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Agent-based modelling of urban expansion and land cover change: a prototype for the analysis of commuting patterns in Geneva, Switzerland.

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Abstract Agent-based modelling has been used in many studies of urban expansion, land use and land cover change patterns. While representing a powerful tool for depicting and formulating predictions about the evolution of interconnected complex systems, this method also poses a series of challenges to the researcher community, most notably in terms of model calibration and validation, and output data visualisation. Based on these findings, we present an agent-based model developed in GAMA, coupled with a data exploration platform coded in python, for analysing commuting patterns in the canton of Geneva, Switzerland. Output datasets generated from a set of simple evolution rules for the agents, are distributed in open access together with the code for the associated data visualisation platform. This prototype is early work in developing a series of agent-based models for simulating urban expansion and land cover change dynamics, together with their own data exploration platforms for calibration, validation and output data analysis purposes. These toolboxes will be developed with the intent of addressing the various shortcomings in agent-based modelling research discussed in this paper.

Keywords Agent-based modelling · Urban expansion · Land use · Land cover change · Commuting patterns

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1 Introduction

Urban management decision-makers, policy makers, and the scientific community recognise the high importance of monitoring the dynamics of land cover change and the evolution of public transportation offer, before, during, and after, urban expansion projects are planned and achieved [2, 6, 12, 13].

In those complex social-ecological systems, Agent-Based Modelling (ABM) is proven to be particularly well suited to understanding, describing, but also predicting phenomena arising from the intricate interactions between the involved parties (such as transportation network, rural surfaces in competition with newly built areas) in a context of rapid urban consolidation [1, 4, 8].

However, ABM research has encountered many challenges and setbacks inherent to this method, such as the requirement of large amounts of data at a fine resolution [12, 13], rigorous model testing and validation [1, 12], and clear presentation of results in the form of calibration, validation, and output data exploration and visualisation [1]. We develop an agent-based model for land use and land cover change in urban areas, coupled with a data visualisation platform, that will help us calibrate and validate our model efficiently, as well as analyse and display its results in a versatile and interactive manner. For this task we benefit from open access to a large database of vector geomatic data¹, which both solves the data hunger aspect of such a model, and provides highly relevant [12, 13] fine spatial detail to the simulation. We present a first version of the model and platform, and demonstrate that they are capable of producing and displaying measurements from data generated from the simulation. This version is early work towards using validated agent-based models to describe, predict and prescribe phenomena related to urban expansion, land use and land cover change in three different case studies, in a way that will be able to inform decision-making processes.

The following sections will navigate us through the context for this study (section 2), a discussion of our research methodology (section 3) and of planned future works (section 4) for the project.

2 Contextualisation

Urban planning occupies a central space in any government's agenda. Rapid urban consolidation bears tremendous impacts on the ecosystems' as well as the residents' well-being. Indeed, not only do negative side-effects build up on the local biodiversity, such as habitat loss from the conversion of rural areas and forests to built areas [9, 11], they also affect the population, who may suffer for instance from the emergence of isolated zones of abnormally high temperatures during heat spells in summer [7].

We focus on the use case of the canton of Geneva and its desire to develop large axes of public transportation in the form of tram lines. Already

¹ *Système d'Information du Territoire Genevois.*

expressed in policies enacted in 1988², this resolution has been concretized more recently through the establishment of tram lines 14 and 18 connecting most notably the city center to Meyrin and CERN – located north-west, next to the international airport of Geneva. By itself, this decision already heavily impacts the urban dynamics along this high-traffic axis. However, it may also prompt the development of additional residential and commercial centers which would benefit from the increased accessibility of the area, resulting into accrued urban consolidation and land cover changes.

Motivated by the works of ABM researchers in the field of urban planning related to land use and land cover change [2, 6, 12, 13] and reviews from An et al. [1], Groeneveld et al. [4], and Rounsevell et al. [8], we develop an agent-based model for the Cornavin-Meyrin-CERN axis, one of the most important transportation axis in the canton of Geneva. By representing individual behaviors at the smallest scale (i.e. the commuter’s perspective and decision-making), and by integrating complex interactions between heterogeneous agents, agent-based modelling proves to be particularly well suited in representing commuting patterns [5] and related urban consolidation processes. Indeed, agent-based modelling encapsulates emerging phenomena, that, despite being only witnessed at the global scale, can not be simply explained and represented by the sum of its parts [3]. It, in facts, remedies the lack of representation of the individuals’ agency that can be found in other types of urban models [1].

3 Method

This section presents all methods used when developing the model, including the collection of data, the model design and building, and the data compilation and visualisation processes.

3.1 Data

We use data sourced from the SITG³ from which we gather vector data in the form of shapefiles. The spatial extent and useful attributes of buildings, tram lines, tram stops, roads and initial commuter places of residence⁴ are harnessed from these shapefiles. We also use statistics from the OCSTAT⁵ to divide the virtual population into an accurate representation of age classes.

² *Votation populaire du 12 juin 1988.*

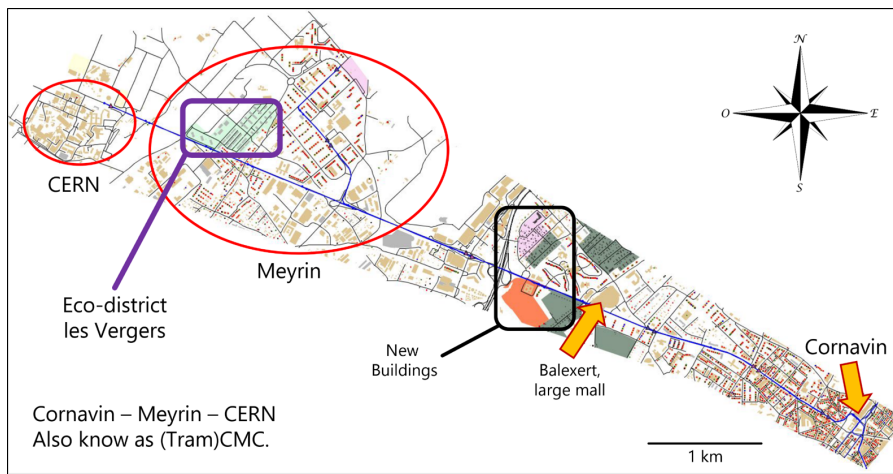
³ *Système d’Information du Territoire Genevois.*

⁴ See section 3.2 for agents details.

⁵ *Office Cantonal des Statistiques.*

Table 1 Commuter agents action plan details.

| Age class | Action plan | Time of day |
|-----------|--|---|
| Children | 1) Go to closest school. 2) Leave school: a. Go to closest leisure (50%). b. Go home (50%). 3) If 2a., go home. | Anytime between 7:00 and 7:59. Anytime between 17:00 and 17:59. 2 hours after arrival. |
| Students | 1) Go to university (Cornavin). 2) Go home. | Anytime between 7:00 and 7:59. Anytime between 17:00 and 17:59. |
| Adults | 1) Go work. 2) Go home. | Anytime between 6:00 and 8:59. 10 hours later. |
| Retired | 1) Choose activity: a. Closest shop (20%). b. Closest leisure (60%). c. Stay home (20%). 2) If relevant, go home | Anytime between 8:00 and 20:59. Spend one hour. Spend two hours. 1 or 2 hours after arrival. |

**Fig. 1** Model visualisation for the Cornavin-Meyrin-CERN axis. The blue lines correspond to the tram lines 14 and 18.

3.2 Model building

We use the GAMA platform [10] to develop our agent-based model (see figure 1 for a visualisation of the model inside the GAMA platform). We define roads, tram lines and stops, buildings, tram vehicles and commuters as agent species, which is the terminology used in GAMA to construct groups of agents. Tram vehicles and commuters are able to move through space, and commuters have their own action plan and decision-making framework.

Whereas tram lines, tram stops, roads and buildings simply provide information about their locations and some attributes, such as building type (residential, business, school, leisure, shop), trams and commuters play a more active role by virtue of being able to move in the virtual environment. Trams service tram stops and follow the path given by the tram lines. They automat-

ically reverse at terminal stations. Among the vast Geneva public transport offer, two different tram lines are represented: line 14 starts from Meyrin center and line 18 starts from CERN. They join shortly after their departure and service the same major axis. Despite continuing their journey past the station of Cornavin towards the communes of Onex and Carouge, respectively, for the interests of this case study, we simplify and set their second terminal station as the station of Cornavin, where they reverse and continue their journey the opposite way.

Commuters represent people who use some transportation method to go to work (or other building types) every day. At model initialisation, they are assigned a place of residence, and an age class (child, student, adult, or retired). Depending on their age class, they adopt different actions plans, which are depicted in Table 1. Based on their action plan and their current intention, commuters evaluate the transportation options and choose the option that fits their needs based on multiple factors: the distance between their origin and their destination, the availability of tram stops within 400 meters of their origin and their destination, and whether or not a tram line directly services both the corresponding stops of their origin and their destination. Commuters will simply walk from point A to point B if the Euclidean distance is less than 800m, and otherwise take the tram or the car. Among adult commuters, 50% will always journey by car. The remaining commuters will evaluate if the journey by tram is possible and if there are stops within 400m of their origin and destination, if yes, they will take the tram, otherwise they will journey by car.

The model proceeds in steps of 10 seconds and simulates whole days starting from 6:00 am. The day ends when all commuters have finished their action plans and reached home. Another day then starts. The model starts in the year 2010, and at the end of each day, may also advance to a new year, as defined by the user. In this case, based on their construction year, new buildings appear and may welcome new commuters inside the virtual world. These new commuters are initialised in the same way as the existing ones, and will also evolve in the system.

3.3 Output data exploration and visualisation

We develop our data exploration, analysis and visualisation platform in python, with the help of libraries such as *pandas*, *geopandas*, *plotly* and *Dash*. Example datasets generated from the model, as well as python code for the aforementioned platform, are available in open access⁶ to anyone willing to analyse model results. The dataset contains information about every journey undertaken during the simulation: who made the commute, what was their age class, what transportation method (by foot, by car or by tram) did they use. The locations of each tram whenever their current number of passengers changes

⁶ https://gitlab.unige.ch/cas/TCMC_ABM_Data_Code

are also recorded. Finally, there is one shapefile containing the road network for each year simulated, and each road holds the information of the amount of unique commuters (journeying by car) it has seen for that year.

4 Future works

The ABM prototype presented in this paper is early work in a larger modelling effort, which includes a total of three different use cases, and a broader field of study. The spatial extent of our model will be expanded to the whole canton of Geneva, and the region of Greater Geneva, which also includes the neighboring areas of the canton of Vaud, Switzerland, as well as the French departments of Ain and Haute-Savoie. We will simultaneously continue developing the data visualisation platform to match the model's calibration, validation and output data analysis needs. The conceptual framework of the system will have its priority shifted towards the representation, understanding, and prediction and prescription of urban expansion and land cover change mechanisms, while retaining parts of the commuting behaviors model we presented in this paper.

5 Conclusion

We have presented an early version of an agent-based model for investigating urban expansion related mechanisms such as commuting patterns and behaviors, applied to the use case of a major transportation axis in the canton of Geneva, Switzerland. A series of evolution rules have been implemented for the different agent types, and the output datasets are available for anyone to peruse. We introduced a data visualisation and exploration platform coded in python, which is and will be dedicated to the analysis and presentation of crucial datasets pertaining to the calibration, validation and exploration of results of the model. The model is still in development and will include a larger spatial extent, sound calibration, validation and results analysis, and consideration of additional phenomena related to urban expansion and land cover change. Additionally, work is being done towards developing a plugin for GAMA, that will be dedicated to linking the model to a knowledge graph server. In doing so, by using the information contained inside this organised information database, agents may be able to dynamically adjust their behaviors and knowledge about their environment.

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