Urban traffic modeling and simulation: Moroccan capital case study

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Abstract—Due to its major role in assuring services based on transportation, urban traffic is no longer a facultative subject. The common step between all existing work related to this area is modeling urban traffic. Different approaches are available, and each one has its benefits and drawbacks, but the main obstacle confronted by many of the existing approaches is the availability of data to use in the model building. In this paper, we propose a data-less solution based on activities to model traffic demand of a generated synthetic population, and the use of a microscopic multi-agent system to simulate and analyze urban traffic in the Moroccan capital city Rabat.

Index Terms—Urban traffic modeling, simulation, Multi-agent simulation, synthetic population, activity-based traffic demand.

I. INTRODUCTION

Nowadays, many researchers are studying problems related to urban areas aiming to build more sustainable and intelligent applications of existing resources. One of those areas is urban traffic, where two main questions arose: the first one is how urban traffic works? the goal here is to understand the causes or mechanisms of some behaviors (example: what cause congestion of traffic in some junctions?); the second question deals with solving problems related to urban traffic, such as how to efficiently use network resources? All these paths of research require an initial work, which is a model of the urban traffic [1]. Modeling urban traffic could be approached from different perspectives related to the level of details a model can capture. From a high-order perspective, macroscopic models, a model is designed to capture few aggregated variables related to traffic like (average) density, (average) flow, and (average) speed. The result is a continuum flow representing traffic. On the other hand, a microscopic model, describes and traces the behavior of individuals vehicles (almost everyone should be represented). The gap between microscopic and macroscopic models is filled by mesoscopic models, where a probability distribution is used to represent vehicle movements. We limit the scope of our work in this paper to microscopic models.

Building a microscopic model requires a detailed description of the traffic components, where each vehicle should be described by some features (we also use an agent to describe the vehicle, since we use a multi-agent system to simulate the resulting model). To describe an agent in the context of urban traffic, two main questions should be answered: what are the dominant characteristics of an agent that decide on the use of traffic? And how an agent uses urban traffic? The first question will gather details about agents (like age, driving license, education level) that will help to answer the second question, that is how a given agent will use the urban traffic resources (it is clear that driving a vehicle needs a driving license, and some a reasons that causes the travel, need some education level). By answering these two questions we are building two models: the first model describes agents; this is the problem of the representing population (agents), that may be solved depending on availability of data. If we already have data that describe some characteristics of each agent, the problem results to expand those characteristics to the rest of agents, if a detailed description of agents is not available and only some atomic characteristics are on hand (like age, level of education, but not aggregated in one ?), the task results to aggregating those atomic data in one for each agent. The second model describes how agents will use urban traffic resources, like the urban network. The resulted models have to be simulated to understand the state of the traffic in function of built models, this task was assured by using a multi-agent environment (MATSIM) [2].

The rest of this paper is organized as follow: in the next section II we present some relevant works related to synthetic population generation and traffic demand modeling. Our method is then presented in section III, and related results are exposed in section V; the work is then concluded in section VI.

II. RELATED WORK

In this section, we present some relevant background and existing work related to synthetic population generation, and activity-based model for traffic demand.

A. Synthetic population generation

Urban traffic is the result of interaction between agents themselves and between agents and urban traffic resources. Usually, in the real-life scenarios, the number of agents could attend millions, which make the task of getting each ones information impossible to realize. A solution may be to generate synthetic (artificial) population using available aggregated data. Two classes to get this problem solved exist in the literature [3]:

- Sample based methods: where a sample of individuals studied zones characteristics is combined with some aggregated global data (demographic indicators) to generate a synthetic population. It has the benefit to produce a reliable representation of the real characteristics of individuals [4], [5], [6].
- Non-Sample based methods: sample-based methods depend on representability and reliability of the used sample, this could be avoided by only aggregating global demographic data to get characteristics of a
population, the drawback here is the reliability of the result vs the implementation as we don't need investing time to prepare a sample, but only using demographics indicators, which is in general available [7].

B. Traffic demand modeling

Modeling traffic demand of individuals (i.e. agents, vehicles) may be achieved in different ways. In the literature, the four-stages trip-based models for travel demand forecasting, whose four steps are:

- Trip generation determining the frequency of trips origins and destinations;
- Trip distribution matching origins with destination;
- Modal choice computing the transportation mode;
- And route assignment.

The drawback of this model is the fact that it ignores the relations between all trips and activities, and only focusing on individuals trips and ignoring the travel demand as being derived from activities seeking. More details about drawbacks are studied in [14], [13]. On the other hand, activity-based modeling could be seen as the current trend, based on the idea that traveler use traffic networks to carry out activities they need or wish to perform. It has the possibility to reflect the scheduling of activities performed by individuals in time and space and the sequence of activities. This approach is now widely used and accepted, and continuously attract more attention. After the step of traffic demand was completed, the ultimate goal is reproducing the mobility behaviors of a large population. This could be attended by massive multi-

III. METHOD

In this section, we present our method used to model traffic demand of a Rabat city’s synthetic population, and the simulation of dynamic assignment using MATSim.

A. Synthetic population generating

Our method uses the minimalist available data to characterize a population, by using data of census of population done by HAUT-COMMISSARIAT AU PLAN in 2014 [12]. The main steps of the developed generator are given in the figure 2.

The problem of synthetic population could be formulated as following: Found a sample $S = < p_1, p_2, p_3, \ldots, p_n >$ of population, where the vector $p_i = < c_1, c_2, c_3, \ldots, c_m >$ is the characteristics of an individual $p_i$, where $S$ is represented as possible of the real population. Figure 2 show main steps in the developed generator in case Moroccan capital. Given HCP data, example figure, demographic indicators, and after clean data, we clean data to get marginal distributions of desired characteristics (age, education level, ...) to use in individuals identification. Then we aggregate marginal distribution using IPF and the result is a vector $p = < c_1, c_2, c_3, \ldots, c_m >$. From these result, we select individuals we select only those we are sure they will use traffic, like select $p_i$ where age $> 18$ and driving license = true. The result is then a pool of individuals $S_{ind} = < p^1, p^2, p^3, \ldots, p^m >$ where $p_i^j = < c_1^j, c_2^j, c_3^j, \ldots, c_m^j >$. The task of aggregating marginal distribution was done by applying Iterative Proportional Fitting Procedure (IPFP). The IPFP is used to estimate a k-way joint-distribution table based on known marginal distributions, it was proposed in [10]. Let $\pi_{i j}$ corresponds to the number of individuals with characteristics $i$ and $j$. And let $x_{i j}$ be the marginal distributions for each $i$ and $j$. The IPFP iteratively updates the cell’s values depending on the marginal distributions of the target until the margins of the computed table match the targets one, i.e. $\pi_{i j}^* = x_{i j}$ and $\pi_{i j}^* = x_{i j}$. The adjustment at iteration $l$ are computed by the equations:

$$\pi_{i j}^l = \frac{\pi_{i j}^{l-1} \cdot x_{i j}}{\pi_{il}^{l-1}}$$

$$\pi_{i j}^l = \pi_{i j}^{l-1} \cdot \frac{x_{i j}}{\pi_{il}^{l-1}}$$

The complete synthetic population should contain information about location of individuals household, that way, and by proceeding by the same approach of individuals characterization, we generate information about households, using HCPs data. The result $S_{hh} = < h_1, h_2, h_3, \ldots, h_n >$ is the sample of households with $h_i = < c_1, c_2, c_3, \ldots, c_m >$ is the $h$s characteristics and take values from: (location, type, number of individuals). The last step is the matching of individuals sample $S_{ind}$ with households sample $S_{hh}$. The result is a synthetic population $S_{pop}$. The algorithm 1 formalize all the above steps.
Algorithm 1 Synthetic population generator

1: Begin
2: \( S_{\text{ind}} = \text{aggregate\_synthetic\_ind}(\text{hcp\_data}); \)
3: \( S_{hh} = \text{aggregate\_synthetic\_hh}(\text{hcp\_data}); \)
4: \( S_{\text{pop}} = \text{initialize\_synthetic\_population}(); \)
5: for \( i = 0; i < \text{size}(S_{hh}); i++ \) do
6: \quad while \ not\_filled(hh\(_i\)) do
7: \quad \quad \text{ind\_temp} = \text{get\_ind}(S_{\text{ind}});
8: \quad \quad hh\(_i\) = add\_ind(hh\(_i\), ind\_temp);
9: \quad end while
10: \( S_{\text{pop}} = \text{add\_hh}(hh\(_i\)); \)
11: end for
12: End

The output of this algorithm is a synthetic population of Rabat studied case.

B. Activity based model for travel demand

Starting from the synthetic population generated, we can now generate traffic demand based on activities model. In this work we study two main activities of functionaries(selected from the generated synthetic population): (i) the task of getting to home is selected and tagged as Home-activity, as the dominant one in general. And (ii) the task of going to work is the second activity and tagged as Work-activity. The result is a chain: Home-Work-Home to describe the activity, as the dominant one in general. And (ii) the task of getting to home is selected and tagged as Home-

Algorithm 2 Activity generator

1: Begin
2: \( S_{\text{pop}} = \text{synthetic\_population}(); \)
3: \( \text{plans} = \text{init\_plans}(); \)
4: home\_activities = set\_act(\text{act\_area, start\_time, end\_time});
5: work\_activities = set\_act(\text{act\_area, start\_time, end\_time});
6: for \( i = 0; i < \text{size}(S_{\text{pop}}); i++ \) do
7: \quad \text{ind\_temp} = \text{get\_ind}(S_{\text{ind}});
8: \quad act\_ch = \text{get\_act\_chain(home\_activity, work\_activity)};
9: \quad \text{ind\_temp} = \text{set\_act\_chain(act\_ch, ind\_temp)};
10: \quad \text{plans} = \text{add(plan\_ind\_temp)};
11: end for
12: End

The result of this algorithm is a traffic demand model (or plans of individuals) based on activities of individuals in Rabat city. The model is then simulated/analyzed in MATSim.

IV. MODEL SIMULATION IN MULTI-AGENT SIMULATION (MATSIM)

After the traffic demand of a generated synthetic population is built, we can turn to its simulation. In goal to understand and visualize the state of the traffic in the city of Rabat. A model of traffic network roads, is then coupled with traffic demand model, and MATSim to assure the task of dynamic forecasting of travel demand. MATSim is an open source framework, agent-based and activity-based microscopic transport modeling. The principal idea is to let synthetic agents act in virtual world, that represent the infrastructures (i.e. network roads). Each agent has its daily activity plan, which describes the chain of activities that

Fig. 2: Selected areas in Moroccan capital, the red zone is for home activities and the green for work activities
it needs to perform in the virtual world (i.e. the Home-Work-Home chain). Each agent tries to perform optimally according to a utility function that defines what is useful for an agent. One virtual day is iteratively simulated. From iteration to iteration, a predefined number of agents are allowed to change some of their daily decisions to try to obtain a higher utility. The iterative process continues as long as the overall score of the population increases. The equilibrium reached represents what real individuals do in the real world (this iterative process is illustrated in figure 3). To use MATSim three principal files should be specified:

- plans.xml: which regroup daily activity plans of all simulated agents (that is the synthetic population with traffic demand model);
- network.xml: which represent the model of the real-world traffics roads, from this, we extract the used map from the open source OpenStreetMap OSM [11];
- config.xml: by using this file a simulation could be configured by adding other disposable modules in MATSim.

![Initial Demand → Execution → Scoring → Analyses](image)

Fig. 3: Graphic representation of MATSim simulation framework.

V. RESULTS AND DISCUSSION

After modeling traffic demand in Rabat city and simulate it in MATSim we present here the results. We first show the convergence of the simulation to reach the state of equilibrium in figure V.

![Score Statistics](image)

Fig. 4: Convergence to the equilibrium state of the simulation

![Different states of the simulated traffic with MATSim in Moroccan capita](image)

Fig. 5: Different states of the simulated traffic with MATSim in Moroccan capita. Green triangles for fluid traffic, and red for traffic jam.

It is clear that to converge to the state of equilibrium, enough time of running is then required until the criterion of convergence is reached, in this case, the average of traveling time, that is no agent could only improve his travel time by only changing/improving its plans. And that is the drawback of building simulation over analytical models is the time consuming of simulations, which will be more pronounced in case of large scenarios studied. The second result we present her is the state of the traffic in function of time in the city of Rabat, see figure 5. It shows different states of traffic in a day. We can see that for in pick hours (i.e. between 7h30 and 9h00) the traffic jam occurs in the built model, and in normal hours traffic is more fluid.
VI. CONCLUSIONS

In this work we studied the problem of modeling and simulating urban traffic in Moroccan capital city, Rabat, in case of a minimum data are available. By using a synthetic population and an activity based model to depict the demand of traffic, the two main approaches that have been presented, have the benefits to be easily reproducible to other scenarios with a minimum effort. As we are convinced that the approach should be improved, we engage in this work to keep improving the reliability of the method and the scope and the scale of the case study. This work, also, could be seen as a way to convince persons in charge to invest in data gathering about urban traffic, in the goal to study in more details this subject motivated by its huge impact and interest in human’s daily life in general.

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