CITY SIMULATIONS IN EXTRAORDINARY CIRCUMSTANCES

MILESTONE 1

ESCOLA TÈCNICA SUPERIOR
D´ENGINYERIA INFORMÀTICA

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Introduction

Valencia is a bustling city, which can create problems when it comes to evacuating the city in exceptional cases. That is to say, in such situations, we should know how to act in order not to create a collapse.

These special events we are talking about could be natural disasters, terrorist attacks, war-related catastrophes, or even festivities celebrations. Therefore, we find it helpful to have a form of prevention that can only be achieved with simulations as they imply a disabling of infrastructure.

For this purpose, we pretend to generate an algorithm that modelizes our city, Valencia. But for what exactly will be helpful to our model?

For a start, it will contribute to the good health and well-being of the population since we will better understand the traffic in extraordinary events. Thus, it will be easy to control the most crowded zones in the city and prevent traffic accidents. It will also permit us to establish an efficient and optimal evacuation plan for Valencia so, in case of disaster, there will be as few casualties as possible.

But that is not all. The second part of the project will include an examination of Valencia in Falles, the most famous festivity in the city. On such days, it is usual that the city council close some streets to the traffic. This is for the protection of the citizens, but it also means that transport in the city becomes more difficult. In order to solve this problem, we are going to propose a model to see the movements of the people in such days. That said, we pretend to establish where the public transport should move so there would be as few agglomerations as possible.

We can also use these simulations to reduce CO2 consumption, i.e. to help the environment as we will be able to know which streets are most crowded when it is time to evacuate. This means that we could provide more or less public transport for evacuation depending on the number of people.

Goals and value

Project's main goal

Agent-based modelling perspective allows us to work in a set of situations that would be somehow difficult to comprehend with other traditional modelling methods. That being said, our primary goal is, given a geographically well-delimited area, to prepare population behaviour with regards to a set of different circumstances: natural disasters, terrorist attacks, war-related catastrophes. Although, given the limited amount of time given for the project, we may as well end up choosing one or two concrete circumstances (we'll probably work with one situation in the GAMA model and the other with Python).

Now to develop such a goal, Python and GAML will be crucial for working with agent-based models. We choose both programming languages because of the already existing bibliography in the case of Python and GAMA, given the specific orientation to Agent-based modelling, which has proven highly effective for cities such as Tokyo and Chicago.

An example of GAMA usage in its website

Our model will combine simple human behaviour, graph-like city modelling, and urban mobility. To make everything work, data about public transportation, shapefiles about Valencia and fundamental knowledge about human life organisation are needed.

We must acknowledge that certain aspects related to our main goal may be challenging on a large scale, so our plan will divide into smaller goals which will, at the end (hopefully), group in the objective we imposed ourselves.

Data related topics

Where will our data come from?

- Geographical data: *.shp* files combined with CSV files containing street names building's colour will be determined according to their functionality (industrial, residential).
- Mobility: Valencia's open data warehouse gives information about bus lanes and underground, which will have a considerable weight when talking about evacuations.
- Agent features: determined by common knowledge, shifts, familiar routes, elemental interaction, life span, and age evolution.

Innovative ideas

As innovative ideas with regards to our project, we have the ones that follow:

- Being able to emulate situations that cannot be studied in real life given the implication from many people.
- Studying how public transport could be helpful in a critical scenario.
- Study everything on a local scale to be useful for local government.
- Adapting our work to certain Valencia-related events, such as fallas.

State of the art

Digital twins

Our first idea was to use the Digital Twins technology to prepare a city model. A digital twin is an identical image of a process articulated alongside the process itself (Batty, 2018, 817). Usually, they match the operation of the physical process, which takes place in real time.

In recent years the construction basis of a smart city has gradually evolved from the original static 3D modeling level towards the digital twin level that combines dynamic digital technology and static 3D model (Deren et al., 2021, 1).

We planned to establish a digital copy of Valencia to observe the impact of an extraordinary event, so it seemed natural to use the digital twins' technology. However, we could not find any digital twins models on the Internet because of how recent this technology is. That caused a problem because we lacked the knowledge to establish a digital twin model from scratch. That said, we examined other methods and techniques to model Valencia.

Agent-based modeling

Since we couldn't establish a solid base in digital twins for our project, we decided that we may use an agent-based model. Individual-based modeling, also called agent-based modeling (ABM), is a relatively new computational modeling technique. It consists of modeling phenomena as dynamical systems of interacting agents (Castiglione, 2006, 1562).

But what is an agent? An agent is an entity with some degree of autonomy. In other words, it is an entity with some characteristic that allows it to distinguish between itself and its environment. This ranges agents from simple pieces of software to automatons with learning skills.

An agent-based model simulates a phenomenon using these entities. To do so, it's necessary to identify the actors (the agents in the phenomenon) and consider the processes (rules) that manage the interactions between them.

Since agent-based models reflect the interactions between different individuals, the advantages of using these kinds of models are pretty relevant (Helbing, 2012, 2.1.4). They allow us to determine the implications and consequences of some hypotheses or scenarios for a start. In some contexts of economic science, they also will enable the replacement of an agent by an aggregate of agents, making it possible to establish a relationship between the micro and macro level of description. Speaking about economics, they have made it possible to overcome some limitations of the theoretical concept of the “Homo Economicus” by relaxing some assumptions not well enough supported empirically. Finally, it’s remarkable that they can also be combined well with other models.

In recent years, this technique has taken a lot of importance. But why is that so? There are three main reasons for its growth (Bankes, 2002, 7199).

First of all, because of the unsuitability of competing modeling formalisms to address social science problems. Fundamentally, there are two widely spread alternatives to agent-based modeling: differential equations and statistical modeling. Both have made significant contributions to social science, but they also impose some assumptions that are not always realistic (linearity, homogeneity, and so on).

The second main reason is that agents are a natural ontology for many social problems. A vast quantity of data can be extrapolated from the agents, such as their behavior, motivations, or relationships. The ABMs are developed around the agents, making them capable of extracting this data, while other models cannot.

The final cause of the popularity of agent-based modeling is the demonstration of emergent phenomena. In social science, some events, such as the emergence of institutions or cultural norms, are caused by the interaction between individuals. Since ABMs can extract data about their agents, they also allow the study of these emergent phenomena in a more exhaustive way than any other current method.

Projects that already use an ABM approach

There are already some projects which try to model a city with an ABM approach in order to achieve different objectives. Here we are going to mention some of them.

The first model we are discussing is the LEAF model (Wiesner & Thamsen, 2021, 29-36). This work establishes a new simulator for modeling Large Energy-Aware Fog (LEAF) computing environments. Essentially they offer a model for simulating decentralized data processing structures (such as data centers). This is not of our interest, but something they also did was evaluate their prototype within a smart city traffic scenario using agent-based modeling in python (https://github.com/ihsan1852/edge/tree/6f15a5a3f19f6b7dfd8ba0641ae5deddbb7d145d/examples/smart_city_traffic). This model can be used to develop a base ABM of the city of Valencia.

Another work in modeling a city using ABM was done in San Francisco (*Traffic Model: Network, Demand and Agent-Based Simulation for San Francisco or Other Cities.*, 2018). In this model, they implemented a graph for the city using OpenStreetMap. Then they used data based on the Traffic Analysis Zone-level travel demand to establish pairs of nodes (origin and destination for the agents). Finally, they used an ABM to find the shortest path for each transport using python-igraph and python-multiprocessing.

In 2019, a paper was published that proposed the usage of blockchain in urban mobility and smart cities fields (Marroco & Castelló Ferrer, 2019, 144-162). The block-chained agent-based simulator for cities (BASIC from now on) that they proposed tried to combine an agent-based simulator with blockchain technology for research on urban scenarios with security requirement purposes. They used an ABM simulator using the Gama Platform (*Gama Main Page*, n.d.), then used a docker container to add the blockchain network to the simulation. Finally, they used a python interface for the connection between the models.

Within the framework of the modeling and simulation of people in an urban environment, a model was proposed in which they tried to model human behavior individually and in groups (Mitropoulos, 2019). They used an agent-based model implemented in GAMA using parameters extracted from data of telephonic companies. The extraction of these parameters and the model itself is very interesting to our work because it sets a precedent on a city modelization. This thesis also contains information about some programs that can create a functional ABM.

Finally, the last project we will mention is research conducted by the University of Leeds and funded by the European Research Council (*DUST*, n.d.). This initiative establishes a simulation of a city so as to address how to best respond in case of an emergency. In order to do so, they try to incorporate up-to-date data into their model using some techniques that may produce a paradigm change in agent-based modeling.

Conclusions

As established previously, it is pretty challenging to create a digital twin for Valencia, so in order to represent the city, we have decided to use an agent-based model.

For this kind of model, there are two paths to be chosen. The first is to generate an ABM using the GAMA language, similar to what Vassily Mitropoulos did in 2019 (Mitropoulos, 2019). The second includes generating a model with Python using as a base the project DUST.

As ambitious as we are, we have decided that it would be good to examine both models and see how many differences we can find between them and which one ends up being better.

Data

With regard to the data, we're going to use figures from the city council open data web page (Valencia City Council, n.d.) to adjust the model parameters, so this way, we should make this model resemble the city of Valencia.

Concerning the statistical source we found adequate, The Valencia city council web page has a wide range of different figures in a wide range of formats. Though there are figures in a bad state or that have no possible use, the website has metrics that are functional for our simulation.

As earlier explained, part of this project will be made with GAMA, so, in order to work with these city representations, the data we're making use of is obtained in ".shp" extension files.

At the present moment, we've got 4 data files which we're working with:

1. We obtained the linear axes of the city streets. This way, we have a starting point from which we can begin to model the municipality (Valencia City Council, 2019) (Valencia City Council, 2019).
2. We also acquired the representation of the conurbation's different squares, with the number of people living in them. This may be utilized for pedestrian and vehicle fluxes (Valencia City Council, 2019).
3. Additionally, we've gathered information about the direction of the circulation in Valencia. This way, we can also determine which courses the traffic will take (Valencia City Council, 2019).
4. Likewise, we've collected data about traffic in some of the significant streets of Valencia. The metric that will be used is the average number of vehicles per hour. These figures might be cardinal for our traffic fluctuation adjustment (Valencia City Council, 2019).

So, with all these statistical records, our objective is to train the model to have a matching digital twin of the entire city. Also, more data may also be used in order to modelate different situations.

Finally, after we've obtained the data and developed the simulation, the figures we're receiving from the model will be determined once the prototype is finished. We already know that we'll require the use of the average vehicles per hour so that we can compare them to the registered data.

Data preparation

Concerning data cleaning and preparation, in general, the datasets we obtained from Valencia City Council were in a good state, so there wasn't much to be done to improve them.

Within our first model, we've only taken into account two datasets, the one with the PGOU (city's urban planning) parcels and the one with the linear axes of the streets. The reason behind this is that in this first model we've decided not to include many of the features explored in all of the datasets. Until now, the only considered aspects have been the type of building in each of the squares and the different streets.

The only problem we stumbled upon was that the city cadastre had a big number of types of buildings, which weren't manageable at all when making the first approach. To solve this aspect, the wide range of classifications was reduced and grouped into 4 main groups: residential, workplace, leisure, and protected (natural) areas. This task was solved with RStudio (IDE for R language).

The reason for this classification was to obtain the main function of each of the buildings. With that grouping, it's far easier for us to work on this project, because we can interpret and parametrize mobility depending on these traits.

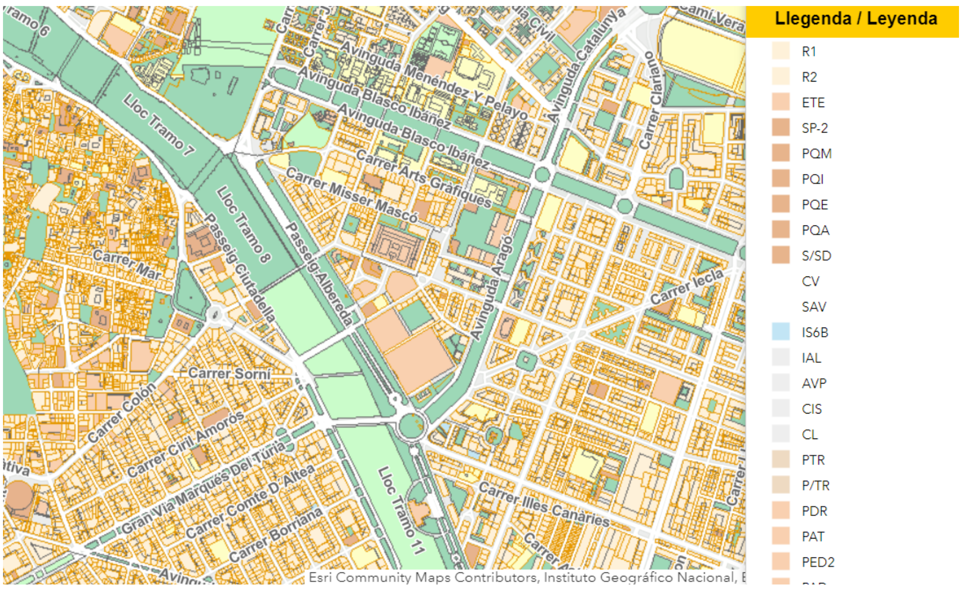


Fig. 1: kinds of buildings according to the PGOU

Materialising minable view

Our model is composed of agents and parameters. The agents are: Street Class, Buildings and People.

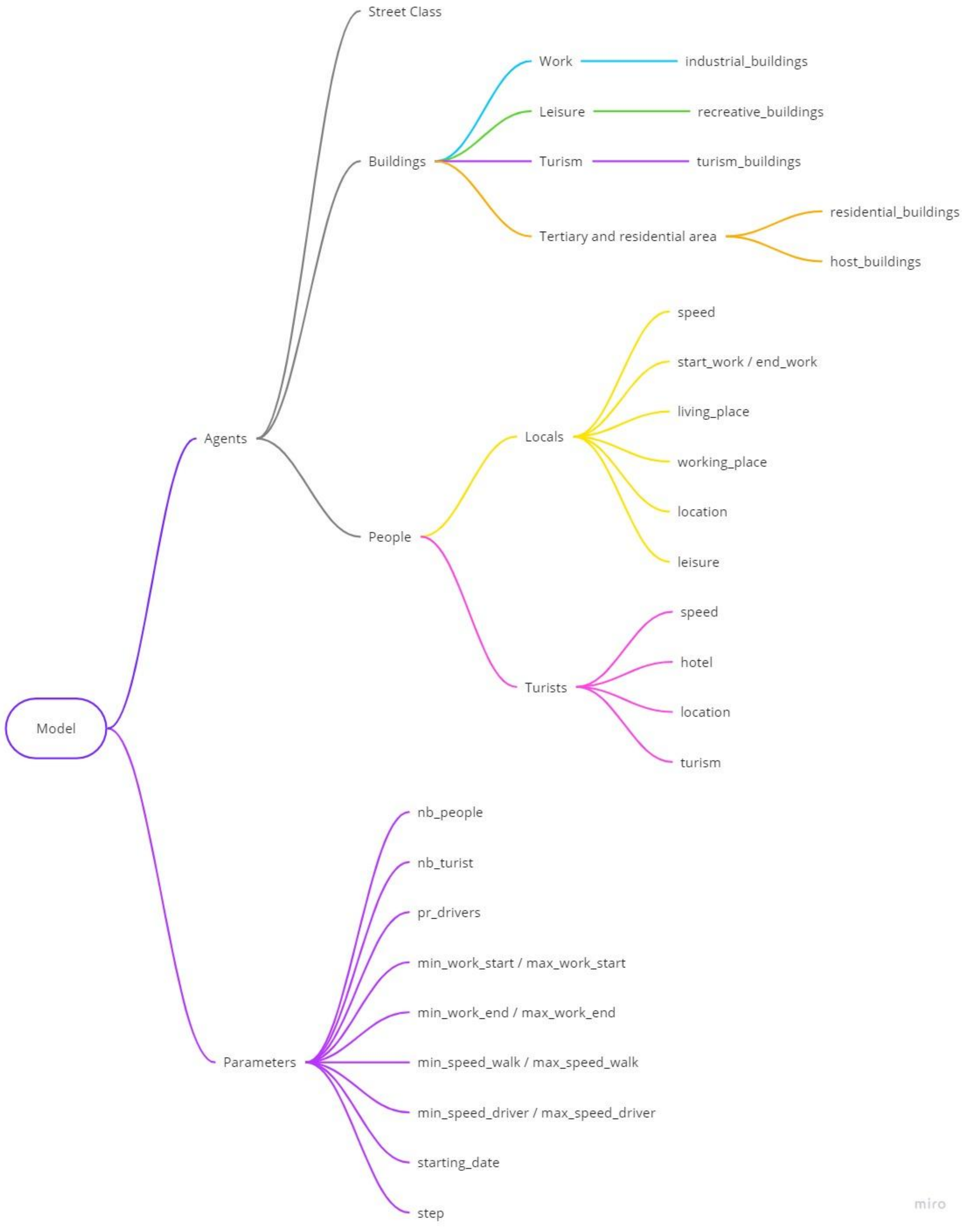


Fig. 2: the components of the model

First, we are going to define the parameters that we are going to use in the model:

Name	Type	Unit	Explanation
nb_people	int	number	Number of people in the city
nb_turism	int	number	Number of tourists in the city
min_work_start	float	hour	Minimum start time
max_work_start	float	hour	Maximum start time
min_work_end	float	hour	Minimum end time
max_work_end	float	hour	Maximum end time
min_speed_walk	float	km/h	Minimum walking speed
max_speed_walk	float	km/h	Maximum walking speed
min_speed_driver	float	km/h	Minimum driving speed
max_speed_driver	float	km/h	Maximum driving speed
starting_date	date	date	The date of simulation

Let's first define and explain the variables of the Buildings:

Name	Type	Explanation
industrial_buildings	list	A list of all industrial buildings
recreative_buildings	list	A list of all recreative buildings
turism_buildings	list	A list of all turism buildings
residential_buildings	list	A list of all residential buildings
host_buildings	list	A list of all host buildings

The following are those for local persons.

Name	Explanation
speed	A random number between the parameters of min_speed_walk and max_speed_walk
start_work	A random number between the parameters of min_work_start and max_work_start
end_work	A random number between the parameters of min_work_end and max_work_end
living_place	A building on the list of residential_buildings
working_place	A building on the list of industrial_buildings
location	Any location in living_place
leisure	The list of recreative_buildings

Finally, the tourist variables are:

Name	Explanation
speed	A random number between the parameters of min_speed_walk and max_speed_walk
hotel	A building on the list of host_buildings
turism	The list of turism_buildings
location	Any location in hotel

As an output of the problem we will get a graph showing the streets with the types of buildings and the local people and tourists interacting.

All of this is covered in more detail in the Deployment mockup section.

Model building

Agent classes

Talking about the model, we have established three agent species; that is to say, we have distinguished three agent classes.

The first class we are going to discuss is the street class. Like any town, Valencia has a complex network of pathways that connect the different areas inside the city and that people use to commute. In our model, the idea is quite similar. We have established a graph in which the edges are these streets while the nodes are the street junctions. Remarkably, the graph is not entirely connected since some areas in the city's suburbs don't seem to be connected to the rest by streets but by roads. This has made it difficult to establish a coherent model, but we will discuss it later.

Now, we will talk about the buildings. These are the second agent species and represent, as evident, the buildings in the city. Using the PGOU qualification for the ground, we have determined five types of buildings. The first one is the working centers. These are the places in which people will work, such as factories, schools and so on. The second buildings type is the residential one. These are the places in which people live. Then, we also considered restaurants and hotels as another class. Next, we have the recreative areas, places such as parks, gardens but also sport centres or cultural places. Finally, we have considered tourist centers, protected sites because of their relevance historically or ambiently.

Finally, we will talk about the people agents. As their name claims, these agents represent the people who live in Valencia. We have considered two subspecies inside this species: the tourist agents and the local agents. They will inherit the attributes of their parent species, so both of them can be regarded as people agents.

The local agents are the people who live in Valencia. We have considered a cycle in which they will start the day resting, go to work at a determined time, work for a time, and finally go home. There is also a random component in which the resting locals could go to recreative areas instead. However, they will always return to their homes to rest. As we said before, the non-connectivity of the graph can result in some problems since sometimes, the locals won't be able to go to work. While waiting for a solution to this problem, we will consider they will be telecommuting.

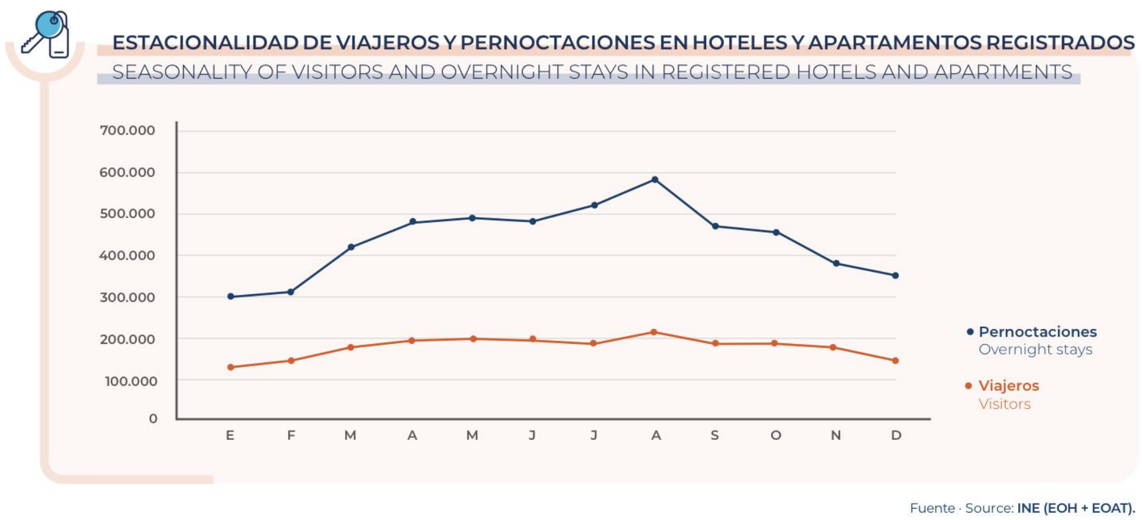
The tourist agents are people who live outside Valencia and are visiting the city. These people will have a hotel appointed as their resting place, and their cycle will consist of them walking in the streets visiting the tourist centers. They will also go to their hotel to rest at a particular time.

Parameters

There are some parameters we would like to account for. Among others, we need to discuss the number of people we will consider for our model. In 2021, the number of people registered in the city was 789744 (Instituto Nacional de Estadística, 2021), so this is the number of local agents we will initialize.

On the other hand, we also need to obtain the number of tourists per day. To do so, we have searched how many people spend the night in the city (Visit València, 2022). From these data, we supposed a uniform distribution. That is to say, we assume that every day the number of tourists in Valencia will be this because even if on the weekend more people are going to visit the city, there will also be some visitors throughout the week according to the flight offers.

Finally, to simplify the model, we have considered the average tourists amount as the only value instead of varying the number of tourists through the months. This way, we initialize 15000 tourist agents.



As we established previously, the people agents will move through the streets. However, they will need a velocity to do so. This velocity will depend if the person is walking or driving, so we will need to estimate how many drivers are in the street. To do so, we have considered the amount of vehicles as a percentage of the amount of people travelling (“Radiografía Al Tráfico En Valencia: El Tiempo Que Se Pierde, El Día Con Más Atascos, La Peor Hora Del Día...” 2020). This way, we have deduced that the number of cars on the roads will range from 20% to 5%.

However, in the model, we will have drivers working or resting. That means we will not have all the drivers simultaneously on the streets. That’s why the probability of a person commuting via car is increased to 30% to correct this difference.

And about the pedestrian and car velocity, we need to say that, to simplify, we haven’t considered increments or decrements. We assumed a uniform speed. For the pedestrians, this velocity ranges from 3.76 to 5.76 km/h (Coffin & Morrall, 1995), while for vehicles, the speed is comprehended between 30 km/h to 50 km/h. We have chosen this velocity range for cars because these are the minimal and maximal velocities allowed in urban areas in Valencia.

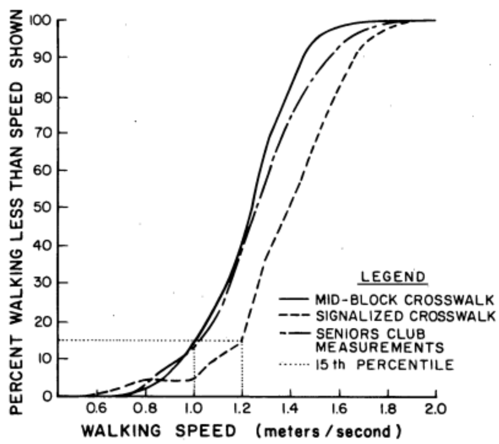


FIGURE 2 Cumulative distribution of walking speeds of elderly pedestrians.

Finally, we need to discuss the work start and work end times. For this, we have assumed only the complete morning working day. This way, we have taken the start working time between 6:00 a.m. and 10:00 a.m while the end working time is between 4:00 p.m. and 8:00 p.m.

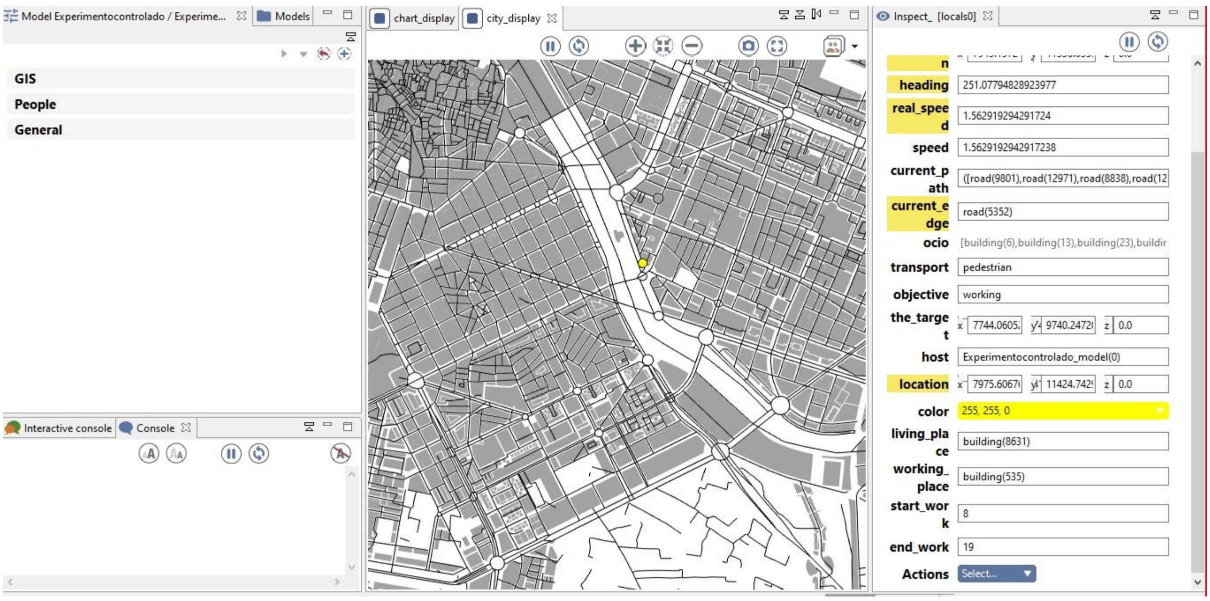
Evaluation

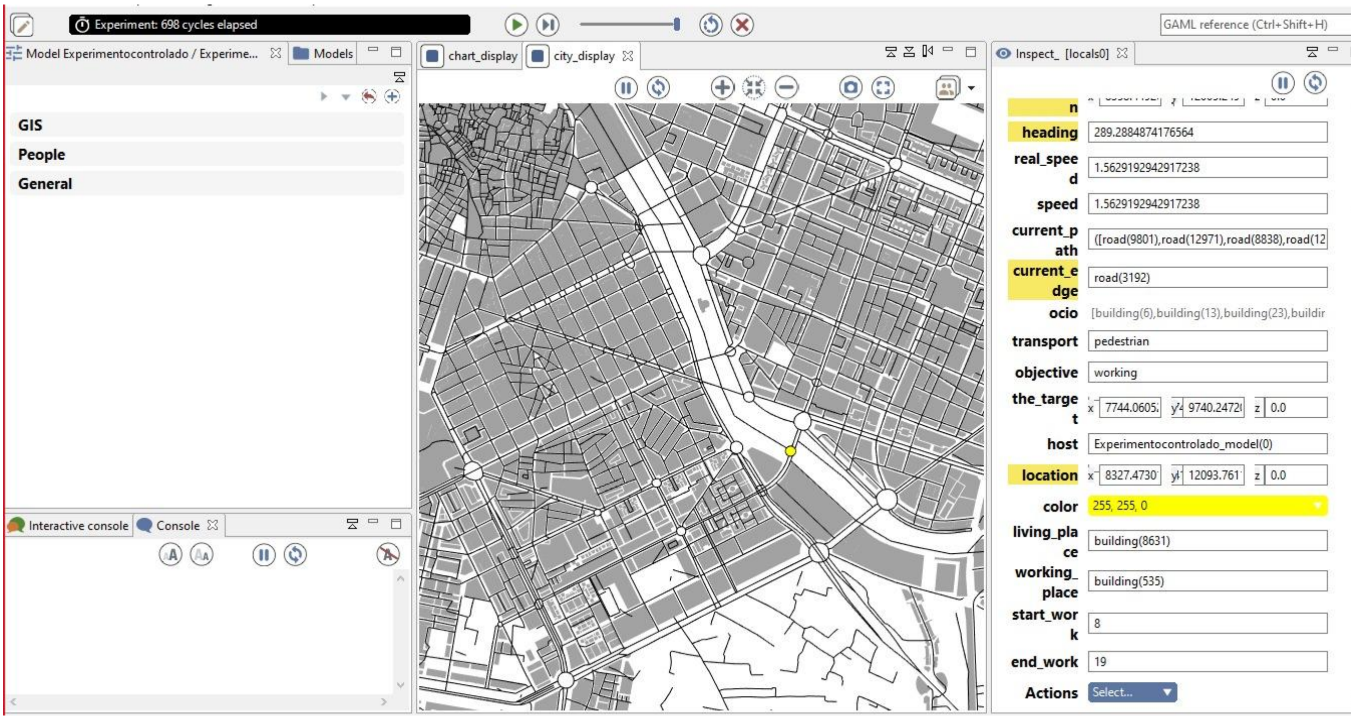
In order to check whether the model is correctly completed, we are going to focus on one single person, a pedestrian. Specifically, we are going to prove if his speed and his mobility can be related to the rest of the cases.

First of all, we are going to take a starting point where the pedestrian starts to walk and we will see how much has he walked after ten minutes. The initial point is shown in the first picture and the point where he stops after ten minutes appears in the one below.

To make sure that this measures are actually correct, we use an application named “Google Maps”. Here we indicate the initial and the final point and it tells us how much time it should take to walk the distance between the two locations. The application calculates that the distance is of 889 meters and it takes 11 minutes. This data compared to our own measures, indicates that our pedestrian walks faster than the average, but that is likely to happen so it should not be any problem. Apart from this, we can prove that the distance we had previously indicated is pretty much the same as the real one.

Therefore, taking in account that our pedestrian walks faster than the average (but not out of the normal range), our data would be accepted, so we can verify that the model is correctly evaluated.

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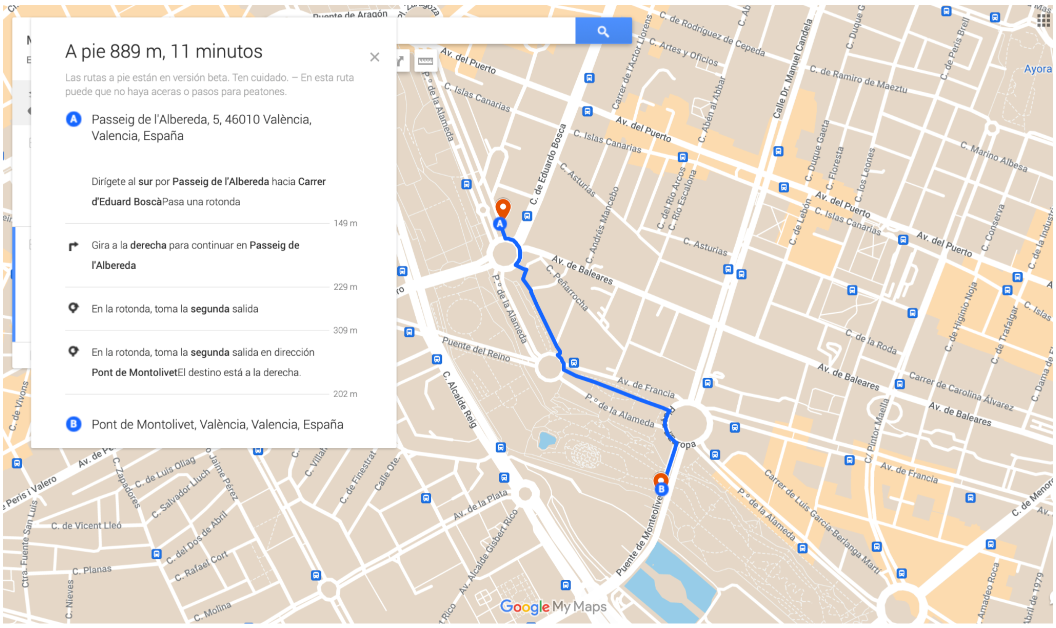
A pie 889 m, 11 minutos
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Dirígete al sur por Passeig de l'Albereda hacia Carrer d'Eduard BoscàPasa una rotonda
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En la rotonda, toma la segunda salida en dirección Pont de MontolivetEl destino está a la derecha.
202 m
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Av. del Puerto
Av. de Baleares
Av. de Francia
P.º de la Alameda
Puente de Montolivet
Puente del Reino
C. Islas Canarias
C. Asturias
Google My Maps

Deployment mockup

What does our model look like?

Our model, specially the one developed in GAMA has a graphical-oriented methodology with its results being finally shown in a window where each object represents an important contributor to the results. Such objects are called agents and are represented in the following way:

- **Residents**: represented by yellow circles, limited speed and will follow familiar routes.
- **Tourists**: in color pink, behave in a different way than usual residents, as they primarly visit parks and more touristic areas.
- **Car**: red circles, quicker, a person can turn into a car with a certain probability, this cange occurs in a residence.
- **Buildings**: viewed as squares, different colors represent variations on building's purpose.
- **Roads**: lines (usually between buildings).

Which parts is it made from

There are two main components in the GAMA prototype: the basic environment and the agents. Agents interact with the graph in the same way as people would live in a city: Agents reside in a building (residential zone), they move both walking or by car which requires them to move between roads.

Now, with regards to the technical mecanism that puts the graph and the agents together it is done in the background of our model but before understanding the interaction between the two key components of the prototype let's explain each part briefly:

1. **Graph:** given by external data contained in shape files, it represents the city of Valencia. Colored squares represent buildings and lines represent streets. The graph is not given from an only shp file, rather by a compound of various files. This is made in the following code lines:

```
global {
    file shape_file_roads <- file("C:/Users/Home/Desktop/EJES-CALLE.shp");
    file shape_file_buildings <- file("C:/Users/Home/Desktop/buildings2.shp");
    geometry shape <- envelope(envelope(shape_file_buildings) + envelope(shape_file_roads));
```

2. **Agents:** they don't come frome external data. Agents are emulated and their behaviour is determined by both parameters in background and user interaction at the time of deploying the code. Now we will see an example of a certain agents and its parameters:

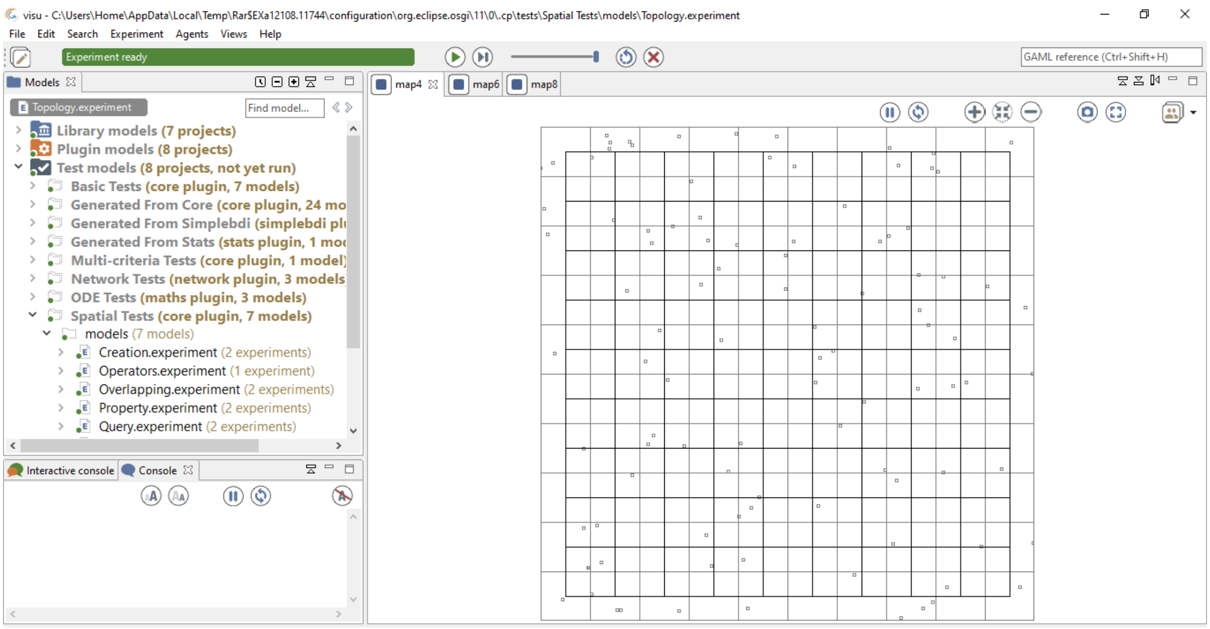
```
create locals number: nb_people {
    speed <- rnd(min_speed_walk, max_speed_walk);
    start_work <- rnd (min_work_start, max_work_start);
    end_work <- rnd(min_work_end, max_work_end);
    living_place <- one_of(residential_buildings);
    working_place <- one_of(industrial_buildings);
    objective <- "resting";
    location <- any_location_in (living_place);
    color <-  #yellow;
    ocio <- recreative_buildings;
}
```

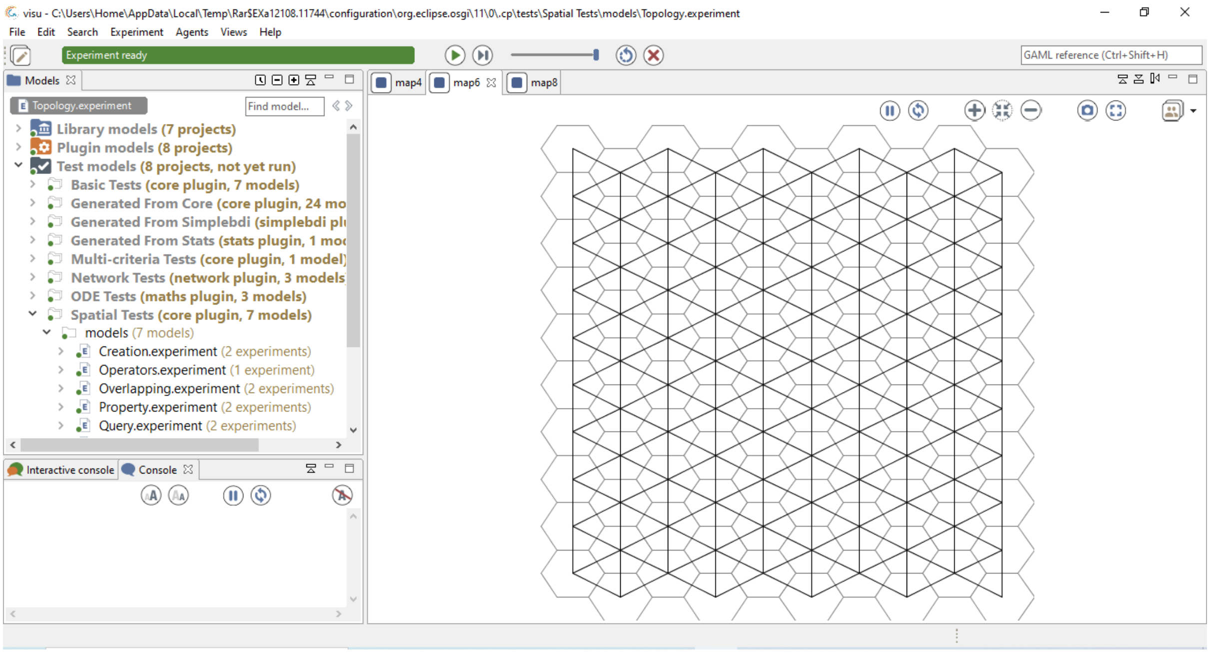
Here locals get assigned a speed when walking (a random between min speed and max speed assigned before), work starting and finishing hours, the places where people live and work according to the zoning and other parameters such as the color (yellow) they'll be shown when displayed.

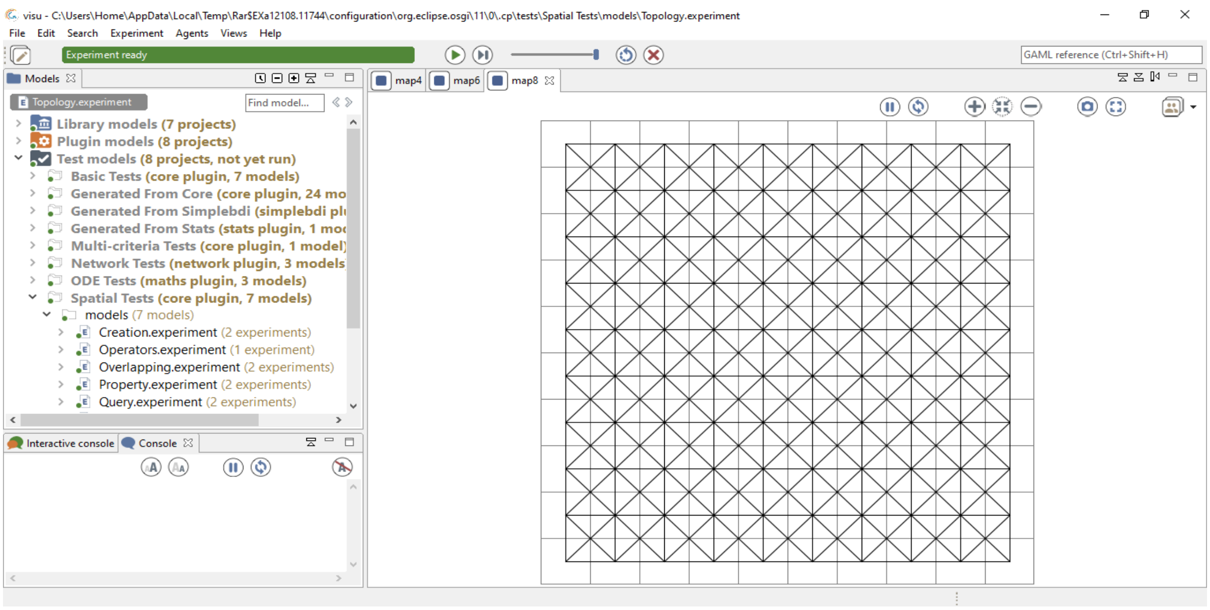
How is it executed?

In the GAMA platform each model is written in a script, when opening pur model GAMA will automatically pop up a green square with a play button, which when clicked will start a new window in which the experiment is executed.

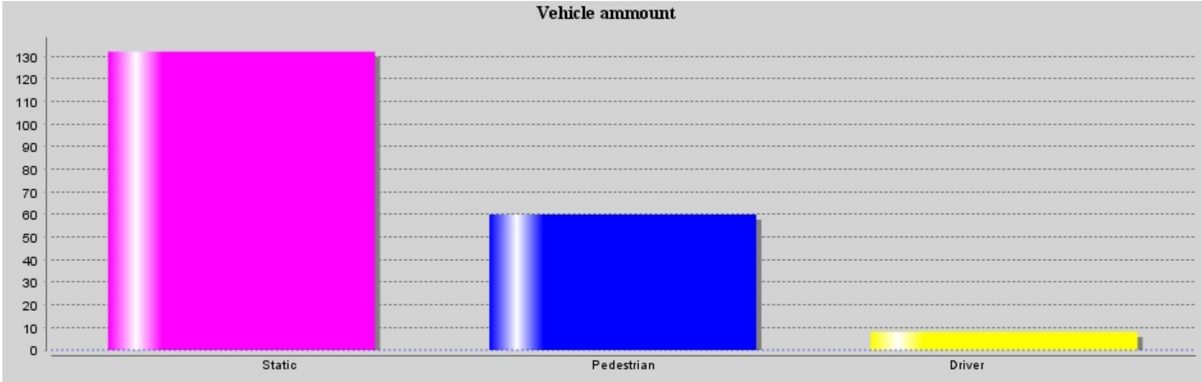
For example in the case of this topology graph, when play the “Topology” option this displays are shown:



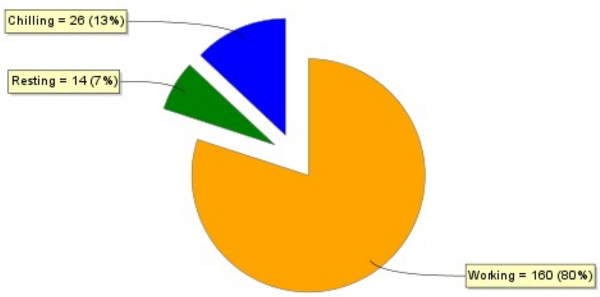




In our case, besides the graphilcal representation, a statistics page will apear in which for example the number of people walking, using cars or resting are collected each moment in a bar graph.



Locals status



Furthermore a pie graph shows in each moment the proportion of poopulation working chilling and resting.

Use of Technology

The tool used to achieve our objectives will be GAMA. a programming and software development language, which we will use to carry out the simulations and build the model.

GAMA is a model and simulation development environment for building spatially explicit agent-based simulations.

In GAMA we have simulated Valencia inspired by projects on the 'GitHub' page, a collaborative platform for hosting projects in different programming languages. In addition, we have built the agent-based model.

Dust was created for the purpose of understanding and managing cities, planning to explore and prepare for possible emergency situations and as a real-time management tool.

Final impact

It should be taken into account that the model will have an associated computational cost, since the code executed to simulate the cities will take some time to run, in addition to the time worked by the members of the group.

This project will not affect people's privacy, since we will not use people to build it, but simulations, thus avoiding that people's privacy is affected.

As for the benefits, we will obtain a way to evacuate a city in case of war, bombing, etc., thus improving the safety of the civilian population within the city.

In addition, we will improve mobility in the city, trying to find the best routes to circulate depending on the traffic in the city at any given moment, avoiding traffic jams, agglomerations, accidents, etc.

We could make traffic more fluid, thus reducing the time it takes for a person to move from one point to another. This could also have a positive impact on pollution, as we can make cars run for less time, causing fewer emissions.

As for the risks, the results of this model could end up in the wrong hands and be used to commit crimes. For example, a person who wants to commit a robbery will be able to investigate in which streets there are few people so as not to be discovered and/or caught.

Also, a person being chased by the police will be able to know how to leave the city without exposing himself too much, which would endanger certain people.

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