RBT1 and RBT2 and two lanes on the other arterials. All roundabouts are suburban with small pedestrian impedance. I1 has a fixed cycle with the same setup during the day (overall cycle time is 83 seconds). The shopping mall nearby has 1960 available parking lots, and these roundabouts record high traffic volumes in some periods (especially on weekends and lunch/dinner periods).

One set of traffic, vehicle dynamic and noise data were collected during 12 hours (9 am – 9 pm) on a Sunday (which is the day with the highest number of trips to the shopping mall) in June 2017 under dry weather conditions. Cameras were installed at each intersection to gather intersection-specific direction split patterns (Figure 3).

GPS devices were mounted on one passenger vehicles to record vehicle dynamic data (second-by-second speed and acceleration-deceleration). The data were mostly collected during the morning (9 am - 11 am) and afternoon (5 pm – 7 pm) peak periods. Four different drivers (three males and one female, ages 27 to 35) performed these routes and used both test vehicles to assure variability in driving behavior.

Noise data were collected using an integrating sound level meter RION-NL52 installed at locations near videotaping and followed the ISO 11819-1:1997 standard. Tests were conducted with wind speeds lower than 4km/h without the effect of other external sources, such as reflection and traffic from minor roundabout legs. The microphone was in the acoustic field at 1.2 meters from the ground and 15 meters from the road axis. The sound pressure levels were recorded every 1 second.

3rd Case Study

The third case study was developed on an intercity scale, the origin-destination pair Angeja-Estarreja, Portugal (see Figure 4). These intercity corridors provide a direct connection between Aveiro and Estarreja (Portugal) and are located near a high-density industrial complex with moderate Heavy Duty Vehicles (HDV) traffic; hence, the air quality and traffic-related noise can represent an important issue, specially for local population.

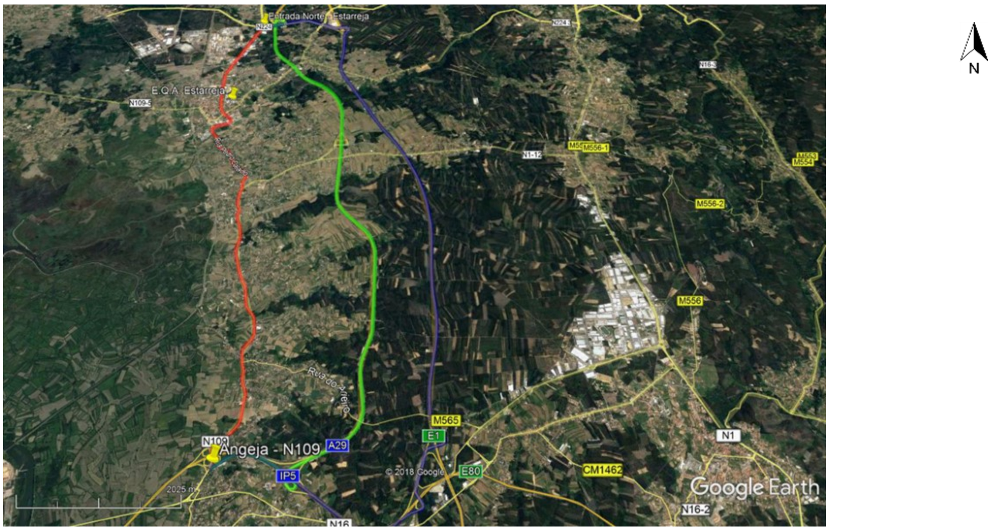


Figure 4 - Location of the 3rd case study - road network (N109, A1, A29) [Source: Google Earth]

Field data was gathered to correlate several traffic conditions with pollution and noise levels, as well as to calibrate and validate the modelling framework.

Measurements of traffic parameters were performed: traffic volumes, noise levels, vehicle dynamics (second-by-second speed, acceleration and slope). Data acquisition also considered the use of additional sources, such as floating car data, precision driving behavior, and radio broadcasts. For floating car data, a smartphone application (METRIGET), purpose built for the project, enables smartphones to gather inertial data and location from moving vehicles. Driving behavior was captured by a purpose build, OBDII enabled, Inertial Measurement Unit, that combines multiple (and redundant) sensors, with a precise GPS. This enables the correlation between road conditions, driver behavior and vehicle state. Figure 5 depicts an acceleration profile in multiple trips over a roundabout.

Figure 5 - Acceleration profile with In Car tracker. Red equals acceleration, white equals deceleration

Data was recorded along a road network comparing three different type of roads: R1, R2 and R3, 2 highways and 1 national road.

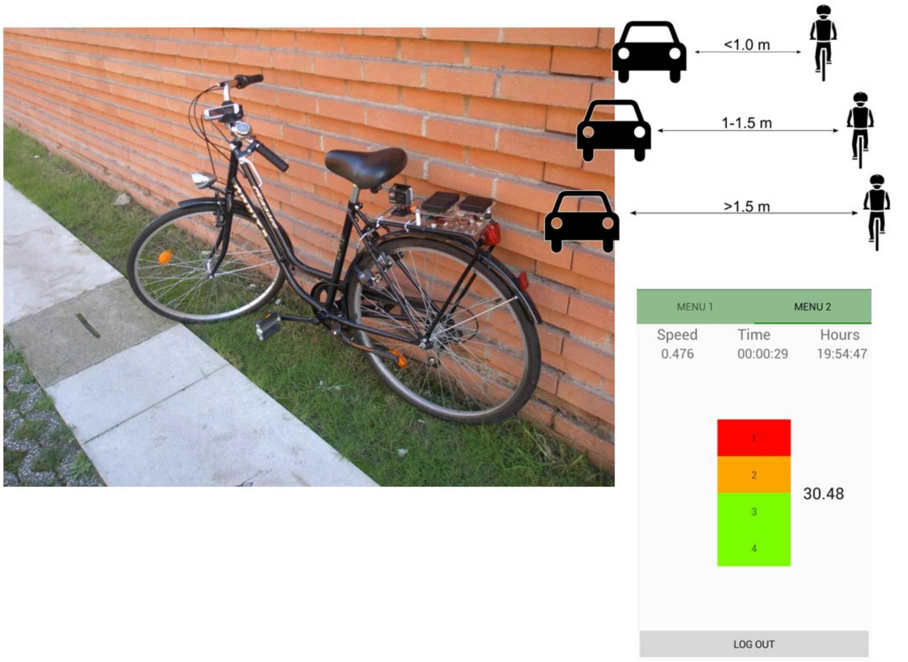
Traffic data were collected in the morning (7 am – 10 am), off-peak (11 am – 2 pm) and evening peak (5 pm – 7 pm) during six typical weekdays in May, June and November 2018 under dry and windless weather. Traffic volume manual counting was performed in 15 minutes time intervals (in both traveling directions) at specific sites and video cameras were used to collect intersection-specific demand and turning split distributions. A total of 42 monitoring points (including intersection entry and exit points) were evaluated in the studied location, allowing an accurate assignment of road traffic along the overall network.

Sound pressure levels were measured using an integrating sound level meter RION-NL52 (0.1 second basis) installed in 14 locations points of the study network. To account for variability in noise values, tests were conducted in cruise speed, acceleration and highway points. The microphone was in the acoustic field 1.5 meters from the ground (height of tripod) and 7.5 meters and 15 meters from the main road axis. More than 50 data sets of 15 minutes (equivalent continuous sound level – L_{eq} - and respective arterial traffic) were collected.

The six routes across the study domain were covered using GNSS data-logger and On-Board Diagnostic (OBD-II) system in nine equipped Ligh Dutty Vehicles - LDV (gasoline and diesel) and six different drivers to record vehicle speed in 1 second interval considering North to South and South to North directions. Prior to on-road dynamic tests, the minimum number of travel times was determined for each route based on literature methodology (Turner, 1998) considering the minimum sample size of 8 trips per route.

Vulnerable road users (VRUs) monitoring

An on-board sensors platform that could warn the cyclist of the proximity of obstacles, namely motor vehicles, was developed (see Figure 6). It has two major components: the first one was based on the development of a sensor system to be installed on a bicycle to detect obstacles. For this, Arduino Uno, sensor distance MB1200 XL-MaxSonar-EZ0 and Bluetooth module HC-05 was used. The second component was focused on the development of a smartphone app which allows the cyclist to be aware of the approaching of other vehicles in real time. The developed prototype shows the distance between an approaching vehicle and the bicycle. The mobile phone also vibrates with a greater frequency as the vehicle approaches. The development of the hardware included the study of the performance of different sensor solutions. Several static tests were carried out to certificate the proper function of the device. Dynamic tests were also made in an urban context, in the city of Aveiro, in different routes and under several levels of road traffic.



Speed	Time	Hours
0.476	00:00:29	19:54:47

Figure 6 – On-board sensors platform for bicycles.

References

Moreno T, Lavin J, Querol X, Alastuey A, Viana M, Gibbons W. Controls on hourly variations in urban background air pollutant concentrations. Atmos Environ. 2009; 43: 4178-4186.

Turner S. Travel Time Data Collection Handbook: Office of Highway Information Management, Federal Highway Administration, U.S. Department of Transportation, 1998.

Chapter 3: Development, integration and validation of related-traffic models

This chapter is dedicated to the description of link-based models and integration of traffic-related models. This was the preliminary process for the development of Link-based Eco-indicator (Chapter 4). The main goal is to integrate instantaneous emissions (Vehicle Specific Power – VSP), safety, and noise models.

A MATLAB numerical computing second-by-second LDV and HDV dynamics data from VISSIM output (speed, acceleration and slope), a methodology that correlates traffic models/traffic behaviour and emissions and a library of link-based performance function were developed. With this, traffic emissions were characterized, as well as simplified based traffic emissions models, multiobjective dynamic traffic assignment model and a predictive model of vulnerable road users risk factors based on severity levels were concluded.

3.1. Road traffic data analysis

VISSIM microscopic model was used for traffic modelling. Vehicle Specific Power (VSP) methodology for estimating real-world emission rates based on on-road experimental measurements of road vehicles was used; VSP is determined from a second-by-second speed profile for a specific vehicle; thus, it is dependent on the vehicle's speed, acceleration, and road grade. The feasibility recognizing relationships between traffic patterns and corresponding pollutant emissions, according to VSP, was developed. At this stage, the research team has several hours of data collection that allows the calibration and validation of the integrated modelling platforms.

A pilot experiment was developed to identify key variables towards the development of advanced link-based performance functions for characterizing the environmental and traffic performance of the road network. Figure 7 presents the comparison between the congestion level and VSP mode for different route tested.

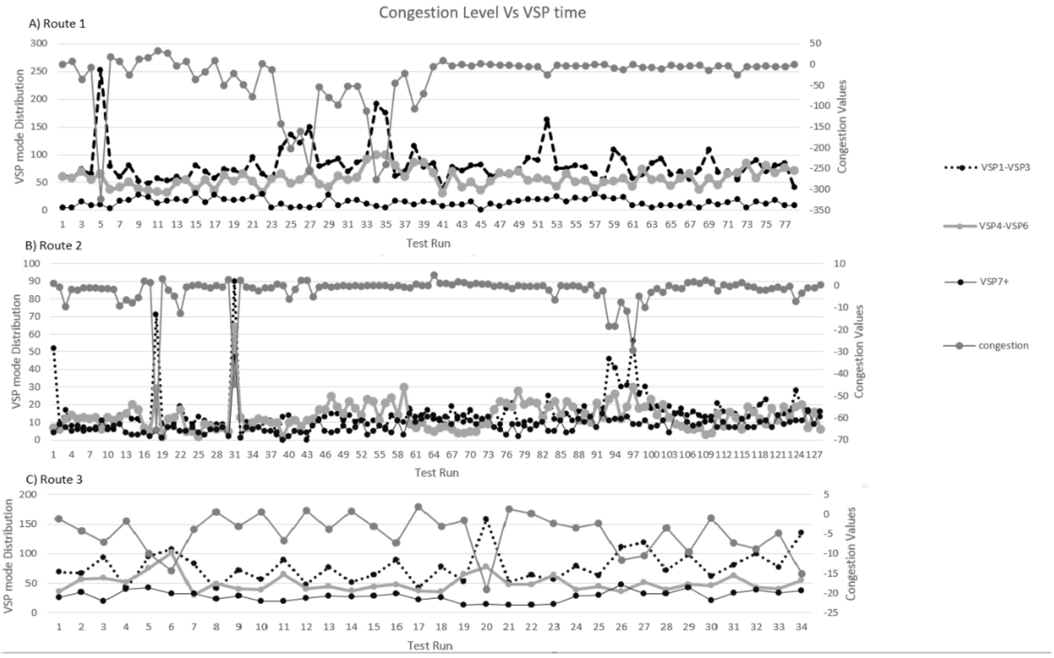


Figure 7 - Comparison between congestion levels and VSP time A) route1, B) route 2, C) route 3

Figure 8 relates CO_2 emissions for diesel and gasoline vehicles with VSP mode distribution. The values showed, represented the mean of each variable for each test.

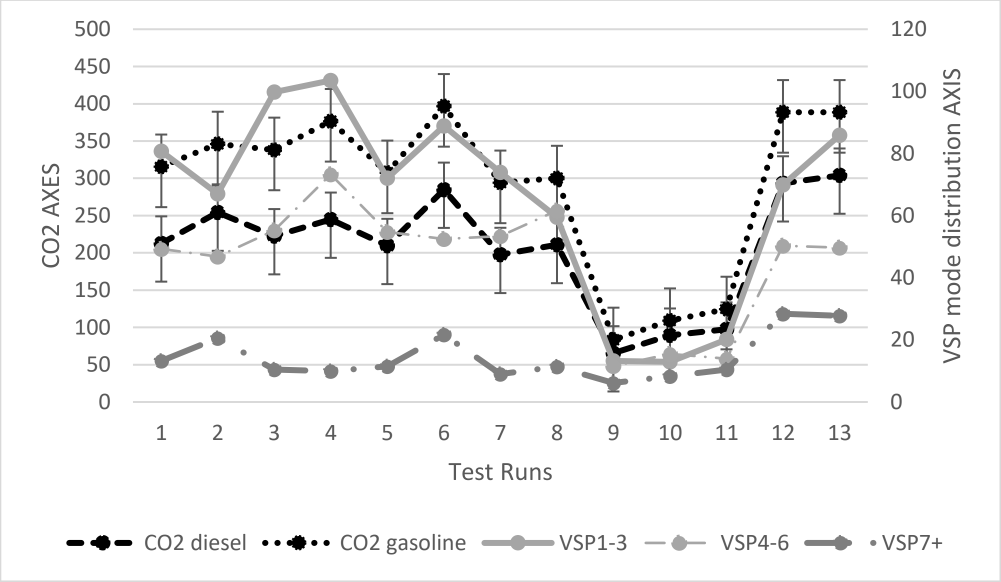


Figure 8 - Comparison between total CO2 emissions in each route and time spent on VSP intervals

It was noticed that CO_2 consumption is higher when the time spent from VSP1 to VSP4 is higher. With these perceptions, and associating them with the congestion level algorithm, it is expected to reach an understanding about higher CO_2 consumption, about if it is happening due to stop-and-go situations (specifically intersection cases) or to inconstant speeds (due to the dynamic of the route, if the flow is slow or fast, or if it is related to aggressive conductions or passing by) (Teixeira et al., 2017).

A multi-objective traffic assignment approach was developed to minimize system-wide travel time, distance traveled (associated with fuel consumption) and global and local pollutant emissions. Results highlight that system optimal distribution based on the suggested multi-objective traffic assignment based on three components yields savings in terms of distance travelled (2.6%) and emissions (1.3% for CO_2 and 1.1% for NO_x), but penalizes travel time 3% translated in an increase of 20 seconds per vehicle, when compared to solution only focused on minimizing travel time. The multi-objective traffic assignment approach that we propose seeks to minimize travel time, distance traveled and pollutant emissions, and involves the following objective functions within each component:

Efficiency: $\sum_{a}\sum_{m} x_{am} l_a / s_{am}$ (travel time), $\sum_{a}\sum_{m} x_{am} l_a$ (distance travelled),
Climate: $\sum_{a}\sum_{m} x_{am} ef_{CO_2}(s_{am}) l_a$,
Air quality: $\sum_{a}\sum_{m} x_{am} ef_{NO_X}(s_{am}) l_a$,

where x_{am} and s_{am} are the vehicle type m inflow to and the average speed on link a, respectively, and l_a(km) represents the length of link $a \in A$.

The presented objectives are used to determine optimal traffic distributions using a DTA model to account for traffic dynamics and time-variant demand. The VISSIM microsimulation tool (PTV AG, 2016) is an efficient way of describing time-varying network traffic conditions and finding shortest routes (in terms of travel time, distance travelled, and/or a specific cost per link) in networks where link travel times may change over time. Thus, a DTA simulation-based modelling approach using Vissim was used in the performance analysis of an intercity corridor. We developed in Matlab a custom procedure able to access Vissim through COM (Component Object Model) interface in order to incorporate the multi-objective nature of the proposed model and with the objectives we want to focus. The controlling process launches VISSIM, loads the network, integrates the objective functions at each DTA step, and sends back costs per link to Vissim. This allows controlling VISSIM model and simulation in real-time (Macedo et al., 2019).

3.2. Safety models

SSAM was used to model conflicts between different types of roads users. SSAM automates traffic conflict analysis by processing vehicles trajectories from microscopic traffic model as VISSIM. For each simulation, SSAM stores the trajectories of vehicles and bicycles from the traffic model and determines whether an intercepconfltion between vehicle-to-vehicle or vehicle-to-bicycle satisfies the condition to be deemed a traffic conflict (Fernandes et al., 2015). SSAM computes three types of estimated conflicts: rear-end, lane-change and crossing conflicts. Specifically, a given interaction between two converging vehicles is tagged as a conflict when the minimin time to collision (TTC) and post encroachment time (PET) values drop the threshold values.

Fernandes et al. (2019) developed an approach that combined an emission methodology (VSP) and safety model (SSAM) with microscopic traffic model (VISSIM) to identify hotspots in terms of emissions, costs and conflicts in a University Campus parking area. Figure 9 shows the conflicts simulations for 2 scenarios:

- Baseline Scenario: Actual traffic conditions on study area where parking search routing was done using the Dynamic Traffic Assignment (PTV AG, 2016) since no origin-destination parking surveys were available;

- Scenario 3 (S3): I1 and I4 are replaced by conventional single-lane and two-lane roundabouts, respectively. In addition, vehicles can enter or exit in the campus using I4 west leg;

- Scenario 5 (S5): Same as previous scenario, but barrier gates now allow entering or exiting parking and campus as well.

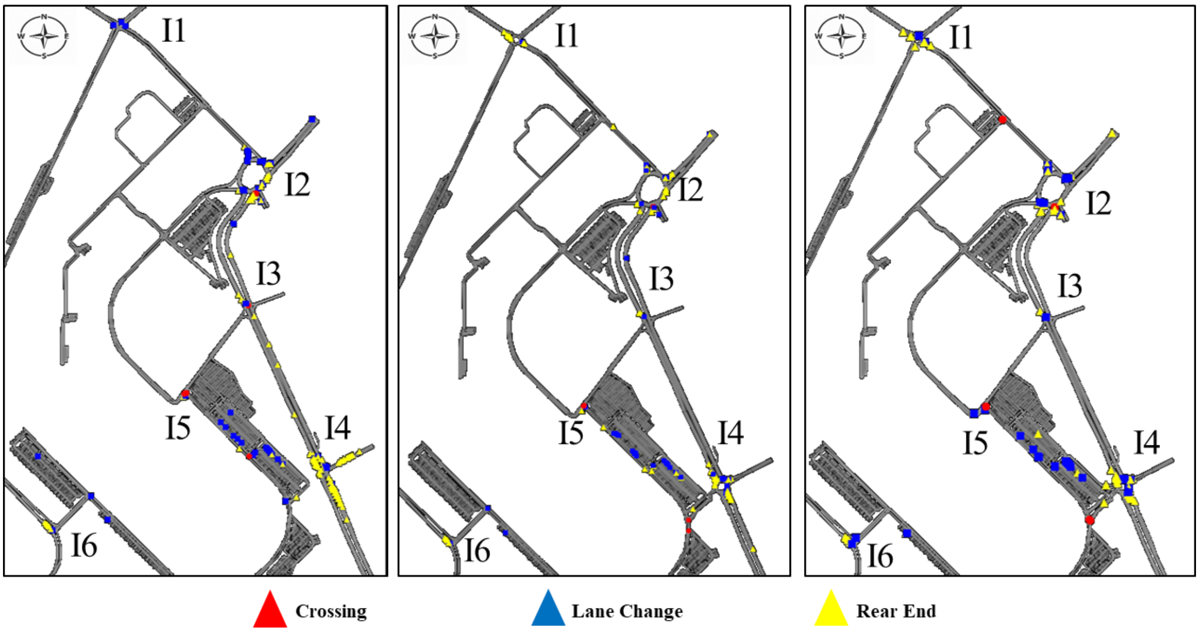


Figure 9 - Hotspot conflicts location: a) Baseline Scenarios; B) S3; C) S5

Figure 9 shows conflicts for the baseline, and S3 and S5 (best scenarios for the study area). The concentration of traffic conflicts in the baseline scenario was found at the most heavily congested I1 and I2 entries. Also, the signalized intersection (I4) also had a predominance of rear-end conflicts (yellow triangles), especially in North and South main approaches. Both S3 and S5 visibly reduced the number of conflicts at I4 influence area and I2 south approach (vehicles that came from South study area no longer use I2 to enter to campus). Yet, SSAM graphical representation showed that additional crossing conflicts occurred in the intersection between new entrance and campus main road. This phenomenon may represent future operational and safety issues if more drivers choose to use this new entrance to the campus area. (Fernandes et al., 2019).

Figure 10 displays the effects of varying the traffic demand at the above scenarios on CO_2 and NO_x emissions and a number of conflicts. S3 and S5 showed as good options up to vehicle demands of 260 vph. Both scenarios decreased emissions in 1% and 4% for CO_2 and NO_x, respectively and costs up to 2% compared with that of the existing conditions. This work was useful to identify both positive and negative impacts concerning the implementation of specific mobility measures on University campus environment (Fernandes et al., 2019).

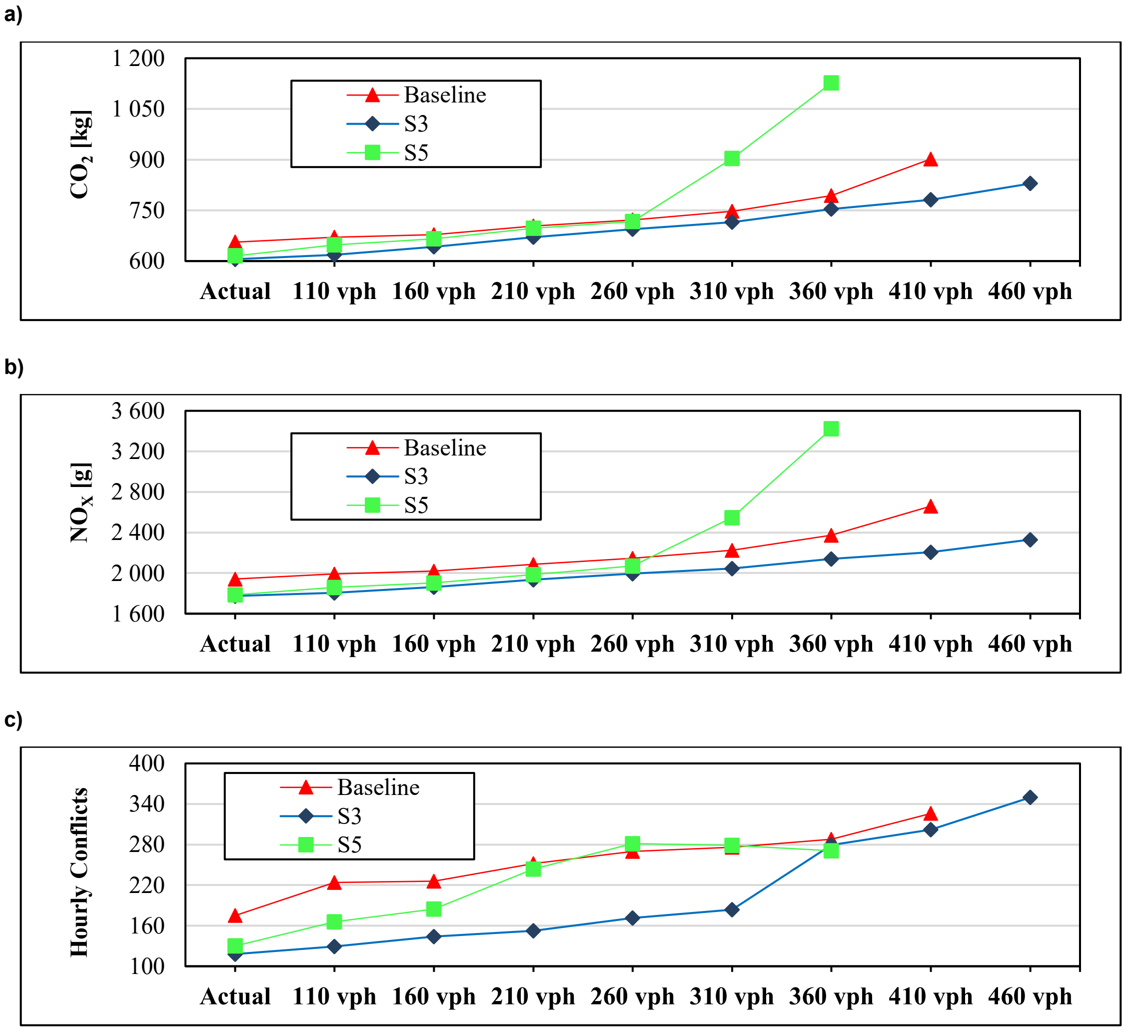


Figure 10 - Outputs trends with variations in traffic demand: a) CO_2; b) NOx and c) Number of conflicts

Bahmankhah et al. (2017) evaluated traffic performance, pollutant emissions and road conflicts between bicycles and motor vehicles at signalized intersections. The microscopic traffic model (VISSIM) paired with emissions (Vehicle Specific Power – VSP) and safety (Surrogate Safety Assessment Methodology – SSAM) models were used to assess intersection-specific operations. The results showed that two-lane roundabout outperformed the existing traffic control (number of spots and travel time reduced in 78% and 14%, respectively). It was also found that the number of conflicts was significantly reduced (-49%) with this latter layout even in maximum bicycle demand scenario. Linear regression analysis was conducted to identify if the simulated traffic conflicts provided reasonable estimates for the observed traffic conflicts. Linear regression models were fitted to relate the simulated conflicts to total observed conflicts in the site. It was found that the relationships between the simulated and observed conflicts were statistically significantly and acceptable (Figure 11).

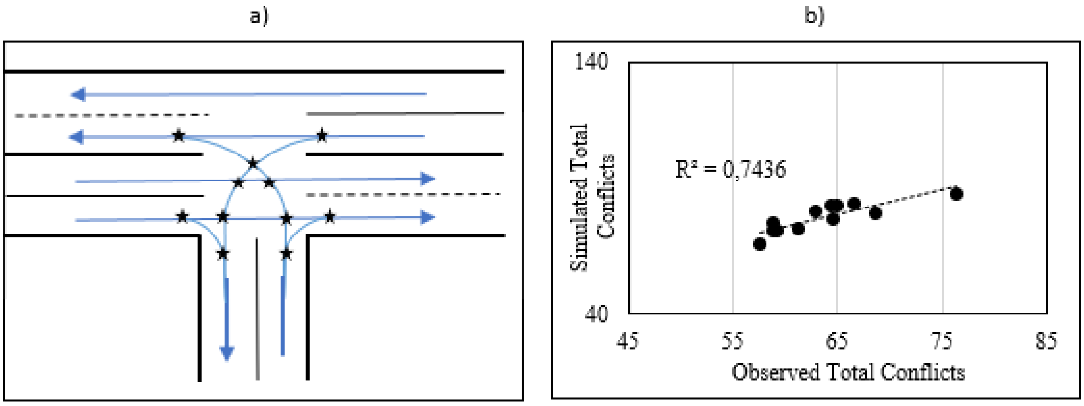


Figure 11 - a) Conflict types observed at three-leg signalized intersection; b) Relationship between observed and simulated conflicts.

A particular attention was given to safety involving VRUs; the variables that influence a crash involving a pedestrian or a cyclist were identified, and a spatial-temporal analysis was made, using statistical methods, with real crash data given by the Portuguese Authority for Road Safety (ANSR).

In a first step, a database of crashes registrations involving motor vehicles and vulnerable road users (VRUs) from Aveiro, Portugal, between 2012 and 2015 was analysed and a binary logistic regression was used to understand the factors that affect the probability of the VRU involved in a crash to be a pedestrian when compared with a cyclist (Table 2). From Table 2 we can conclude that the probability of a VRU be a pedestrian increase by 2.7 times if the crash occurs on an urban street segment, 10.6 times if the crash occurs at a pedestrians' crosswalk, and 3.5 times if the VRU is a female (Vilaça et al., 2017).

	B	*p*-value	*Exp(B)*
VRU Genre (female)	1.252	0.000	3.496
Location (urban street segments)	0.987	0.004	2.682
Crosswalk (yes)	2.364	0.000	10.635
Meteorological Conditions (good)	-1.459	0.003	0.232

Table 2 - Binary logistic regression independent variables

Considering the injury severity levels from crashes involving VRUs, a spatial and temporal analysis between three different (Aveiro, Porto and Lisbon) were achieved, and a model was developed to predict the likelihood of VRUs to be involved in a crash.

Kernel Density Estimation was applied to identify blackspots based on injury severity levels (Figure 12). Afterward, a multinomial logistic regression (MLR) model was developed to identify statistically significant variables to predict the occurrence of these crashes.

The main findings allow to conclude that most injuries occur in surrounding areas of high attraction places, such as train stations, shopping malls and touristic points, where speed limits are relatively low. The developed MLR models for each city revealed that VRU gender and age, as well as weather conditions, are statistically significant variables to predict this type of crashes (Vilaça et al., 2018).

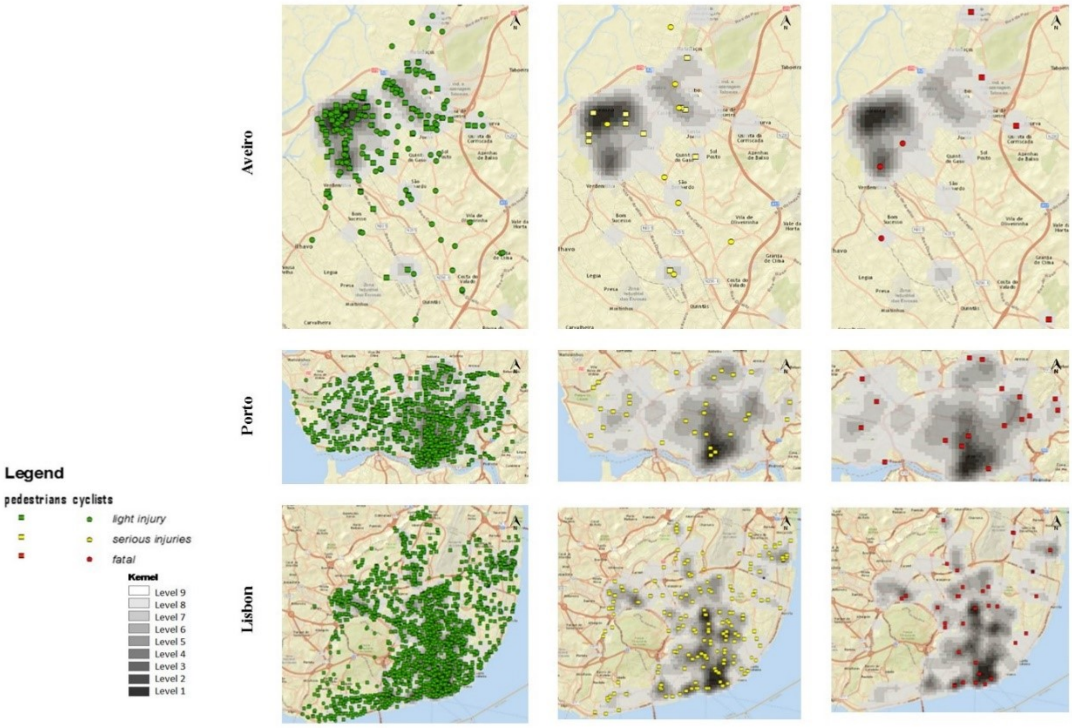


Figure 12 - Spatial distribution of crashes involving VRUs based on level of severity injury

Road crashes datasets are usually imbalanced (the number of occurrences classified under the fatal and severe injuries is significantly lower than the light injuries), these represents an issue for a classification learning algorithm – the result could be biased from the majority class. For that purpose, a comparative evaluation of two machine learning classifiers - Decision Tree and Logistic Regression - considering three different resampling techniques (under-, over- and synthetic over-sampling) is presented, comparing both imbalanced and balanced datasets. The main conclusion that can be drawn from this study is that oversampling techniques improve the ability of the classifiers to identify risk factors. On the one hand, this analysis revealed that road markings, road conditions and luminosity affect the injury severity of a pedestrian. On the other hand, age group and temporal variables (month, weekday and time period) showed to be relevant to predict the severity of a cyclist injury when involved in a crash (Vilaça et al., 2019).

3.3. Noise

Noise modelling was developed within a partnership between TEMA and Prof. Claudio Guarnaccia, from the University of Salerno, Italy. Two main methodologies approaches have been developed and improved as described in the next points.

CNOSSOS-EU model

The CNOSSOS-EU model is suggested by the European Commission as the reference model (Kephalopulos et al., 2012). The basic concept is to evaluate the source power level of the traffic, assumed to be a line source, composed by several point sources moving on the road, each of them including the rolling and the propulsion sources. The propagation at the receiver is calculated assuming confident percentages of “favorable” and “homogeneous” conditions and including possible reflections and diffractions. A comparison of CNOSSOS-EU model performances with respect to other predictive models results and with field measurements, in different case studies and conditions, can be found in Guarnaccia et al. (2018).

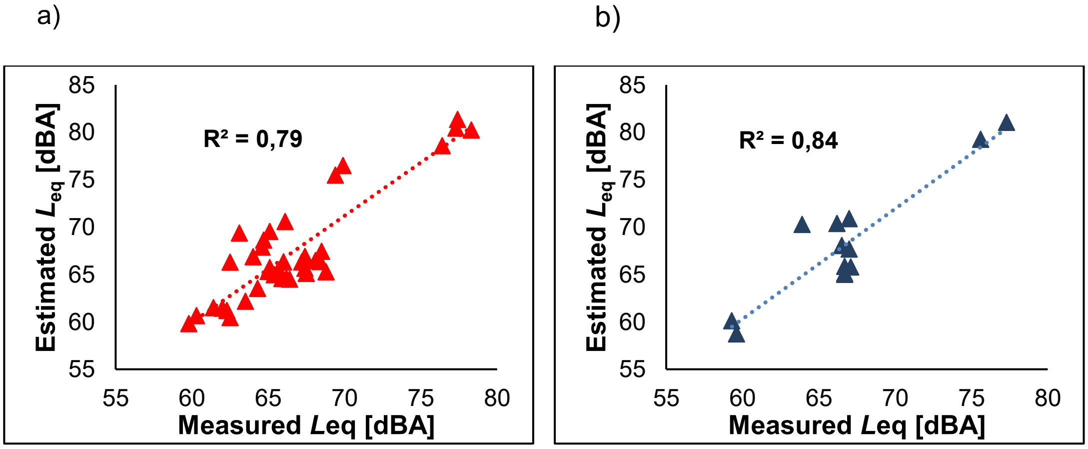
Quartieri et al. model

A numerical approach developed by Quartieri et al. (2010) presented a simple way to modify the general statistical approach for road traffic noise prediction. This procedure relates directly the acoustical energy sent to a receiver to the number of vehicles, to the source-receiver distance and to the mean traffic speed. The above information is used to assess source power levels and then, equivalent noise levels for a particular segment k ($L_{eq,k}$), which are obtained at a fixed distance d, according to the distance between the road axis and the receiver. Equation 2 gives the hourly equivalent noise level by segment (Guarnaccia, 2013):

$$L_{eq,k} = 10\log(V_{LDV} + nV_{HDV}) + 53.6 + 26.8logV_k - 20logd - 46.563$$

where $L_{eq,\ k}$ is the segment-specific equivalent noise level (dBA); V_{LDV} and V_{HDV} are the hourly LDV and HDV, respectively, volumes (vph); n represents the acoustic equivalent, i.e., the number of LDV that produce the same noise of a HDV; v_k is the segment-specific average speed (km.h^{-1}); d – Distance between the road axis and the receiver (m) (Quartieri et al., 2010).

During the development of the third case study was found that the noise estimates using this methodology matched the field measurements (training test). Higher the high noise values, the model tends to overestimate experimental data. Under high noise values, the model tends to overestimate experimental data. This happens because field measurements taken at bridges end up being affected by screening due to the bridge itself, even considering diffraction, i.e., noise emitted by vehicles outside the viewing angle of sound level meter. The predicted coefficient of determination (R^2) was almost 80% for simulated L_{eq} using a linear regression analysis (Figure 13). An identical trend was observed for noise validation (testing set fit simulated data in 84%).



<u>Note</u> – p-value of F-test (ANOVA) performed in R^2 coefficient was 0 in both linear regression models, indicating statistical significance; estimated values were computed by adopting an average acoustic equivalent (n) value of 8.

Figure 13 - Noise methodology: a) Calibration; b) Validation.

References

Bahmankhah B, Fernandes P, Coelho MC. Cycling at ntersections: A multi-objective assessment for traffic, emissions and safety, Transport Journal. 2019; 34(2):225-236.

Dias D, Amorim JH, Sá E, Borrego C, Fontes T, Fernandes P, et al. Assessing the importance of transportation activity data for urban emission inventories. Transportation Research Part D: Transport and Environment. 2018; 62: 27-35.

EC. (2006). ExternE - Externalities of Energy Methodology 2005 Update: European Commission, http://www.externe.info/externe_2006/.

Fernandes P, Fontes T, Neves M, Pereira SR, Bandeira JM, Rouphail NM, et al. Assessment of Corridors with Different Types of Intersections. Transportation Research Record: Journal of the Transportation Research Board. 2015; 2503: 39-50.

Fernandes P, Sousa C, Macedo J, Coelho MC. How to evaluate the extent of mobility strategies in a university campus: An integrated analysis of impacts. International Journal of Sustainable Transportation. 2020;14(2):120-136.

Guarnaccia C, Bandeira JM, Coelho MC, Fernandes P, Teixeira J, Ioannidis G, Quartieri J. Statistical and Semi-Dynamical Road Traffic Noise Models Comparison with Field Measurements. Proceedings of the 2nd Int. Conf. on Mathematical Methods & Computational Techniques in Science & Engineering (MMCTSE), University of Cambridge, UK, February 16-18, 2018.

Guarnaccia C. Advanced Tools for Traffic Noise Modelling and Prediction. WSEAS Transactions on Systems. 2013; 12: 121-130.

Kephalopulos S, Paviotti M, Afonsso-Lédéé F. Common Noise Assessment Methods in Europe (CNOSSOS-EU) - EU Science Hub - EC., 2012.https://ec.europa.eu/jrc/en/publication/reference-reports/common-noise-assessment-methods-europe-cnossos-eu

Lee R, Naesslund E. Lagrangian stochastic particle model simulations of turbulent dispersion around buildings. Atmos Environ. 1998;32:665-672.

Macedo E, Tomás R, Coelho MC. Assessing Road Transportation Impacts of Connected and Automated Vehicles in metropolitan freeways, 22nd Annual Meeting of the EURO Working Group on Transportation (EWGT2019), 18-19 September, Barcelona, Spain, 2019.

PTV AG. PTV VISSIM 9 User Manual: Planung Transport Verkehr AG. Karlsruhe, Germany, 2016.

Quartieri J, Iannone G, Guarnaccia C. On the Improvement of Statistical Traffic Noise Prediction Tools. 11th WSEAS Int. Conf. on Acoustics & Music: Theory & Applications, Iasi, Romania, June 13-15, 2010, pp. 201-207.

Teixeira J, Fernandes P, Bandeira JM, Coelho MC. Information management for smart and sustainable mobility, 96th Transportation Research Board Annual Meeting, Washington DC, January 2017.

Vicente B, Rafael S, Rodrigues V, Relvas H, Vilaça M, Teixeira J, Bandeira J, Coelho MC, Borrego C. Influence of different complexity levels of road traffic models on air quality modelling at street scale. Air quality, Atmosphere & Health. 2018;11:1217-1232.

Vilaça M, Macedo E, Coelho MC. A rare event modelling approach to assess injury severity risk of vulnerable road users, Safety, 5(2), 29, 2019.

Vilaça M, Macedo E, Tafidis P, Coelho MC. Occurrence and severity of crashes involving vulnerable road users – An integrated spatial and temporal analysis, 97th Transportation Research Board Annual Meeting, Washington DC, January 2018.

Vilaça M, Silva N, Coelho MC. Statistical analysis of the occurrence and severity of crashes involving vulnerable road users. 20nd Annual Meeting of the EURO Working Group on Transportation (EWGT 2017), 4-6 September, Budapest, Hungary, 2017.

Vlachokostas C, Achillas C, Moussiopoulos N, Kalogeropoulos K, Sigalas G, Kalognomou E-A, & Banias G. Health effects and social costs of particulate and photochemical urban air pollution: a case study for Thessaloniki, Greece. Air Quality, Atmosphere & Health. 2012;5(3):325-334.

Chapter 4: Dynamic link-based eco-indicator

The main objective of this task is to develop a dynamic link-based eco-indicator (also referred as “sustainability indicator”). Integration of multiple traffic externalities into a common measure was performed. This task was developed considering an urban scale and an intercity scale.

4.1. Urban Scale

The proposed eco-indicator can adapt to different traffic monitoring systems. In a microscopic approach, we simulate existence of Floating Car Data (FCD) based on onboard sensors capable of predicting driving cycles using Global Navigation Satellite Systems (GNSS). The macroscopic approach is based in average speed (e.g., loop detectors, video, Bluetooth sensors). For this purpose, two types of emissions models (VSP – Vehicle Specific Power (Coelho et al., 2009) and COPERT (Emisia, 2016)) were used. COPERT is an average speed-based emissions model widely used in Europe and it is easily adapted to the data available in terms of local fleet distribution, being this average speed-based emission models commonly used in eco-routing systems (Guo et al., 2012).

The determination of the costs of externalities associated with crossing a particular link by a specific vehicle is based on the methodology described in Korzhenevych et al. (2014). Costs of crossing a given link were adjusted to local vulnerability factors associated to each zone and potential exposed population (Figure 14).

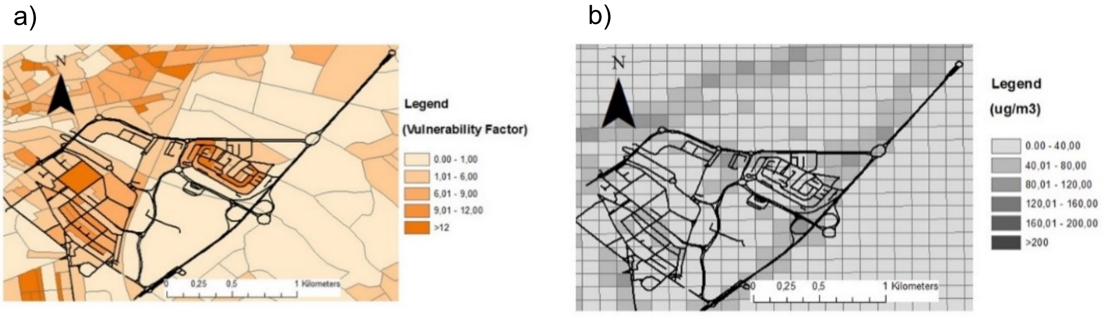


Figure 14 - a) Link-based vulnerably risk adjustment factor. b) NOx concentration grid.

A link-based eco-indicator was designed to assess greenhouse gases costs (GHGc) emissions, air pollution costs (APc) and noise pollution damages (NPc), for different vehicle types, weighted by local indices of vulnerability and real-time environmental conditions (Fernandes et al., 2018). One of the main advantages of this approach is the reduction of the computational resources required for multi-objective route optimization, since the problem of dealing with complex nonlinear functions (one for each externality) is minimized in a first phase. The link-based eco-indicator (LBEI) can be given by:

$$LBEI = GHGc + APc + NPc,$$

where, $GHGc = E_{CO_2} \cdot ECf_{CO_2}$; $APc = \sum Ep_i \cdot ECfp_i \cdot \frac{\overline{Pd}}{1500} \cdot cf$; $NPc = NC \cdot pop$, with Epi is the emission (g) of pollutant i (NO_x, NMVOC, $PM_{2.5}$); ECfpi is the average national emissions damage cost factor for pollutant i; Pd is the average population density in adjacent blocks; and cf is the concentration adjustment factor related to background concentration; pop is the estimated population in adjacent blocks (Sampaio et al., 2018).

Figure 15 provides an example of a link based on an eco-indicator close to a school with a mean average speed (36 km/h) and a high number of people exposed. When the LBEI is based on National Average (NA) damage cost values, the cost of CO_2 and noise accounts for 76% of the total link cost (with $PM_{2.5}$ representing 22%). Regarding the link with Vulnerable Factor (VF), the influence of CO_2 and noise is 27%, while the $PM_{2,5}$ costs represent 67% of the total link costs.

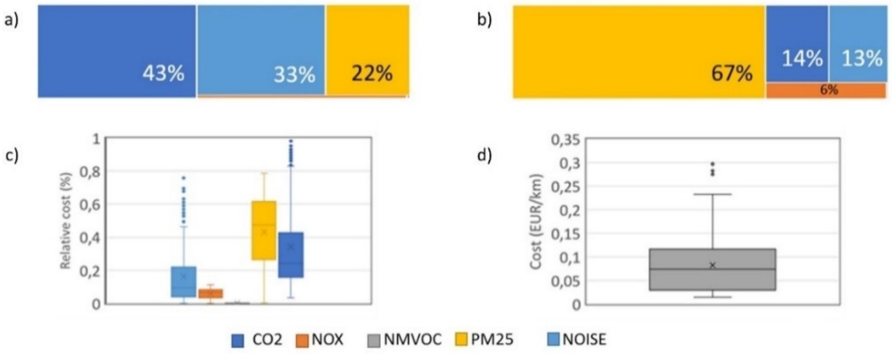


Figure 15 - Example of link based eco-indicator. a) based on national average values b) weighted by local vulnerability factor. Box and whisker plots of c) relative costs and d) LBEI variations (links > 50 m).

4.2. Intercity Scale

Considering an intercity network the sustainability indicator is intended to account monetary costs per vehicle (€.veh^{-1}) from road transportation activities in term of: traffic congestion, noise, greenhouse gases - GHG, Nitrogen Oxide - NOx, health impacts and road crashes. The core idea of the methodology was to use and test a modelling platform to evaluate external costs of road transportation at a segment level. It proceeded in five steps, illustrated in Figure 16 (Fernandes et al., 2018). The development of the sustainability indicator involved first, collecting traffic volumes, noise, vehicle dynamic (second-by-second speed, acceleration and slope), crash data and population per unit square from one real-world intercity corridor (3rd Case Study described at Task II). Second, the modelling platform was calibrated and validated, and then, studied location was divided into multiple sub-segments according to road type. Finally, external costs of road transportation (Korzhenevych et al., 2014) were computed to obtain the sustainability performance measure in monetary values.

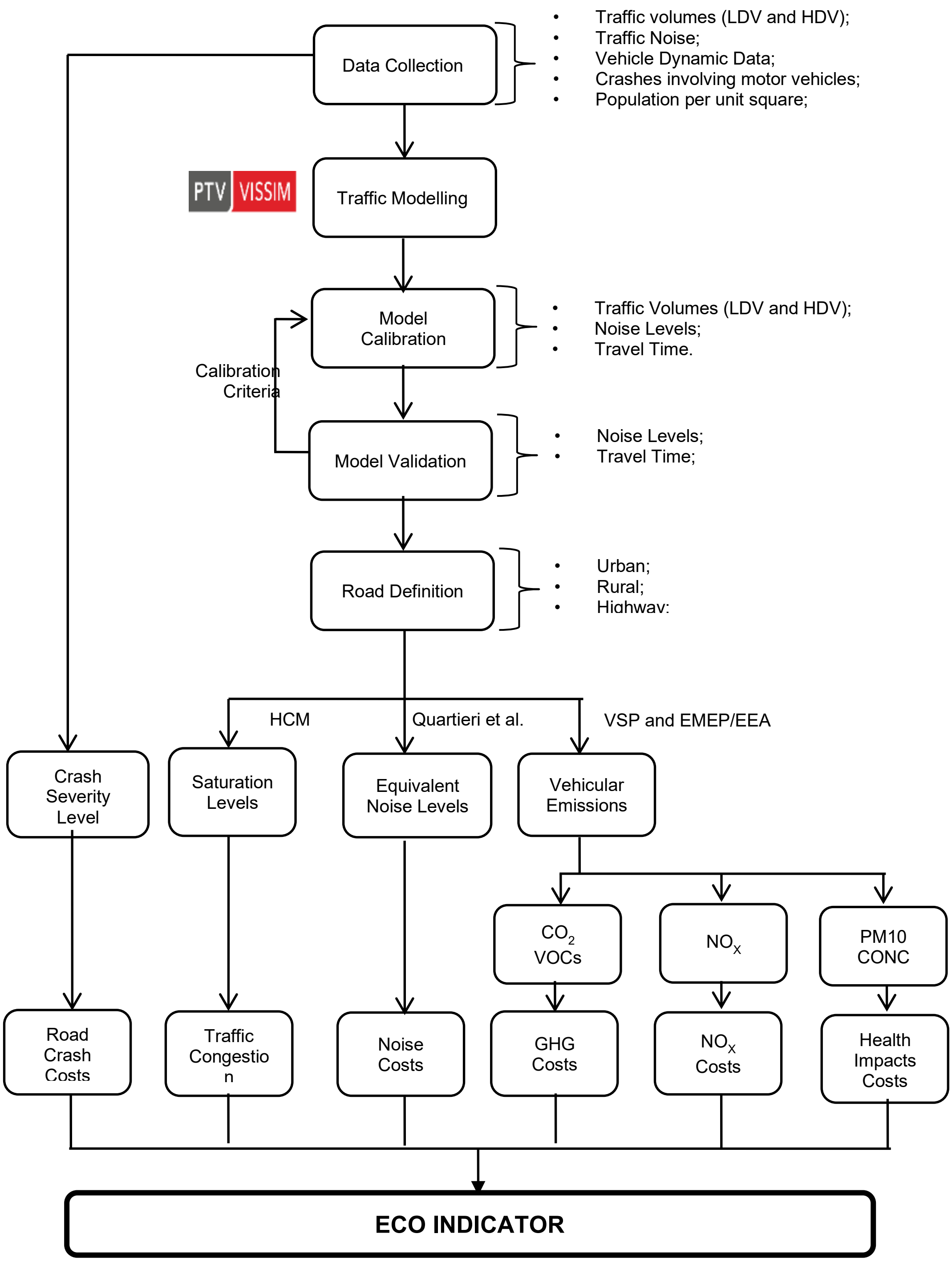


Figure 16 - Overview of the research methodology (LDV – Light Duty Vehicles; HDV – Heavy Duty Vehicles; HCM – Highway Capacity Manual; VSP – Vehicle Specific Power; EMEP/EEA – European Monitoring and Evaluation Programme by European Environmental Agency; CONC – C

The sum of each segment costs (*EC*) along each route confirmed R2 as the best option for the study domain (Figure 17). For instance, if one driver chooses R2 from south to north direction, then one could save 28% and 32% in external costs when compared with R1 and R3, respectively.

The analysis of the distribution of cost components along R1 showed the largest share corresponded to the road crashes (RC)-related costs; they represented around 31% and 30% of external costs in south-north and north-south directions, respectively. Greenhouse gases (*GHG)* showed as the largest contributor to external costs (40-45%, depending on travelling direction) in R2. For the latter route, results indicated the share of *RC* in south-north direction (16%) was higher than in north-south (9%). This happened because one crash involving a serious injury was recorded, resulting thus in high social costs. Almost half of external costs along R3 were based on *GHG* emissions, and more than 18% based on NO_X. This was due to the fact HDV traffic is relevant in that route. In turn, other externalities (Health impacts - *HI* and traffic congestion- *TC*) had slight impacts.

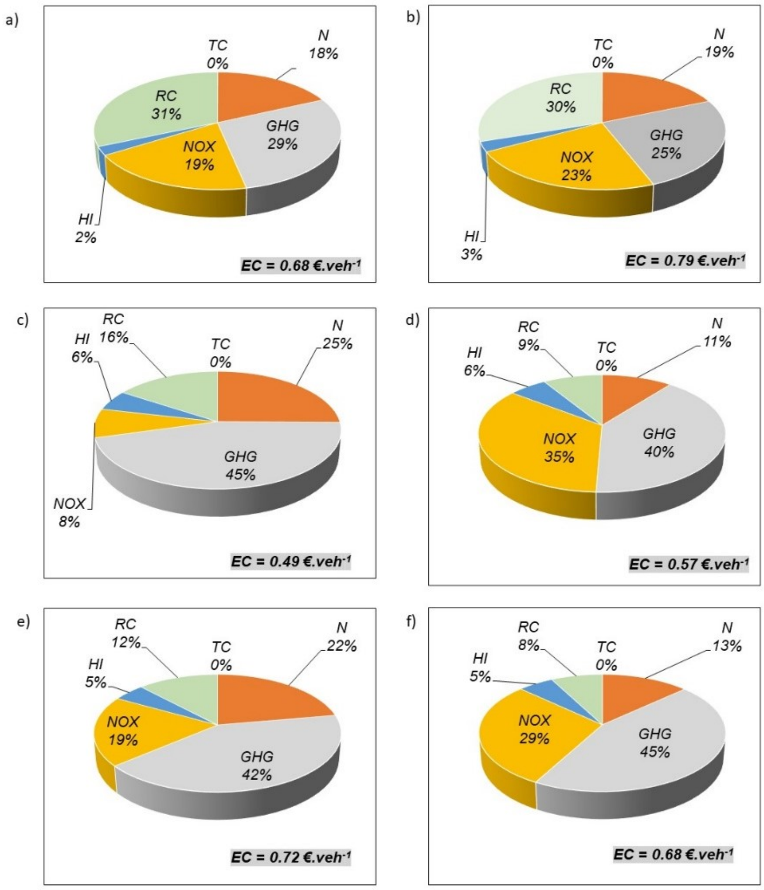


Figure 17 - Distribution of external costs by route: a) South to North (R1); b) North to South (R1); c) South to North (R2); d) North to South (R2); e) South to North (R3); f) North to South (R3).

The distribution of cost components differed from the type of road (Figure 18). The highest share of external costs per vehicle, which was about 33% of traffic-related costs in urban sections, was due to noise generated by road traffic. This happened because noise (*N)* is very sensitive to changes in potentially exposed population, which is clearly high in urban segments. Albeit small, NO_X *and PM10* represented together 35% of costs in urban areas thereby, reflecting its impacts on local population. The findings from rural sections suggested a different trend (*GHG* accounted for 33% of external costs, followed by *RC*, with 30%). Concerning the highway, it is interesting to note that *GHG* represented around 74% of the external costs, while *N* and NO_X had small impacts (~10% each). From Figure 18, traffic congestion had a small expression in external costs regardless of the type of road (Fernandes et al., 2018).

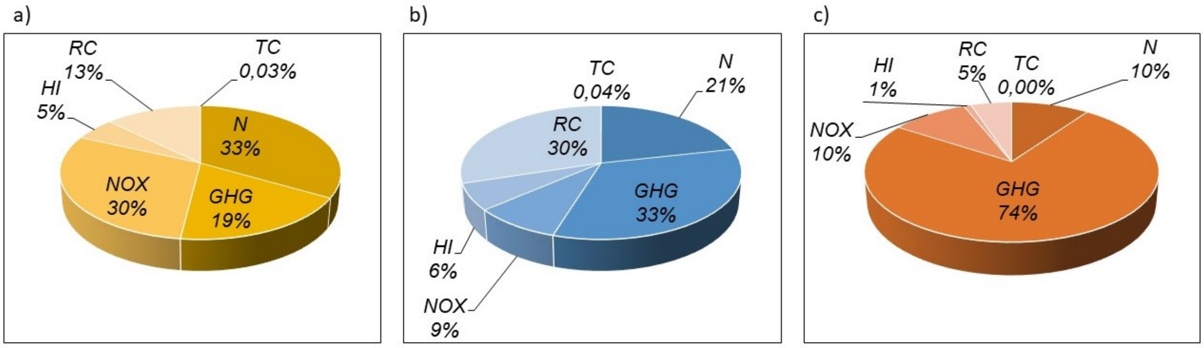


Figure 18 - Distribution of external costs by type of road: a) urban; b) rural; c) highway.

References

Coelho MC, Frey HC, Rouphail NM, Zhai H, Pelkmans L. Assessing methods for comparing emissions from gasoline and diesel light-duty vehicles based on microscale measurements. Transportation Research Part D: Transport and Environment. 2009;14(2):91–99.

Emisia. COPERT4 v.4.11.4. 2016. https://www.emisia.com/

Fernandes P, Vilaça M, Macedo E, Sampaio C, Bahmankhah B, Bandeira J, Guarnaccia C, Rafael S, Fernandes A, Relvas H, Borrego C, Coelho MC, Integrating road traffic externalities through a Sustainability Indicator, Science for Total Environment. 2019;691:483-498.

Guo, C, Ma, Y, Yang, B, Jensen, CS, Kaul M. EcoMark: Evaluating Models of Vehicular Environmental Impact. Proceedings of the 20th International Conference on Advances in Geographic Information Systems (pp. 269–278). 2012. New York, NY, USA: ACM.

Korzhenevych A, Dehnen N, Brocker J, Holtkamp M, Meier H, Gibson G, Cox V. Update of the Handbook on External Costs of Transport. 2014. https://ec.europa.eu/transport/sites/transport/files/handbook_on_external_costs_of_transport_2014_0.pdf

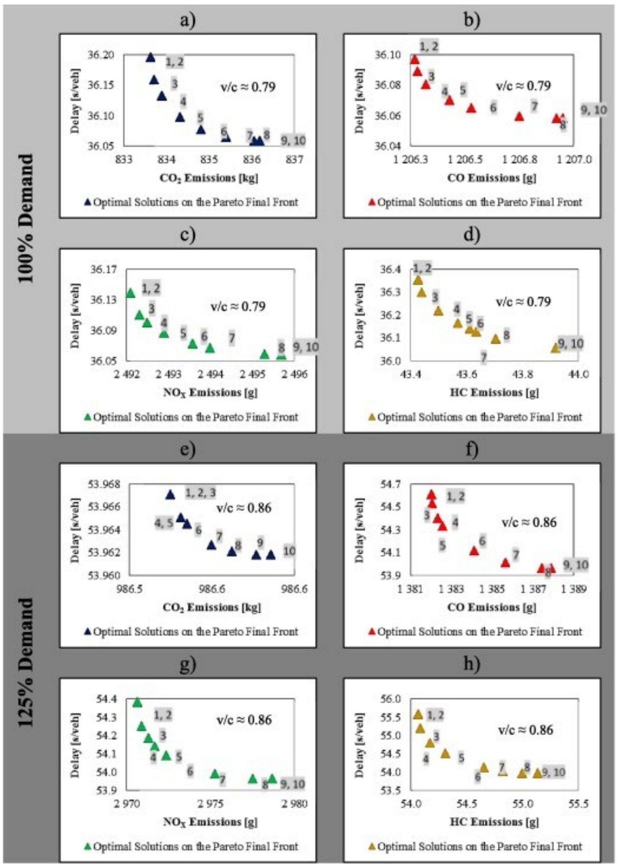
Sampaio C, Bandeira JM, Macedo E, Vilaça M, Guarnaccia C, Friedrich B, Relvas H, Rafael S, Rodrigues V, Coelho MC, A dynamic link-based eco-indicator for supporting equitable traffic management strategies. 21^{st} EURO Working Group on Transportation Meeting, EWGT 2018, 17-19 September, Braunschweig, Germany, 2018.

Chapter 5: Network optimization and design of a decision support system

This chapter is dedicated to the development of a set of optimizations tollboxes for exploring advanced traffic management systems. Based on holistic approaches the proposed solutions can contribute to improve sustainability of networks.

A multi-objective optimization was developed in an urban road. The analysis was focused on two major intersections of the corridor, a roundabout and a traffic light spaced lower than 170m apart under different traffic demand levels. The traffic data and corridor geometry were coded into VISSIM and compared with alternative scenario where the traffic light was replaced by a single-lane roundabout. Several spacing values were tested to find a set of optimal spacing location between two roundabouts that allowed minimizing delay and vehicular emissions. Scenario 1 with 100% and 125% demand levels was applied, assuming several spacing lengths (S) between from 70 meters to 250 meters. The following objective variables were optimized: (1) delay versus CO_2; (2) delay versus CO; (3) delay versus NO_x and (4) delay versus HC (Fernandes et al., 2017a).

For the 100% demand factor level (Figure 19a–d), the findings confirmed that low-spacing values (<180 m) and high-spacing values (>222 m) were not good options. Furthermore, no significant differences in the optimal spacing set among pollutants were observed. For solution 5 (data label point which is closest to the abscissa of the graph), that is, 207 meters of spacing, average delay and CO_2 emissions decreased by 5% and 2%, respectively, when compared to the existing spacing. For a chosen value of the lowest optimal spacing value (solution 1), reductions of 3%, 2%, 4% and 6% in CO_2, CO, NO_X and HC, respectively, can be expected on case study corridor in relation to 167 meters of spacing (Fernandes et al., 2017a).

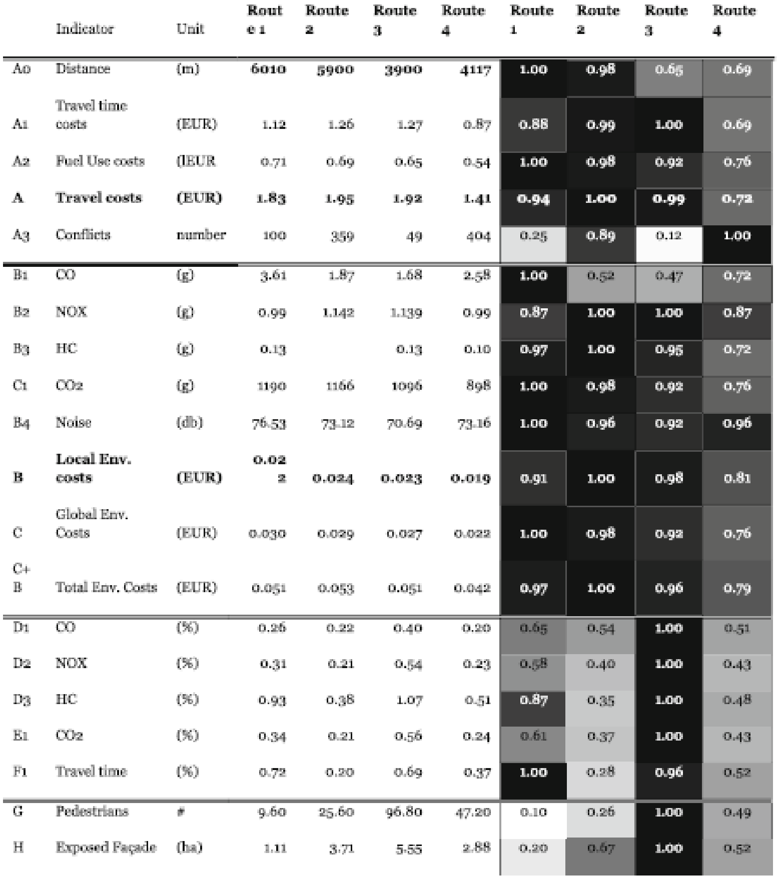


Note: v/c is the average volume-to-capacity ratio with optimized traffic conditions

Figure 19 - The approximate Pareto front for scenario 1 under different traffic conditions: 100% demand factor (a, b, c and d) and 125% demand factor (e, f, g and h).

A multi-objective optimization approach was also developed considering the location of a crosswalk between two roundabouts considering emissions, travel time and noise. Traffic and pedestrian volumes, vehicle dynamic and noise data were collected during morning and evening peak periods. Traffic and pedestrian performance, and vehicular emissions were evaluated using VISSIM traffic model and Vehicle Specific Power (VSP), respectively. Traffic noise was estimated with a semi-dynamical model and an estimation of the corridor Source Power Level (SPL) was used as a distance-free parameter to be compared with other emissions. Finally, a Genetic Algorithm (GA) was applied to find optimal crosswalk locations (Fernandes et al., 2017b). Considering the foregoing discussion, three main conclusions can be drawn: *i*) crosswalks near the roundabout exit section had a negative impact on both traffic delay and vehicular emissions; *ii*) noise levels had small variations, in a range of about 2 dBA, regardless of the crosswalk location and analysis period; *iii*) locating a crosswalk near the midway positions resulted in good traffic and emissions outcomes, however, this fact did not hold for pedestrians (higher travel time) (Fernandes et al. 2017b).

The research team developed a plataform based on both empirical GPS data and microscopic simulation models of traffic, pollutant emissions and noise, as well as a road conflict prediction to characterize in detail 4 routes of an origin/destination pair (Bandeira et al., 2018). In addition to the traditional indicators considered in common navigation systems and even in eco-routing systems, new variables have been consided such a noise and road safety. A novelty was also the preliminary inclusion of social criteria in defining sustainable routes. Table 3 quantifies the overall results presented previously for each route and provides economic cost values based on the monetization criteria. For facilitating a comparative analysis among indicators, the four right columns show the relative results represented by a graduation of colors on the various parameters analysed (darker cells are worse options for each indicator).



	Indicator	Unit	Route 1	Route 2	Route 3	Route 4	Route 1	Route 2	Route 3	Route 4
A0	Distance	(m)	**6010**	**5900**	**3900**	**4117**	1.00	0.98	0.65	0.69
A1	Travel time costs	(EUR)	1.12	1.26	1.27	0.87	0.88	0.99	1.00	0.69
A2	Fuel Use costs	(IEUR	0.71	0.69	0.65	0.54	1.00	0.98	0.92	0.76
A	**Travel costs**	**(EUR)**	**1.83**	**1.95**	**1.92**	**1.41**	**0.94**	**1.00**	**0.99**	**0.72**
A3	Conflicts	number	100	359	49	404	0.25	0.89	0.12	1.00
B1	CO	(g)	3.61	1.87	1.68	2.58	1.00	0.52	0.47	0.72
B2	NOX	(g)	0.99	1.142	1.139	0.99	0.87	1.00	1.00	0.87
B3	HC	(g)	0.13		0.13	0.10	0.97	1.00	0.95	0.72
C1	CO_2	(g)	1190	1166	1096	898	1.00	0.98	0.92	0.76
B4	Noise	(db)	76.53	73.12	70.69	73.16	1.00	0.96	0.92	0.96
B	**Local Env. costs**	**(EUR)**	**0.022**	**0.024**	**0.023**	**0.019**	0.91	1.00	0.98	0.81
C	Global Env. Costs	(EUR)	0.030	0.029	0.027	0.022	1.00	0.98	0.92	0.76
C+B	Total Env. Costs	(EUR)	0.051	0.053	0.051	0.042	0.97	1.00	0.96	0.79
D1	CO	(%)	0.26	0.22	0.40	0.20	0.65	0.54	1.00	0.51
D2	NOX	(%)	0.31	0.21	0.54	0.23	0.58	0.40	1.00	0.43
D3	HC	(%)	0.93	0.38	1.07	0.51	0.87	0.35	1.00	0.48
E1	CO_2	(%)	0.34	0.21	0.56	0.24	0.61	0.37	1.00	0.43
F1	Travel time	(%)	0.72	0.20	0.69	0.37	1.00	0.28	0.96	0.52
G	Pedestrians	#	9.60	25.60	96.80	47.20	0.10	0.26	1.00	0.49
H	Exposed Façade	(ha)	1.11	3.71	5.55	2.88	0.20	0.67	1.00	0.52

Table 3 - Overall results for the analysed indicators

References

Fernandes P, Coelho MC, Rouphail NM. Assessing the impact of closely-spaced intersections on traffic operations and pollutant emissions on a corridor level. Transportation Research Part-D: Transport and Environment. 2017a;54:304-320.

Fernandes P, Guarnaccia C, Teixeira J, Sousa A, Coelho, MC. Multi-Criteria Assessment of crosswalk location on a corridor with roundabouts: Incorporating a Noise related Criterion, Transportation Research Procedia. 2017b;27:460-467.

Bandeira JM, Guarnaccia C, Fernandes P, Coelho MC, Advanced impact integration platform for cooperative road use, International Journal of Intelligent Transportation Systems Research. 2018; 16:1-15.