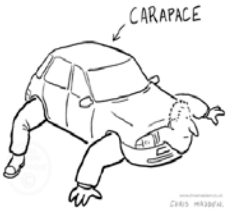
LABEX – Appel Bourse de Thèse

Understanding and Modeling Mobility Characteristics of Scooters and Motorcycles for User-centric ITS Applications.

1. Introduction and Objectives



Vulnerable traffic users represent a category of users not protected by a “car-apace”, such as pedestrians, bicycles, motorcycles or scooters. Unlike in China, where visible social achievements are represented by owning cars, the western world follows the opposite trend and witness a steady increase of vulnerable road users.

The increase of vulnerable users coexisting with cars is a direct consequence first of worsening traffic congestions, which triggered recent efforts either by city councils to propose multi-modal transport solutions, or by drivers to spontaneously shift to alternative transportation means (e.g. walking, motorcycles, scooters or bicycles). Such trend would be seen as positive if the peculiar mobility behavior of vulnerable traffic users was not a challenge to a smooth coexistence with other road actors. This is clear concern to road authorities and city councils, as such traffic coexistence needs to be kept safe and efficient.

Traffic safety and efficiency may be provided through cooperative mobility and networking between traffic users. By equipping them with communication devices, it is possible to exchange self-presence and awareness with each other through cooperative communications. Presented already in 1939 at the *Futurama World Fair* [Futurama] by General Motors as a mean to reach “safety at an increased speed”, cooperative ‘vehicular’ communications only reached pre-deployment stage in 2013 with the EU FP7 Drive-C2X project [DriveC2X] and the finalization of the standardization at the ETSI TC ITS.

Yet, all these efforts focused so far on increasing traffic safety and efficiency of cars alone. The most vulnerable traffic users, e.g. pedestrians, scooters, bicycles, are therefore not ‘visible’ to the cooperative traffic safety and efficiency applications currently being developed. Safety measures are therefore not provided to the traffic actors that would require them the most. This is a very critical aspect to address and has been set as a key objective by the European Commission in its H2020 Transport calls.

In this project, we will focus on vulnerable 2-wheel vehicles (scooters, motorcycles), which showed a significant increase in urban and highway traffic over the last 10 years. For example, according to a study of the “Observatoire de la Mobilité en Ile-de-France” [DRIEA île de France] related to the evolution of mobility habits in Paris, scooters showed a 34% increase in traffic volumes between 2001 and 2010, while cars showed only a 0.6%. Beside cost and ease of use, the major interest comes from the ability of 2-wheelers to avoid traffic and reduce travel times.

Isolated, 2-wheel vehicles are not more vulnerable than any other type of traffic, but when mixed up with cars in traffic, in particular when their traffic share increases, 2-wheelers generate a difficult cohabitation with other types of traffic that leads to safety and capacity concerns. On highways for instance, 2-wheelers flow around cars and create safety issues to drivers. In urban areas, multiple 2-wheel vehicles regroup on single lanes making car driving more challenging.

So far, cooperative mobility and networking solutions addressing such concerns are quasi-inexistent, mostly as the mobility of 2-wheel vehicles is not precisely understood. It would yet be an opportunity for traffic authorities to improve flows and adapt traffic policies. It would also help to estimate the additional capacity created by 2-wheel vehicles, or to dimension policies to gradually adopt 2-wheel rather 4-wheel vehicles in urban environments.

The understanding of 2-wheel vehicles’ peculiar mobility characteristics, and their interactions with 4-wheel vehicular traffic would therefore pave the way for innovative applications through a wide range of actors. Policy-makers could evaluate the benefits of a modal swap between cars and scooters/motorcycles, also highway operators could integrate 2-wheel vehicles in their capacity estimates, and traffic authorities would be able to identify safety requirements for a sustainable cohabitation between 2-wheel and 4-wheel vehicles. Personalized navigation and location-based solutions for 2-wheel vehicles could finally be offered to drivers, or innovative start-up and SMEs could develop innovative services, such as scooter-sharing.

The first objective of this project is therefore to develop mobility models capable of jointly modeling cars as well as vulnerable 2-wheel vehicles in highway and urban environments at macroscopic and microscopic scales. The second objective is to provide a methodology to analyze and evaluate the peculiar mobility characteristics of 2-wheel vehicles alone, as well as integrated with 4-wheel traffic. These two objectives would allow for instance to:

- Identify safety conditions of vulnerable motorcycles and scooters when sharing roads with cars.
- Develop a Floating '2-wheel' Data methodology to extract and monitor integrated traffic volumes.
- Evaluate the benefits of 2-wheelers peculiar mobility characteristics on traffic, in terms of capacity, congestion dissolution, or carbon footprint.
- Estimate the impact of modal swap of cars to 2-wheel vehicles to mitigate road congestions.

2. Scientific and Technical Objectives

The scientific and technical objectives for modeling 2-wheel vehicular mobility are related to the peculiar mobility characteristics of 2-wheel vehicles. They first have different kinematic characteristics (e.g. stronger acceleration and deceleration), and second they have the ability to share a lane or even move between lanes, whereas 4-wheel vehicles must occupy a full lane. The coexistence between 2-wheel and 4-wheel in a single unified model is therefore challenging.

Vehicular mobility may be modeled at macroscopic scale, where only macroscopic scale parameters (e.g. speed, density, flow, capacity) are modeled, or at microscopic scale, where the precise kinematic parameters (acceleration, speed, position) of each single vehicle are modeled.

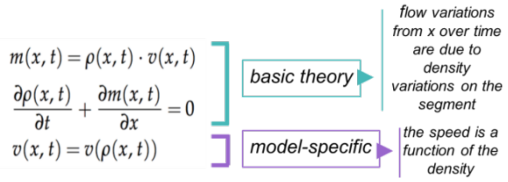


Figure 1 Lighthill-Whitham-Richards (LWR) hydrodynamic model

Macroscopic vehicular mobility represents traffic flows as a fluid. Significant literature has been proposed to provide fine equations for modeling 4-wheel vehicular mobility starting from the '50s [*Lighthill-Whitham-Richards, Hoogendoorn-Bovy*]. On the contrary, only a few tried to address 2-wheel vehicular mobility as a fluid [*Nair-Mahmassani-Miller*]. Moreover, the challenge is not to model 2-wheel or 4-wheel mobility independently, but rather to have a multi-class mobility description of their interaction. Although multi-class macroscopic models have been introduced to consider different vehicles classes, such as cars and trucks [*Benzoni-Colombo*], it is not clear if and how such methodology could apply to our case.

One approach we propose to follow in this project is to consider 4-wheel vehicles as mobile obstacles, through which 2-wheel vehicles would flow around as illustrated on Figure 2 . Such relaxation is required, as macroscopic models may not easily model the flows of single entities, illustrated here as 4-wheel vehicles (single or cluster), around which 2-wheel vehicles would flow.

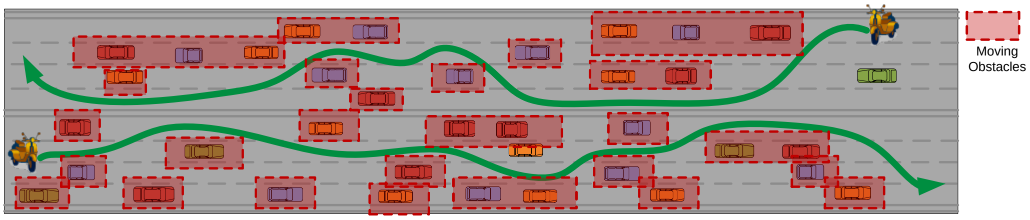


Figure 2 two-wheel vehicular macroscopic flow concept, where vehicles are considered as mobile obstacles to a fluid

Although integrating static obstacles in macroscopic models does not pose critical issues, integrating mobile ones would require a tight interaction with microscopic-scale modeling. Microscopic modeling of 2-wheel and 4-wheel vehicles would need to identify the length and dynamics of moving obstacles (i.e. cluster of 4-wheel vehicles). It would also be required to understand the potential tight interactions of 2-wheelers on 4-wheel vehicles in creating such obstacles and potentially breaking them. Another key advantage of microscopic-scale modeling is to be able to evaluate the safety conditions , such as the safe inter-distance, safe-overtaking speed, and any dangerous manoeuvers of one or the other class of vehicles.

We will develop and integrate a 2-wheel microscopic vehicular model in the traffic simulator SUMO (Simulator of Urban MObility) [*SUMO*]. From a microscopic scale , there is no benefit for 2-wheel vehicles to occupy a street lane, except when 2-wheel vehicles are stopped at traffic lights or when traffic density is sparse. In any other cases, they move 'between' lanes, which is a challenge to the spatial representation of microscopic models, such as Car-Following (CF) or Cellular Automata (CA), and also to SUMO. Some microscopic 2-wheel vehicular models have been proposed in literature, either following a CA or a CF approach [*Hemakom-Pan-Narupiti, Lan-Chiou-Lin-Hsu, Shih-Tsai-Lin-Pang*]. It is yet unclear if their spatial representations could fit to our objectives to extract safety conditions of 2-wheel vehicles, to extract mobile obstacles for macroscopic models, or simply to fit into SUMO.

The integrated modeling methodology is defined as follow. We first develop a microscopic integrated model into SUMO. We then extract the mobility statistics of single or cluster of 4-wheel vehicles (mobile obstacles), which we then integrate into the macroscopic model. We finally extract statistics on the macroscopic models for traffic efficiency evaluations, while we rely on microscopic models for safety-related evaluations. As it may be illustrated, a tight interaction is therefore necessary between macroscopic and microscopic modeling of 2-wheel and 4-wheel vehicles.

In macroscopic modeling, an efficient usage of road capacity is evaluated through fundamental flow diagrams, while the appearance, propagation and dissolution of traffic congestions are evaluated through shockwave diagrams. As 2-wheel vehicles have different kinematic parameters, it is not clear if and how fundamental diagrams could be employed for mixed traffic. Another technical objective of this work will therefore to apply the previously developed models to evaluate the pertinence of these diagrams and to calibrate them.

In microscopic modeling, safe driving conditions are controlled by adapting driving dynamics to respect a safe inter-distance between a vehicle and other vehicles directly preceding it on the same lane and on the immediate adjacent lanes. 2-wheel vehicles however mostly drive 'between' lane, even though from their perspective, they also follow a 'lane'. Moreover, the dynamism and smaller size of 2-wheelers allow them spontaneously occupy the safe inter-distance respected by 4-wheel vehicles. Accordingly, 4-wheelers either need to break and create unwanted traffic perturbation (shockwaves), or fail to fulfill safe driving conditions. A technical challenge of this work is therefore to develop a cooperative driving methodology between 2- and 4-wheel vehicles with better tolerance to the various safe inter-distances of all classes of traffic.

The technical and scientific objectives of this project may be summarized as follows:

- Extract and integrate mobile obstacles in macroscopic flows of 2-wheelers traffic.
- Enhance microscopic Car-Following-Models (CFM) with better spatial models for 2-wheel traffic.
- Analyze shockwave and fundamental flow diagrams to extract 2-wheelers'specific dynamics.
- Develop cooperative behavior between 2-wheel and 4-wheel vehicles to respect safe inter-distances.

Addressing the previously described objectives implies multiple technical challenges, yet leads to major innovations in **traffic forecast and in sustainable and safe transportation**.

3. Pertinence and Strategic Aspect with respect to LABEX Topics

The project addresses the Intelligent Transport Systems (ITS) application domain of the LABEX. It proposes to investigate the mobility characteristics of vulnerable 2-wheel vehicles. Although not directly addressing ICT, it aim at providing the theoretical and methodological foundations for developing ICT for 2-wheel vehicles.

Traffic in the area between Nice and Sophia-Antipolis is famous for being saturated with no alternative road to reduce congestions. An increasing trend by commuters is to replace their 4-wheel vehicles by 2-wheel vehicles (scooters or motorcycles). Yet little is known of the impact of such modal swap in terms of traffic safety, capacity, and even pollution. What are the benefits and drawbacks of a gradual swap between 4-wheel and 2-wheel vehicles? How to adapt road infrastructure for them? What are the new safety concerns?

Whereas we observe an increasing popularity of 2-wheel vehicles, only a few ITS applications directly address them. This project is expected to provide a key catalyst to innovation and outstanding applications for smart mobility and multi-modal transportation. We heard of car-sharing but what about scooter-sharing? We heard of modal swap (a.k.a. Park&Ride) between 4-wheel vehicles and public transportation to reach city centers. What about a modal swap between 4-wheel vehicles and 2-wheel vehicles, which keeps the key advantage of personalized mobility, yet providing a reduced influence on traffic? Modern navigators prove to be critical to 4-wheel drivers. What about 2-wheel vehicles?

Answering these questions requires openly accessible 2-wheel mobility models and a solid understanding of the mobility characteristics of 2-wheel vehicles. These are the strategic innovations aimed by this project that first fits to the scientific themes of the LABEX, but also brings the LABEX as front-runner in addressing a new generation of ITS applications critical to the local community.

4. Expected benefits on LABEX & Local Area

The ambitions of this project and key innovations are first to **produce a set of models** allowing an easy study of 2-wheel vehicular traffic trends and vulnerabilities, forecasting rather than enduring traffic events, and assisting decision making in providing sustainable and safe mobility in a controlled environment. Second, to **establish a cooperation link** on sustainable and safe mobility aspects within the LABEX between EURECOM and INRIA.

A solid understanding of the mobility characteristics of 2-wheel vehicles and their interactions with 4-wheel vehicles in transport networks and systems is expected to have a wide benefit. Highway operators (e.g. Vinci Autouroutes/Escota) could adapt their networks and traffic advices. City authorities could develop multi-modal alternatives to 4-wheel vehicles, where 2-wheel vehicles would be seen as an optimal trade-off between congestion, pollution and personalized mobility. The gradual increase of 2-wheel vehicles on urban networks and highways require traffic authorities to redefine safety regulations, for example a middle safe overtaking lane for 2-wheel vehicles. Policy makers would benefit from solid grounds to encourage a gradual replacement of 4-wheel vehicles to 2-wheel vehicles in terms of congestion but mostly in terms of energy and pollution reduction. Last but not least, ITS applications to scooters could be a major innovation ground for local start-up and SMEs in the domain of user-centric ICTs.

All developments and the source codes of all models will be open-source and made openly available. This project will offer an innovative and open-source tool illustrating the LABEX leading research quality in the Sophia and Metropolis area.

5. Consortium

4.1 Partners

EURECOM is a French graduate school and a public research center in communication systems based in the international science park of Sophia Antipolis, which brings together renowned universities such as Telecom ParisTech, Aalto University (Helsinki), Politecnico di Torino, Technische Universiät München (TUM), Norwegian University of Science and Technology (NTNU) and Vietnam National University Ho Chi Minh Ville (VNU). The Institut Mines Telecom is EURECOM's founding member. EURECOM benefits from a strong interaction with the industry through its specific administrative structure: Economic Interest Group, (kind of consortium), which brings together international companies such as: Swisscom, SFR, Orange, ST Microelectronics, BMW Group Research & Technology, Symantec, Monaco Telecom, SAP, IABG.

EURECOM has been working on microscopic vehicular models since 2005 and on SUMO since 2007 in the FP7 iTETRIS and COLOMBO projects, and other various activities in smart and safe mobility. EURECOM, in collaboration with the German Aerospace Agency, is currently developing pedestrian mobility for SUMO.

INRIA (National Institute for Research in Computer Science and Control) is a public science and technology institution placed under the supervision of the French ministries of research and industry. INRIA research activity is fully dedicated to computational sciences, combining computer sciences with mathematics.

INRIA is structured in 8 research centers located throughout France (Rocquencourt, Rennes, Sophia Antipolis, Grenoble, Nancy, Bordeaux, Lille and Saclay) and a head office in Rocquencourt, near Paris.
The research is organized in about 180 project-teams. OPALE project -team is specialized in the numerical simulation and optimization of systems of partial differential equations. A recently opened research direction concerns the study of macroscopic models for vehicular and pedestrian traffic derived from fluid dynamics.

4.2 Complementarity

EURECOM and INRIA will provide fully complementary skills and expertise required for the success of this project. EURECOM will bring its **theoretical and applied expertise in microscopic vehicular mobility modeling**, as well as its experience on the SUMO tool. EURECOM will also bring its **experience in cooperative vehicular mobility and networking for ITS applications**. INRIA on the other hand will bring its **recognized theoretical and applied expertise in macroscopic vehicular mobility modeling**.
This project will also be a key catalyst to initiate a bridge between two research teams of complementary skills to work together within the LABEX.

4.3 Organization and Advisory

Dr. Habil. Jérôme Härri (EURECOM) will be the prime advisor, with Dr. Habil. Paola Goatin (INRIA) as secondary advisor. Both Dr. Härri and Dr. Goatin hold an HDR.

The Ph.D. Candidate is expected to be hosted in EURECOM premises, even though the strong complementarity between the two advisors would also allow INRIA to host the Ph.D candidate if necessary.

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