Steps Towards Simulating Smart Cities and Smart Islands with a Shared Generic Framework

A Case Study of London and Reunion Island

Tahina Ralitera[1], Maxime Ferard[2], Gonzalo Bustos-Turu[2], Koen H. Van Dam[2] and Rémy Courdier[1]

[1] *Laboratoire d'Informatique et de Mathématiques (LIM), University of Reunion Island, Parc Technologique Universitaire, Saint-Denis, France*

[2] *Department of Chemical Engineering, Imperial College London, South Kensington, London, U.K.*

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Abstract: Simulation models can be used as decision support tools for smart city design and planning. They allow to evaluate the possible consequences of projects, before their implementation in the real world. Decision makers could benefit from replicable ones that can be relevant and easily transferable from one territory to another so solutions can be compared and re-use of model components can save time. In this paper we consider the case of citizen's mobility flow simulation. However, most of such simulation models are designed to be suitable for a specific kind of territory. Some of them are reusable, but in a context that does not differ much from the original one for which they were designed, or require lots of changes to be relevant in another context. We classify those contexts into urban and insular and we show that despite their difference, they could be complementary. We demonstrate that testing a simulation model designed for an urban context, in a context with strong constraints can help in its consolidation. Thereby, after testing an Agent Based Simulation Model originally applied to a case study in London, in Reunion Island, we present a more generic simulation model that works for both systems.

1 INTRODUCTION

Currently, combining competitiveness and sustainable urban development in cities becomes a challenge. Consequently, government, citizens and stakeholders have to search for technical solutions to reduce economic and environmental crises that come with the growth of urbanization. On the other hand, since these last decades, the development of ICTs has contributed to great changes in cities in all points of view (economic, cultural, transport...). Those trends have led to the growing popularity of the concept of "smart city" (Dijkstra et al., 2013), defined by (Longo et al., 2014) as a "place and territorial context, where use of planned and wise of the human and natural resources, properly managed and integrated through the various ICT technologies already available, allows for the creation of an ecosystem that can be used of resources and to provide integrated and more intelligent systems".

A city system is considered as a complex system (Batty et al., 2012) characterised by:

- Micro-interactions of both human-human and human-environment;
- Emergence of unexpected phenomena that arise from the behaviour of independent units;
- Non-linear dynamics i.e. it is difficult to predict the output of the system from its inputs;
- Feedback loops.

It is composed of different recognizable subsets, including individuals with various behaviours, who are no more considered only as users of the system, but as part of it. Proposed smart city solutions should therefore consider those characteristics and should be able to adapt to the individuals and to the environment in which they are. Agent-Based Modelling is a promising solution in developing such a complex system. It allows to break down city into smaller simpler subsets handled by several autonomous, social, reactive and proactive entities. An approach that allows to model non-linearity and favors the emergence of necessary standards and protocols needed for the Smart Cities (Roscia et al., 2013).

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Different projects are done and simulation models are often used by policy makers to evaluate their possible consequences before their application in the real world. It would be therefore interesting to have replicable simulation models that could be easily transferable from one context to another. However, currently, many of them are designed for a specific environment and are only transferable to a context that do not differ much from the original one. Making experimentations in insular territory such as islands could be interesting for the consolidation of a simulation model designed for urban territories, as islands might be considered as an ideal candidate for tests under real-life conditions before later implementation in urban areas. In this paper, the SmartCityModel, an agent based simulation model, originally applied to a context of urban systems such as London, is tested. Insights gained from applying this model to Reunion Island help develop this framework further to be more widely usable in different contexts and thereby contributes to a generic simulation model presented here.

This paper is structured as follows, section 2 gives an overview of smart cities, smart islands and agent based simulations of mobility flow as stated in the literature. Section 3 is about a comparative study between urban and island systems and section 4 describes the experimentations. Finally, Section 5 reflects the approach and discusses the contributions.

2 RELATED WORK

2.1 Smart Cities and Smart Islands

The ”smart city” is considered as a solution that could solve the problems linked to the growth of the urbanization and the increase of the environmental and economic crises in the city. Currently, there is still no universal definition, but (Longo et al., 2014) define it as a ”place and territorial context, where use of planned and wise of the human and natural resources, properly managed and integrated through the various ICT technologies already available, allows for the creation of an ecosystem that can be used of resources and to provide integrated and more intelligent systems”. A smart city is well performed in 6 key fields (Giffinger, 2011), related to some urban life aspects (Albino et al., 2015): smart economy, smart mobility, smart environment, smart people, smart living, smart governance. The experimentation described in this paper is focused on the smart mobility part of this smart city, but could also be applied to the other parts.

Islands are also facing the same problems as cities, to which additional constraints are added. Indeed, due to their remoteness, their isolation and other specific geographical constraints, islands are facing multiple challenges in managing energy, resources, transport... Those lead to think about ”smart islands”. Currently, to our knowledge, the concept of smart city is subject to lots of study, however few works are talking about smart islands. And most of the time, the given solutions suit to a particular territory (Choo, 1997) (Gioda, 2015). Sometimes, however, it is interesting to have a re-usable simulation model that could be easily transferable from one territory to another, by taking into account characteristics which are proper to different types of territories such as cities and islands (Comparison will be discussed later, at Section 3).

2.2 Agent based Simulation Models

Different approaches were used in the literature for simulating transport mobility: trip-based approach, tour-based approach and activity-based approach. The proposed simulation model uses activity-based approach which supposes that travel derived from the demand for personal activities (work, shopping, leisure...) that individuals need or wish to perform (McNally and Rindt, 2007). In the example, the SmartCityModel (Bustos-Turu et al., 2014) (see Section 4.1) is used to simulate the electric transport and the impact of that on the electricity consumption, depending on agents activity schedule. Similar works can be found in the literature (Sweda and Klabjan, 2011) but none take into account the specific constraints that could be very important for some kind of territory such as oceanic islands. For example, they do not consider the geographical parameters such as road slopes (Maia et al., 2011). Also, transport behaviour considerations such as vehicle speed or the use of comfort items, that could also influence the energy consumption (Bingham et al., 2012) (Karabasoglu and Michalek, 2013), are usually neglected. So, such simulation models may not be transferable in the context of a territory where these missing parameters could strongly influence the electric vehicle’s consumption. Consequently, testing such simulation models in a very different context, such as an oceanic island one, could help to improve their generic nature by detecting such missing parameters. It is also interesting to explore how these features could be added to an existing approach.

To support these proposals, a comparative study between urban and insular context is done in the next section, followed by experimentations on the particular case of London and Reunion Island.

3 COMPARATIVE STUDY

3.1 Urban and Insular Systems

An urban area generally contains one or several of the following features: local municipality, large population, high population density, and economic activity which does not mainly depend on primary resources exploitation (Unicef et al., 2012). However, it is strictly defined at a national level, but there is no international agreement on this topic. This raises important issues in the comparison of urban zones located in different countries, as diverging city definitions might create misleading results. It must also be noticed that the administrative definitions of cities boundaries are not covering the entire real city. However, the major part of the data are from the local government, and are therefore based on that definitions. As a result, using another boundary would strongly increase the complexity of the research, both in terms of geographic limits setting and data collection.

Many simulation models are tested only on urban systems (Badariotti and Weber, 2002) (Sweda and Klabjan, 2011) (Čertický et al., 2015), so there could be a problem in translating them in systems with different geographical and socio-cultural characteristics such as insular systems.

Insularity refers to areas with more or less marked spatial boundaries that identify, at least in theory, a set of elements from diverse origin, participating in the same territorial dynamics. It is therefore favorable to the study of the functioning and the viability of systems, and the islands are interesting examples (Magnan, 2009). Indeed, islands are pieces of lands surrounded by water and which are above water at high tide (Nations, 1994). Their boundaries are already set by geographic constraints and are time-independent. Moreover, unless they have a direct link with the mainland (e.g. electrical network, bridge), every flows that come from and to the islands are easily traceable as they occur by plane or boat. The usual classification of islands is also relatively clear (ocean and continental) and independent of the local government. Apart from these facts, islands can be home to different cities and towns. In this respect, the previous considerations about urban system characterisation are also valid for islands having high population levels and urban centres.

3.2 Comparison

When comparing them, island and urban systems present very different structural features. Because of their relative differences, the two systems could react in very different ways to the same changes. Table 1 summarizes the comparison of the two systems. Indeed, urban areas are hard to define and to break down into elementary units, whereas islands have fixed boundaries and a more common structure due to their geographical characteristics. From a system perspective, islands appear to be easier to define and study. They might be considered as an ideal candidate for tests under real-life conditions before later implementation in urban areas. However, despite their differences, islands and cities could be complementary. Therefore, making experiments on both cities and islands can generate useful insights for the discussion of transferability of smart city solutions from islands to cities.

4 CASE STUDY

4.1 The Simulation Model

Proposed simulation SmartCityModel is built upon the free and open source Agent-Based Modelling and Simulation platform Repast Simphony (North et al., 2013). It was used for different case study around urban systems, such as for simulating the interactions between land use, transport and electric vehicle charging demand (Bustos-Turu et al., 2015), residential electricity and heat demand (Bustos-Turu et al., 2016), estimating plug-in electric vehicle demand flexibility (Bustos-Turu et al., 2014) or for modelling water and sanitation infrastructure use in urban systems (The Ecological Sequestration Trust (TEST), 2016).

In this paper, the application area is electric transport and the example simulate Plug-in Electric Vehicle (PEV) flow in the city. PEV owners are modelled as agents who take travel and charging decisions based on their perceptions and memories. They use an activity schedule and are capable to adapt their behaviour given a particular situation such as a reduction in the charging tariff. The environment, in which they are situated and act, is represented by a collection of objects, each representing a fragment of the modelled physical reality. It is defined using a GIS representation (shape files).

To summarise, the simulation model takes, as input, GIS and statistical data. As output, it generates metrics such as electricity consumption and charging station usage profiles, which are stored in .csv files. Those .csv files could be used for further studies, using post-processing software. Figure 1 shows the initial experiment process of the simulation model.

Table 1: Key structural differences between islands and cities.

	Islands	Cities
Physical boundaries	Set by geography, Constant	Many possibilities, Time-dependant
Geographical constraints	Often strong in oceanic island	Often small or null
In/out flows	Easy to evaluate	Hard to determine

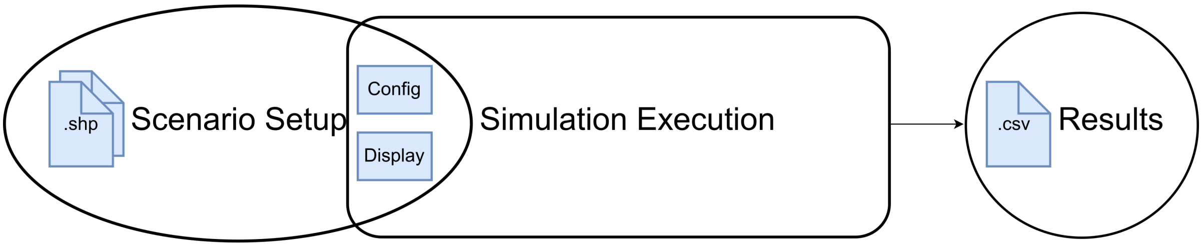

Figure 1: SmartCityModel initial experiment process.

Experiments are carried out in London and Reunion Island, in 2 steps: a comparative analysis between the 2 contexts and experiments by simulation. The approach adopted follow the three steps experiment process used in (Čertickỳ et al., 2015): experimentation specification (scenario definition and setup), simulation execution, result analysis and visualisation. This allows not only to make adjustments in the parameterization of the simulation, but also to take into account all the aspects going from the initialization to the interpretation of the results. Aspects that seem important to consider because they are all linked and contribute to the generic nature and the relevance of the simulation model.

4.2 London and Reunion Island

London (Figure 2) is the capital of the United Kingdom. It is an urban area of 1,572 km^2, populated by 8,538,700 inhabitants (in 2014). Situated in the north hemisphere, it has a temperate oceanic climate.

Figure 2: London map.

Reunion Island (Figure 3) is a French island situated in the south hemisphere, in the Indian Ocean, nearby Madagascar and Mauritius. It is an oceanic island of 2,512 km^2, with a tropical climate and populated by 843,529 inhabitants (in 2015).

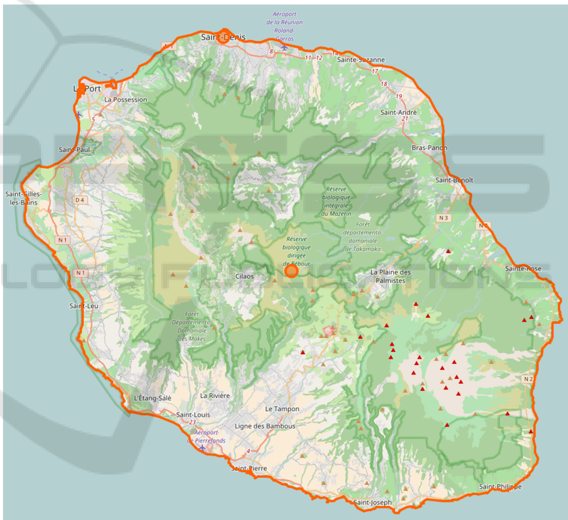

Figure 3: Reunion Island map.

First of all, as opposed to London, which has moving boundaries, Reunion Island has boundaries that are delimited by the sea. Moreover, it is a completely remote island and in and out flows are easier to define. The center of the island is a national park, with a very high elevation, so population housing and mobility are constrained by the physical characteristics. Moreover, Reunion Island has a contrasted relief, with an altitude variation from 0 to 3070.50 m (the Piton des Neiges), while in London the slope is negligible. Consequently, if in London, the population and their mobility are scattered across the territory, in Reunion Island, they are concentrated in the coastal areas. Second, due to their different geographical position, their environment, their relief and their climate are also different. The average temperature in London is 12.4°C against 27.7°C in Reunion Island. However, in Reunion Island the temperature can be lower in the mountainous areas and higher in the coastal areas. The average precipitation is also higher in Reunion island: around 10 000 mm per year against 622.5 mm. Therefore, the use of comfort items in vehicles such as air conditioning, heating, wipers, etc. is not the same. Finally, compared to its small size, London is 10 times more populated than Reunion Island.

To sum up, to be transferable to a context similar to Reunion Island, the simulation model should take into account the parameters listed in table 2 (non-exhaustive list).

Table 2: Non-exhaustive list of parameters.

Classification	Examples
Geographical	Slope
Socio-cultural	Population density and geographical distribution, speed
Climate related	Use of comfort items, temperature variation

4.3 Experimentations

In this experimentation, the SmartCityModel is used to implement a Reunion Island case, what entails changes in the maps, the statistical data used and the agent behaviour (mobility concentrated in the coastal roads for example).

4.4 First Improvements

First experimentations on Reunion Island revealed some limitations. Limitations that could also appear in other simulation models and in similar territories (oceanic islands or territories with high geographical constraints). The experimentations follows the three steps cited in section 4.2. The results and the discovered limitations and problems are summarised in Table 3. Improvements are done following the same 3 previous levels:

4.4.1 Initialisation of the Simulation

The initialization process of the simulation model is reorganized, based on works done by (Čertický et al., 2015). Now, a .csv file is used to define the scenario parameters and the display is set up automatically. Consequently, the user will no longer have to change the source code of the program or the display, manually. Moreover, wrong file, variable formats and missing attributes, are checked at this level, in order to avoid errors that could appear during the simulation run.

4.4.2 Simulation Core

Improvements can be classified in 2 categories:

First, there are improvements in the algorithm. In fact, to address the problem of unrealistic geographical population distribution (see Table 3), a buffer zone is added around the road network. It allows to generate agents location and activities areas nearby roads. Therefore, population distribution is more realistic: concentrated in the coastal areas and the few people who are in the center of the island live nearby roads. The following pseudo-code show how the buffer zone is used to generate a random location nearby a road:

```
set BUFFER_DISTANCE to buffer radius
Initialise nearestRoad to null
while nearestRoad==null do
   set coords = random coordinate inside
   a building
   set nearestRoad = the road where the
   distance from coords is equal
   to BUFFER_DISTANCE
end do
return coords;
```

Then, an alternative method that consists of defining the activity area locations from shape files (one shape file for an activity zone) is created to address the problem of missing land use distribution data used for the generation of the activity areas location. Generated locations correspond to the precise location of the activity zones in the real world. However, we kept both methods. The method used is chosen automatically at the initialisation of the simulation, according to available data.

Second, there are improvements in the simulation setting. It is about the implementation of the parameters listed in Table 2. Parameters that, according to studies described in Section 4.2 could influence the relevance of the simulation results. This part is still in progress, but currently the speed variation is already taken into account in the simulation. For that, a new attribute is added to the road shape files. This new attribute takes the value of ”majorRoad” if the road is a major road. Then a speed advantage is assigned for car drivers when driving on a major road.

4.4.3 Visualisation of the Simulation Results

It is interesting to link the simulation platform with post-processing tools in order to have an automated treatment as well as a more adequate visual exploitation of simulation results. (Augusseau et al., 2013)

Table 3: Experimentations on Reunion Island.

Step	Details	Limitations
Simulation initialisation	File processing	Shape files have to be contained in a specific folder, if not, need to change the path in the source code Shape files content are not checked so that induce errors during the simulation execution
	Display configuration	Manual
	Scenarios definition	Need to set global variables value in the source code
Simulation core	Population distribution	Unrealistic population distribution Large number of agents are located in the center of the island which in reality is a very sparsely populated area
	Data availability	Some important data are not available. For example: land use distribution (percentage of the different activity zones per commune)
	Simulation configuration	Geographical, socio-cultural and other parameters not taken into account (slope, speed, etc.)
Results		A post-processing step must be done for analysis and visualization, using different tools

and (Čertickỳ et al., 2015) show that having a spatialized display of the simulation metrics in an earth browser such as Google Earth can be interesting. It gives the possibility to replay a previous simulation run, particularly useful for validation by domain experts. Indeed, recording a model as a video preserves the movement, but removes inspection capabilities. Moreover, it is then difficult to include the animation in web applications and to layer it with other spatial data sets. To address this, an export mechanism which records the simulation and its metrics and exports it to KML format is developped. It allow to incorporate data in displays using an interactive geobrowser. This export function can be used to create a web interface showing the output of a simulation run and the variation in the time of the metrics across different parts of the simulated area. An example of display is shown on figure 4.

Figure 4: An example of results display on Google Earth.

4.5 Results

Figure 5 shows the new process of the SmartCity-Model. The 3 parts (scenario definition, simulation execution, result analysis and visualisation) are separated into 3 connected blocks. This new organization make the initialisation of the simulation and the scenario definition simpler, so the user do not need to be familiar with Repast Simphony. Changing the simulated territory is easier as the user only have to add the shape files and the display is configured automatically. Moreover, results visualization is better and there is an automatic first results post processing.

5 DISCUSSION AND FUTURE WORKS

The paper present experimentations done on an Agent Based Simulation model originally applied to a case study in urban systems, on strong constraints systems such as insular systems. By taking a model previously used in a London case study and applying it to Reunion Island by a new team of modellers, some limitations were detected and improvements are done on 3 levels:

- The scenario definition and setup;
- The simulation execution;
- The result analysis and visualisation.

They show that making such experimentations could generate useful insight that can help at improving the transferability of such simulation models from one context to another. Most of the functionality implemented are generic enough to be easily transferable to other contexts. However, there are still some further improvements and verifications that should be done to validate the simulation model, in particular,

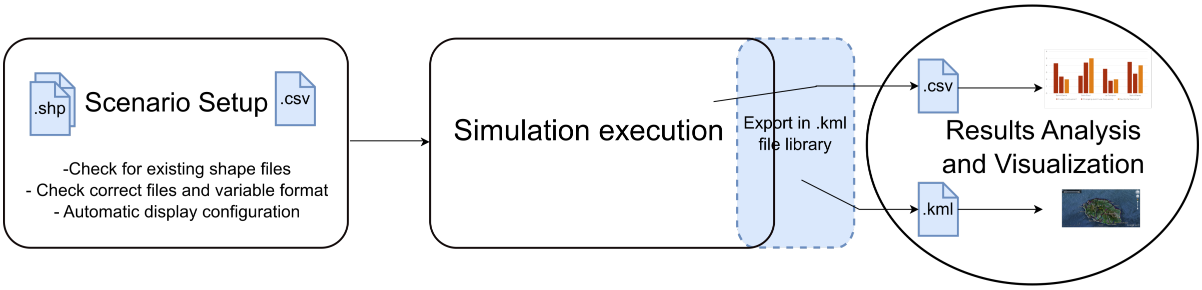

Figure 5: SmartCityModel 3 steps process, after improvements.

in the simulation core by implementing missing essential geographical and socio-cultural parameters.

One of the most important is the slope. Indeed, currently, in the SmartCityModel, the agent route is chosen following the shortest path algorithm, a method that could be improved by adding more criteria for the choice of the road. For example, for energy saving and vehicle power reason, an agent could choose a road with less slope even if it is longer in distance instead a short one but with high slope. This could produce the emergence of a collective phenomenon that lead to the concentration of the traffic in coastal roads, where slopes are lower. A phenomenon that corresponds to the reality in the Island. Moreover, it has also impact on efficiency, especially with EV used as case. As we need to know how much energy is used, maybe it is beneficial to charge at the top of the mountain than at the bottom. And it is applicable not only for islands case but also for cities with big hills or even mountains such as Rio de Janeiro of Lisbon where these improvements following the islands application will be relevant.

So, the future work will be first of all focused on the implementation of those geographical and socio-cultural parameters. Then, we can proceed to validation by experimentations on other urban and island systems. Finally, verification of the simulation results could be done by domain experts.

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