Towards Multimodal Mobility Simulation of C-ITS: The Monaco SUMO Traffic Scenario

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***Abstract*—The information that we are collecting in the cities is enhancing our understanding of their dynamics. Cooperative Intelligent Transportation Systems (C-ITS) are using mobility information from vehicles and vulnerable road users to improve road traffic and safety in urban and extra-urban environments. In this field, optimizations are usually done through simulations. An interactive mobility scenario has to fully integrate different means of traffic to achieve this goal; nonetheless, a scenario able to integrate vulnerable users such as pedestrians, bicycles, and motorbikes, is not yet available. In this paper, we present the analysis of the requirements and preliminary work to create a realistic scenario for urban mobility able to integrate vulnerable users. Based on the Principality of Monaco, the Monaco SUMO Traffic (MoST) Scenario presents a perfect playground to study advanced parking management solutions, and alternative transport modes applications, while keeping into account realistic telecommunication models.**

I. The Future of C-ITS Simulations

Our cities are complex systems that evolve rapidly over time. The information that we are collecting is enhancing our view and understanding of their dynamics. Cooperative Intelligent Transportation Systems (C-ITS) are using mobility information from vehicles and vulnerable road users to improve traffic and the quality of life in the cities and their surroundings. This objective requires understanding not only of traffic flows theory and telecommunications, but also human behavior and social interactions.

Scientists are always looking for methods and tools to test theories and develop state of the art C-ITS protocols and applications, improving road traffic, safety, and security. Given that mobility patterns are able to influence telecommunications in a critical way, a simulation environment capable of providing an interactive smart city scenario has limitations and requirements coming from both mobility and telecommunication simulators, and their possible interaction. Extended surveys such as [1] and [2] provide a good overview on the different mobility and network simulators available to the scientific community. We chose Simulator of Urban MObiltiy (SUMO) [3] as mobility simulator because its community is very active on Intelligent Transportation Systems (ITS) topics and it provides a socket interface that allows easy communication with other simulators. OMNet++ and NS3 are network simulators that may be interfaced with SUMO using Vehicles in Network Simulation (VEINS) [4], iTETRIS [5], and VSimRTI [6].

An interactive mobility scenario for C-ITS has to fully integrate different means of traffic. Public transports have well defined schedule and routes, and in many situations they have priority over other means of transports. Usually the majority of the traffic is composed by cars and trucks of various kind. These vehicles are more variable in shape and behavior. Some mobility scenario that include the above-mentioned means of transport are available. The available scenario are the SUMO TAPAS Cologne [7], the mobility traces for the city of Bologna [8], and the Luxembourg SUMO Traffic Scenario [9]. At the best of our knowledge a scenario able to integrate vulnerable road users (e.g. pedestrians, bicycles and motorbikes) is not yet available. However, in the traffic demand evaluation of the LuST Scenario [9], the authors show that to achieve a more realistic mobility in an urban environment, the presence of the vulnerable users must be taken into account. Our aim is to create a realistic scenario for urban mobility able to integrate vulnerable users too.

Fig. 1. Principality of Monaco [Wikimedia]

A. Principality of Monaco

A single environment able to provide a complete playground required to work on various aspects of C-ITS is complicated to find and model. We need a multidimensional environment to work on geo-location and telecommunication aspects. It has to be densely populated, and there must be congested traffic patterns to work on alternative means of transportation and mobility optimizations. Finally, it has to be scalable and controllable.

We chose the Principality of Monaco as a case study because of its size, peculiar features, and availability of public information. The discussion concerning the dataset requirements and the sources of information is presented in Section II. The city itself covers and area of 2 km^2 and the greater area (composed of French cities adjacent to Monaco) is 22 km^2. The size of the city provides a small and more controllable environment, reasonable to model with a microscopic mobility simulator. The preliminary version of the Monaco SUMO Traffic (MoST) Scenario is presented in Section III.

*a) **Multidimensional for communications and environmental studies**:* Monaco is a coastal city built on the mountains' slope, it has a layered topology full of tunnels and bridges. Its topology provides interesting features to study aspects concerning precise positioning and propagation models. Tunnels and bridges are going to create a multidimensional environment more realistic compared to a flat surface. Additionally, these multidimensional features, in conjunction with realistic emission models, can be useful in studying eco-routing, from both energy consumption and environmental impact perspectives.

*b) **Heavily congested for multimodality and parking management solutions**:* most of the people that work in the city are commuters and they live in the greater area. This create directional traffic congestion: in the morning there is a heavy inflow and during the evening, the city experience a congested traffic outflow. In order to accommodate all the commuters, the city provides many parking areas and the public transports are well developed. Nonetheless, the city is not able to alleviate traffic congestion during rush hours. Monaco city presents a perfect playground to study advanced parking management solutions, multimodal and alternative transport modes applications, on a city-scale.

*c) **Densely populated for crowd and vulnerable road users applications**:* Monaco is a touristic city. On top of the pedestrian commuters that are headed to work, there are waves of tourists that reach the city by tour buses, public transports and (even if in a smaller percentage) by car. Additionally, a large scale mobility scenario able to fully integrate vulnerable users can be locally coupled with specific crowds and multi-agents simulators, that given their complexity, would not be otherwise scalable over an entire city.

We want to use this scenario to study the impact of vulnerable road users on the city traffic. Our aim is to use C-ITS applications to shift the users from cars to motorbikes, and electric two-wheelers in general, optimizing traffic and alleviating congestion. In Section IV we discuss about how we are going to use the MoST Scenario and the road ahead.

II. Gathering Information

A mobility scenario is mainly composed of topology information and mobility data. The initial dataset is extracted from OpenStreetMap (OSM) and it provides many of the data we are interested in. Given that OSM is a collection of crowd-sourced information, it is possible that the accuracy is not always consistent. This initial dataset is then integrated and refined using data provided by public websites from the Monaco and France. In the data extracted from OSM we find the location of parking lots and car parks, train stations, bus stops, taxi stands, and bicycle sharing points; these Points Of Interest (POIs) will be used to build the main infrastructure for multimodality and public transportation. The location of additional POIs (e.g.: museums, tourist attractions and parks, shops and restaurants, offices and facilities, and schools) is fundamental to improve the realism of the activity-based mobility we are going to generate. Public transports are gathered from Compagnie des Autobus de Monaco (CAM)[1] and Provence-Alpes-Côte d'Azur (PACA) Mobilité[2], where we found location and schedule for buses and trains, and the location of the electric bicycle stations with their availability. The Monaco Parking website[3] provides location, capacity, schedule, prices and availability for many of the parking lots in the city. A more detailed version of the geographical information is extracted from the Institut Géographique National (IGN)[4] database. Here we can find detailed data concerning altitude and the land registry. This information it will be integrated with the street topology and the POIs dataset to obtain a reliable multidimensional model of the city.

Last but not least, even if there are many public sources available, the datasets tend to be outdated and their format incompatible, making the data aggregation process cumbersome and error-prone. While writing this paper, there is an ongoing discussion with the municipality of Monaco regarding the acquisition of real data for research purposes.

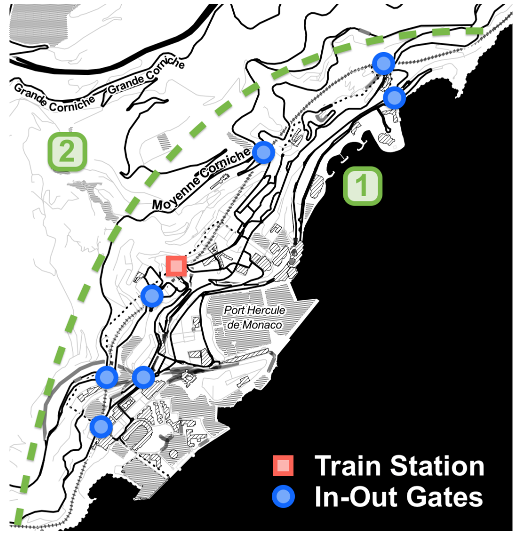

Fig. 2. Monaco SUMO Traffic Scenario

III. Preliminary SUMO Scenario

Figure 2 shows the city of Monaco[5] with the in/out gates for vehicular traffic flows (blue circles) and the train station (red square). The MoST Scenario is built with two different mobility areas, visible in the figure and separated by a green dashed line. In the city of Monaco (area 1), the mobility contains detailed information from pedestrians to public transports; in the surroundings (area 2), the mobility contains informations for vehicles and public transports, but most of pedestrian and bicycle mobility is dismissed. Area 2 is fundamental to create the correct in- and out-flows patterns.

[1]http://cam.mc
[2]https://www.pacamobilite.fr
[3]https://monaco-parking.mc
[4]https://geoservices.ign.fr
[5]Stamen Maps: http://maps.stamen.com

TABLE I
TOPOLOGY INFO

Total area	22 km^2
Total streets length	350 km
Main roads	89 km
Residential roads	110 km
Walkways	62 km
Tunnels	39 km
Bridges	5 km
Traffic lights	8
Roundabouts	38
Priority junctions	1254

TABLE II
ACTIVITY-BASED INFO

Public transports stops	133 of 158
Public transport routes	19 of 49
Parking areas	41 of 224
Buildings	24,573
Total tagged POIs	607
Schools	16
Services	160
Restoration	133
Touristic	122
Shops	98

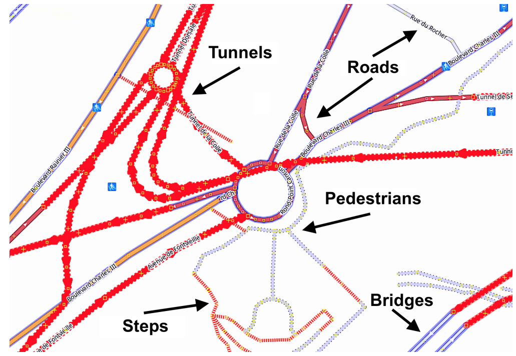

Fig. 3. Tunnels and roundabouts in the city of Monaco.

A. Initial Dataset

The features of the initial dataset are summarized as follows.

Table I contains the topology information. The greater area (comprised of Monaco and the surrounding French cities) is 22 km^2 covered by 350 km of roads with 39 km of tunnels. Information concerning length and shape of these tunnels is complex to acquire given that different sources provide contrasting data. Nonetheless, even if their presence complicates the modeling of the city, it provides a powerful playground for studies on geo-location and C-ITS protocols and applications. The limited number of traffic lights is due to the prevalence of roundabouts and priority junctions in the city. Roundabouts are a major challenge when testing automated vehicles and their interactions with vulnerable road users, even if their modeling is complex, they represent a valuable additional asset in the MoST Scenario.

Table II presents the data that will mainly be used in the activity-based mobility generation [10]. Concerning public transports, 133 stops and 19 routes are only internal to the city, and in the entire area there are a total of 158 stops and 49 routes. With buildings, we intend all the 3D facilities that are retrievable from OSM. Most of the parking areas are underground so they are not part of the buildings, and their shape is unknown. Their shape is fundamental when it comes to properly compute the propagation models. It is noticeable the limited amount of POIs that are tagged (e.g.: school, shop, museum) compared to the number of buildings. It is due to the fact that even aggregating different sources, there is a tendency of information overlapping with various accuracy levels [11].

B. Topology Generation

One of the major challenges is the extraction of a detailed network topology, and the conversion to an usable format for the SUMO simulator. The topology stored in the initial dataset is composed by nodes and edges. This graph representation comes from OSM and it is functional to the mobility generation. However, it is missing a key component essential for a mobility simulator: the actual size of the lanes. Usually, during the conversion from the graph to the SUMO representation, the geometry of the streets changes and they tend to have closer boundaries than in reality. In Monaco this problem is amplified by the topology of the territory itself. The streets are smaller than average and the buildings are very close to each other, leaving no space for the transformation required by the simulator. The problem is always finding the right balance between approximation and reality in order to obtain a realistic scenario usable by the simulator.

An example of the complexity of the transformation is presented in Fig. 3, where it shows some of the intersections in the city of Monaco visualized with JOSM[6]. The roads highlighted in red are the tunnels that runs under the city, and there are multiple layers of them. Pedestrian paths are marked in gray (and the steps are dashed in orange).

This intersection is not an isolate case in the city, it is not possible to simplify it without removing the roundabout altogether and transforming it into a standard intersection. Additionally, the graphical network editor provided by SUMO is not able to deal with complex layered streets. Overlapping nodes and edges cannot be selected and modified independently from each other, making the process cumbersome and error-prone.

Modeling pedestrians and bicycles is a complicated task that introduces additional complexity to the network topology. By design and due to some limitation induced by the simulator, pedestrian and bicycles have their own reserved lanes, and the interaction with the rest of the mobility occurs at intersections and crosswalks. In case of Monaco, given the topology of the city and its layering structure, these limitation are not an issue, and they reflect the majority of the interaction. Pedestrians and bicycles are allowed in the residential roads, but not on the other, given that they have dedicated paths. This more controlled environment, even if it cannot fully represent the chaotic behavior of pedestrians moving in the average city, it is a reasonable start to finally have interaction between vehicles and vulnerable users.

C. Mobility Generation

At the moment there are no mobility information available from the Principality of Monaco and the Institut Monégasque de la Statistique et des Études Économiques (IMSEE)[7]. Some demographic information are available, but all the data concerning commuters and traffic is not reported. It is only available as real time statistics from Info Chantiers[8], Google

[6]https://josm.openstreetmap.de
[7]http://www.imsee.mc
[8]http://www.infochantiers.mc

Maps[9], Waze[10], and some other sources, with different degrees of accuracy. This information is not usable to validate the mobility traces, but it can be used to provide a reasonable estimation of the traffic flows.

The activity-based mobility generation uses information contained in the refined dataset, the traffic estimations and additional demographic information. With it we aim to achieve realistic traces that would represent the day-to-day life of the population. The mobility generation is closely linked with the improvements in the topology; for this reason, the generation process is still ongoing and we cannot yet provide a realistic mobility during peak hours.

In order to calibrate and validate the synthetic mobility traces, additional precise information are required. The main issue is the necessity of having information from different countries, France and Monaco. As previously mentioned, there is an ongoing discussion with the municipality of Monaco regarding the acquisition of real data for research purposes.

IV. Discussion and Future Perspective

Even if the MoST Scenario is only at its initial stage, it is a promising playground to study C-ITS and alternative means of transport in a controlled environment, able to interact with vulnerable road users, in a multidimensional world capable of taking into account location and telecommunications issues.

The future efforts are mainly going in three directions: (i) improving the integration between the topography of the territory and the street topology; (ii) improving the activity-based mobility generation, calibrate it with real data, and evaluate it; and finally (iii) focus on vulnerable road users and alternative transport modes.

The main issues with modeling a multidimensional traffic scenario are the lack of precise information concerning altitude and 3D environment, and their mapping with the simulation environment. SUMO is able to take altitude into account, nonetheless, OSM does not provide the information, and with the changes due to the topology transformation from graph to SUMO, the mapping between the IGN database and the resulting topology is error-prone, with a high risk of creating unrealistic simulation artifacts. Moreover, a correct representation of the topography it is necessary to study subject such as the impact of electric vehicles, eco-routing, and pollution.

Given the lack of real mobility information, computing a realistic traffic demand is going to be challenging. Our best option is the enhancement of the activity-based mobility generation by improving the quality of the POIs and their associated data. A major role is played by the parking areas because they represent the more probable multimodal approach for all the commuters that decided not to use public transports to reach the city. These statistic are not available but they can be inferred from the usage of the parking lots, 41 of which have real time statistics accessible on-line. More statistics on the tourist flows are publicly available, but they do not keep into account the means of transportation used and the definition of tourist is not properly expressed in the first place.

The main reason we decided to build the MoST Scenario is to study the impact of the vulnerable users on the city traffic and if the shift from cars to motorbikes, and electric two-wheelers in general, would improve the traffic congestion in the city. To achieve this goal, the realism of the mobility model provided by SUMO for bicycles, and motorbikes has to be improved. One possibility is to improve directly the mobility model in SUMO, but another option we are going to valuate is the use of the lightweight SUMO mobility on the entire scenario, and to use external specialized simulators to zoom into the specific area that we want to study.

Finally, the MoST Scenario is going to be freely-available and released to the research community as soon as we generate a reasonable activity-based mobility, looking forward to calibrating and validating it with real data on a second step.

[9]https://www.google.com/maps

[10]https://www.waze.com

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