Simulation of the Impact of Urbanization and Demography on the Demand for School Infrastructure in the City of Ouagadougou: Towards a conceptual framework

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Abstract. The growing demography and galloping urbanization of the city of Ouagadougou in recent years had a considerable impact on the demand for school infrastructure. Urban dynamics coupled with school dynamics is a complex system characterized by a set of complex interactions at different spatio-temporal scales. Modeling by its ability to abstract and integrate data from different sources and natures and to predict the state of a complex system is relevant for analyzing the impact of demography on the development of school infrastructures. This study aims at developing an agent-based model to represent the interactions between the urban system and the school system. Throughout this study, a conceptual framework based on a multi-formalism and multi-scale approaches have been proposed. Finally, a simulation prototype was developed to analyze the impact of demography on the development of school infrastructures. In perspective, it will be a question of finalizing the development of the decision-making tool, carrying out simulations and setting up a massive database.

Keywords: Smart city, demography, scenario, agent-based model, Ouagadougou

1 Introduction

The cities in developing countries are characterized by a rapid development of population and urbanization [1, 2, 3, 4]. This rapid demography and rampant urbanization of African cities in recent years had an impact on the provision of basic social services to the population [1, 5, 6]. For the policy makers, providing to the population basic social services such as education is mandatory, particularly in developing countries where inequalities and inadequacies of the education access are caused by the limited numbers of schools and a bad urban planning. For that, policy makers need to know the future impacts of population growth on the demand of school infrastructures and to define an optimal distribution of school infrastructures. Numerous studies have already demonstrated the impacts of the population growth on the demand of school infrastructures in the City of Ouagadougou [1, 2, 3]. These studies showed the inequalities and inadequacies of the school provision in the city of Ouagadougou . However, these studies are based on the past and present situations which do not allow to predict the future impact of

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population growth on the demand of school infrastructures in the city of Ouagadougou. In addition, these studies do not provide any guideline for an optimal distribution of school infrastructures in the city of Ouagadougou. Thus, a new and an innovative method is required.

The school system is a complex system. It is a place of interactions between several individuals (pupils, parents, school managers, policy makers, planners, etc.) at different levels. These individuals differ from their characteristics and their decisions making. Furthermore, education system is a place of interactions between a range of processes such as economic, demographic, land use and urban mobility. Thus, assessment methods used to analyze the sustainability of school system management should integrate simultaneously the multiplicity of actors pursuing various and specific objectives and interlinked dynamics and should require (1) the integration of various points of view – from different actors – for a better understanding of solving problem and (2) an assessment of the dynamics of the system under different short and long-term scenarios. Modeling ability to abstract and integrate data from different sources and natures and to predict the state of a complex system is relevant for analyzing the impact of demography on the development of school infrastructure. Some modeling approaches have been used for this purpose. Among these approaches, the statistical, spatial and agent-based approach. The statistical approach based on mathematical models uses "linear" methods while the education system has a non-linear character [7]. The behaviors of these actors, very often opposed, as shown in the real world, cannot be translated by mathematical models which need balance. As for the spatial approach, if it allows to give a visual scenario to the educational questions, it remains limited throughout the explanation of the behaviors of the agents of the system. Agent-based models help understanding the interactions between the actors of the system and thus make it possible to better clarify all the complexity of the school system [8, 9].

The objective of this study is to propose an agent-based model for assessing the impacts of population growth on the demand of school infrastructures in the city of Ouagadougou. Specifically, this study aims (1) at developing different implementation scenarios in order to reduce the spatial inequalities of education access in the city of Ouagadougou, (2) at proposing a conceptual framework using an agent-based modeling approach to represent the school system in the city of Ouagadougou and (3) at assessing the impacts of future population growth on the school infrastructure demand under various scenarios. In this paper, we present the conceptual framework, the scenarios developed in the context of Ouagadougou and a prototype implement to validate the conceptual framework.

2 Material and method

2.1. Study site

The city of Ouagadougou as the political, economic and administrative capital of the country abounds with the majority of the educational infrastructure. This insufficient educational offer is dominated by the private sector with more than 90% of the educational offer [1, 2]. While the outlying districts bring together more than 48% (941,193 for a total of 1,933,306) of the population, they only have 28% of the schools of the city according to data from [1] (Fig. 1).

In terms of capacity, a school in the central districts welcomes more pupils than all the schools in the second peripheral ring. The school offer is thus more abundant and also more diversified in the Center of the City. This situation leads to a concern for road safety for the movement of pupils in the city, with accidents very often commented on in the newspapers. This also gives

rise to situations for a pupil to travel more than 20 kilometers on a motorcycle to get to his school in the city center. [1, 2].

a) **b)**

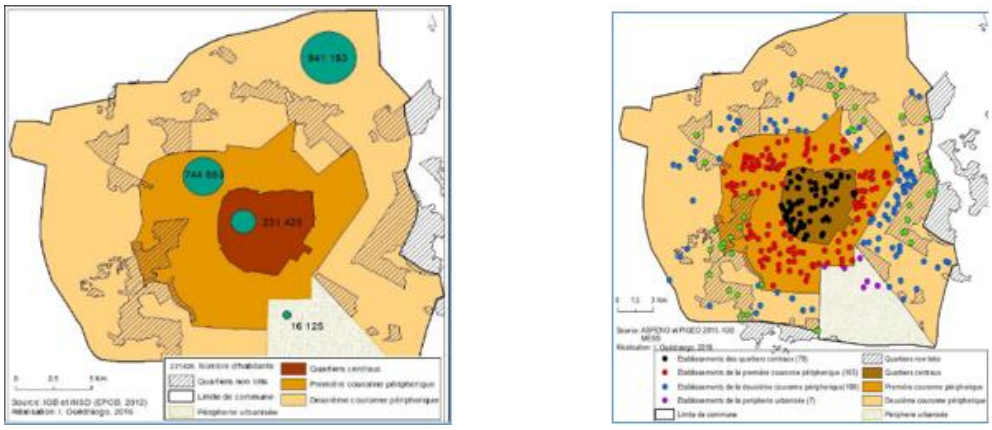

Fig. 1. Presentation of the population of the city and distribution of schools (Source: [1]): a) Demography repartition in the city of Ouagadougou, b) Spatial distribution of the school

2.2 Conceptual model

We use the ODD (Overview, Design concepts and Details) protocol to present the conceptual model. ODD aims at standardizing the published descriptions of individual-based and agent-based models (ABMs). The primary objectives of ODD are to make model descriptions more understandable and complete, thereby making ABMs less subject to criticism for being irreproducible. [10].

2.2.1. Modeling purposes

The objective of this modeling process is to propose a decision support tool in order to assess the future population growth and urban related policy impact on demand and supply of school infrastructures in the city of Ouagadougou. This tool is developed for policy makers, scientists and local stakeholders. Then, the policy makers could use this tool to assess the impact of urban policy on provision and demand of school infrastructures. As to scientists, they could use the decision support tool for knowledge integration and sharing among stakeholders from different domains. Finally, the local stakeholders could use the tool to have a good understanding of the impacts of the urban policy and to collaborate with the decision makers.

2.2.2. Scales and processes

The representation of the system responds to three levels of representation: the individual level, the household level and the city level.

At these different scales, a range of processes have been identified in order to take into account the socio-economic, biophysical and policy dimension of education system. The model takes into account the demography growth as the main driver of the dynamics of the education system, the population settlement in the city, the land use and also land cover change as the main driver of urbanization, the school settlement and the spreading of the information on the schools throughout the social networks as the actors get information on the school throughout their social network.
These processes constitute the different components of the education system derived from the urban system model (Fig. 2).

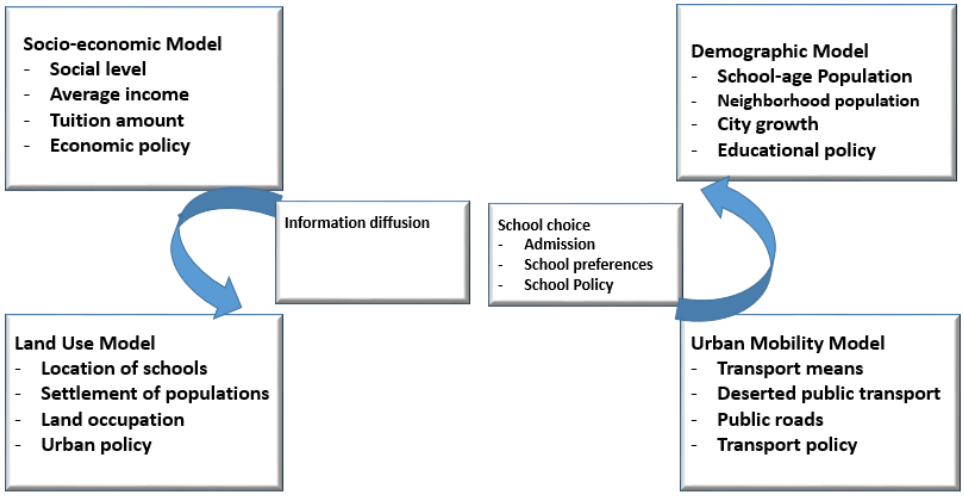

Fig. 2. Components of the education system (Adapted from [11]).

2.2.3. The agents of the system

The education system is composed of four agents which interactions determine how the system operates as described in the diagram class of the model (Fig.3).

Household: represents the main agent of the model. Household is characterized by its income, social status, education level of the household head, the number of the persons and the preferences for schools. Household is a social individual interacting with other households' through their social networks. A household accepts an information from another depending on the weight of their link. Then, each link is characterized by a weight. The weight is randomly defined.

Pupil: represents a social individual belonging to a household. It is characterized by its age, sex, the school level and the education status.

School: represents a school. It is characterized by its notoriety, the number of pupils, the area, the status (private or public), the global performance and its accessibility.

Authority: the authority is a center of exchange for both the determination of educational policies and the urban policy linked to the educational system. The authority thus determines the admission policies in public schools and schooling as well as the surface area of schools and the urban conditions for the construction of schools.

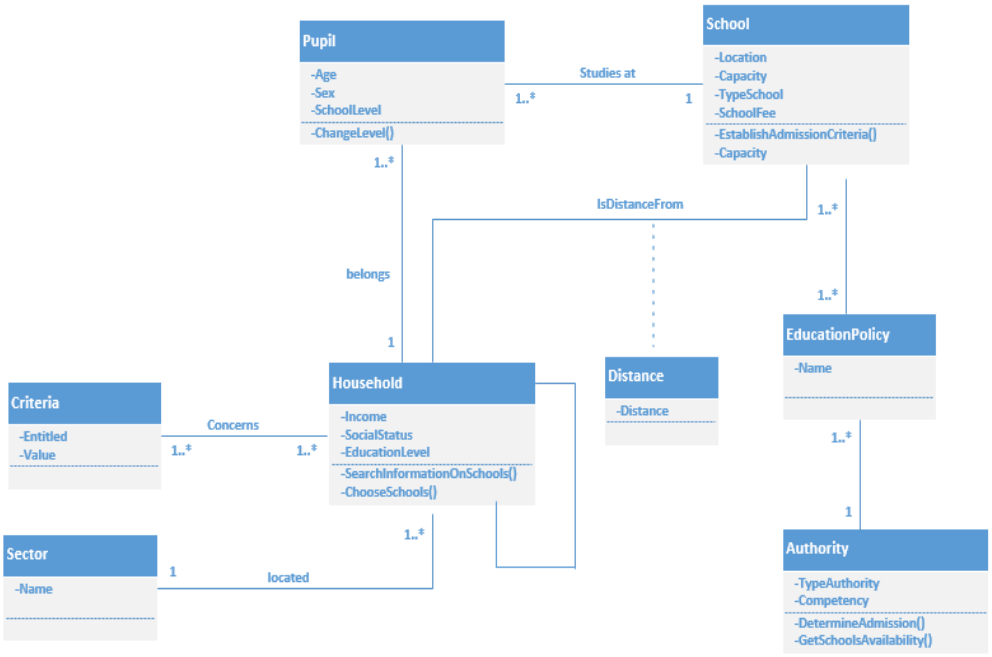

Fig. 3. Model agent class diagram

2.2.4. Sub-models

In this current research we used the agent-based modeling approach to represent the parents' decision making in schools selection, the spread of information on school performance through the social networks, the impact of information spread on the schools selection.

Urban growth model. Most of the urban growth model use geographic space and specifically raster models. The raster models are simpler to implement and require less data which explains their success and why most of the urban growth models are based on this representation.[12]
In the case of Ouagadougou, a raster agent-based model is suitable to consider the availability of data and the dynamics of the town concerning roads and buildings construction.

Information diffusion model. We used the innovation diffusion theory to represent how parents assess schools and recognize the performance of schools. The innovation diffusion theory of Everett Rogers distinguishes five categories of adopters: innovators, early adopters,

early majority, late majority, and laggards. In the current model, the adoption concerns the appropriation (acceptation) of information received from the social networks. To represent how an individual accepts an information and selects a school, we used the threshold models approach. Then, we assume that an individual adopts a school if the trust for the information on this school received from the social networks reaches some threshold. The trust to an information depends on the quality of the relationships between individuals. The quality of relationships is specified by a weight quantifying the social relationship between two agents based on the notion of trust [13] as defined in [14].

School choice model. To represent how individuals select a school according to his preferences, we use decision rules based on the concepts of *bounded rationality* [15]. *Bounded rationality* is based on the assumption that agent seeks satisfactory solutions rather than optimal ones, with his rationality based on limited but dynamic information that evolves according to knowledge acquisition, storing, selection and transmission. These latter variables depend on the dynamics of agent's' socio-professional networks which determine information exchange, knowledge exchange about different schools characteristics, particularly performance, notoriety.

2.2.5. Process overview and scheduling

The education system is made up of four essential components which are represented in the model, namely the socio-economic, demographic, land use and urban mobility models. These components of the education system determine the functionality of the model. There are three main stages in the model: the school selection stage, the analysis stage and the planning stage.

Stage of school choice. At the beginning of each year, pupils who have obtained their Primary Studies Certificate enter 6th grade, i.e. the first year of post-primary school, 6th grade pupils go to 5th grade; pupils who have received their first cycle exam enter second class and second pupils go to first class; final year pupils graduate and leave the system. New 6th grade pupils are integrated into the system and into their respective zones. Each pupil is assigned to an area with social status and economic income. It is the same for new 6th grade pupils. This assignment is made on the basis of census data concerning the populations of the different areas of the city. This is when the admission process begins. Pupils who took with success the entrance exam are assigned to public schools according to their choice accepted by the government. The others use school choice strategies. Schools enroll pupils according to the rules set by the admissions policy. Unenrolled pupils leave the system.
Analysis step. At the end of admissions, the system calculates the differences between the preferences and the actual choices of the pupils and their parents. After the admission process, the system updates the distance traveled by pupils to return to school and the means of transport, the time taken as well as the safety of the daily traffic to school and the presence of a public transport line and calculates the differences between the different areas of the city. Depending on the level of equipment, the size of the school as well as the number of pupils per class, the system analyzes the differences between zones on learning conditions. The school environment is analyzed with regard to the school's distance from main roads, the presence of a fence and its distance from an industrial or drinking area. Scores are assigned to pupils admitted according to the prestige of the school and the system analyzes the differences in the distribution of the average income of families according to their social level and the distribution of average marks. This indicates the inequalities in educational quality and showing up of the academic

performance. The government also sets the rules for building schools. The system analyzes compliance with its construction standards by zone.

Planning stage. This step represents the optimistic scenarios of the model. At the beginning of each year, depending on the number of pupils to be assigned by the government, the system assesses the needs against public schools and calculates the difference to estimate the new classes and schools to be planned. And for all the pupils entering the system the evaluation is based on the capacity of all the schools according to their prestige and also their financial accessibility for families as well as the conditions for distance and travel time for the pupils.

2.2.6. Parameters

The model takes as input the map of Ouagadougou as well as the various system data based on the parameters. These parameters concern the agents of the system, namely households, schools and pupils. These parameters are defined in Table 1.

Table 1: List of parameters and their descriptions

Parameters	Description
Number of schools	These are secondary schools in Ouagadougou
Number of pupils	All pupils from households
Number of households	The number of households distributed according to the 3 zones of the city of Ouagadougou on the map (Centre, First Peripheral Ring, Second Peripheral Ring)
School capacity	Capacity of the school and the different classes
Amount of tuition	Amount of registration fees in the school
Household income	Average household income
Distance from school	The distance between households and schools

2.2.7. Scenarios

Different scenarios were analyzed with actors involving in the education system (Teachers, school founders, Researchers, Urban planners). The scenarios developed are based on the different choices of households by minimizing the distance traveled by the pupils. The household selection criteria are considered in the parameters used in the development of the different scenarios.

3. Implementation and simulations

In order to validate our conceptual framework, we have implemented a prototype using GAMA platform [16]. The prototype basically includes three types of data: the map of Ouagadougou, spatial data of secondary schools in the city of Ouagadougou and household data. The map of Ouagadougou and the school data are from the Ministry of Urban Planning in 2015. The household data are derived from [1].

The simulation takes as input the map of Ouagadougou as well as the secondary schools of the city. 244 secondary schools are thus represented and 400 households are represented in the model. In the current simulations, households have only one child to send to secondary school. At each simulation step, a household seeks to enroll its child in a school located less than 5 kms from their place of residence. And each time a school is chosen it disappears from the simulation. The simulation stops when there are no more schools within 5 kms for households.

The schools are represented in red and the pupils in yellow (Fig.4)

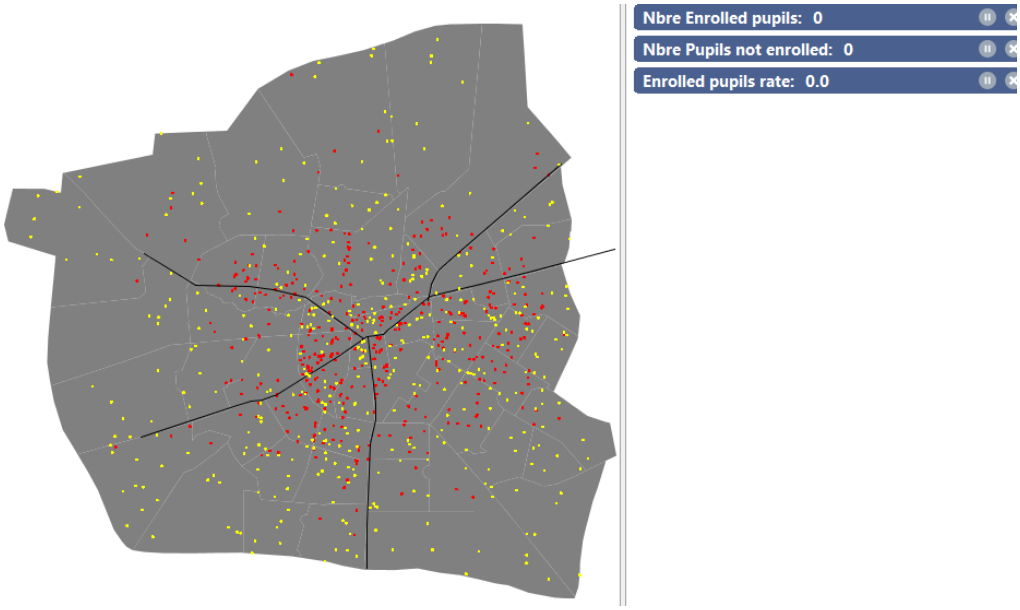

Fig. 4. Simulation of school choice in Gama.

4. Results

The results show 339 pupils enrolled out of 400, i.e. an enrollment rate of 84.75%. Households were able to enroll their child in a school located less than 5 kms away. Also, all households in the central area were able to enroll their child, which is not the case for households in outlying districts (Fig.5). This same observation has been made in many studies on the unequal distribution of schools in the city of Ouagadougou [1, 2, 3].
The school offer is more important in the center whereas the demand is lower because of the socio-economic characteristics of the area, and also because of a population that is less and less important and especially aging [1]. The offer is very insufficient and less diversified in the outlying areas.

For these households in the outlying districts, the children will thus be enrolled in schools more than 5 kms away located in the center of the city with its corollary of difficulties such as transport entailing a fatigue to the learners [1]. It is therefore necessary to build schools in the outlying districts.

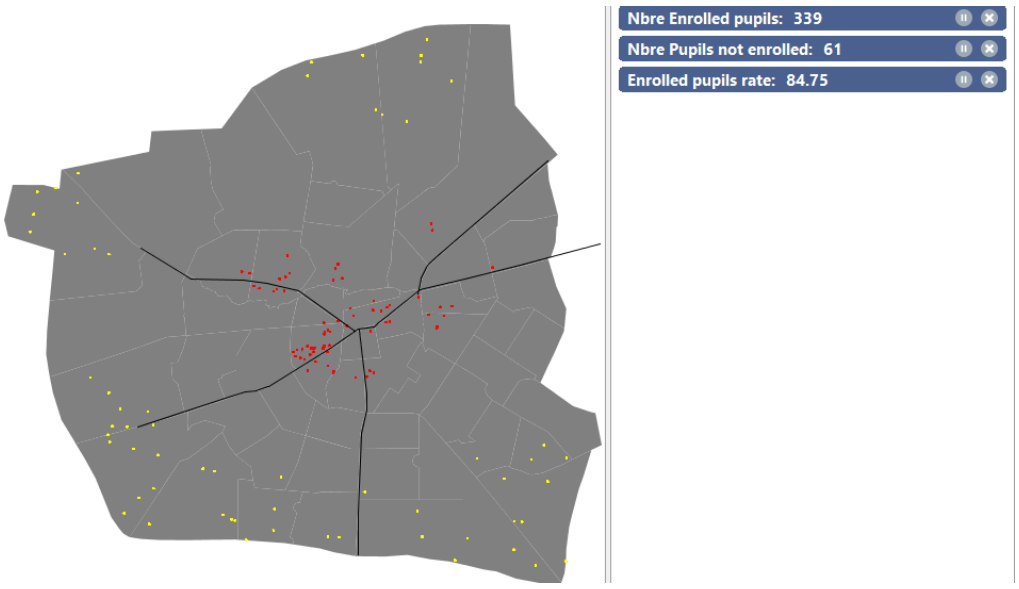

Fig. 5. Result of the enrollment from school choice.

5 Conclusion and perspective

The objective of this research was to propose a conceptual framework to the model of the education system in the city of Ouagadougou, and also to analyze the impact of urbanization on the demand to school infrastructure.
By analyzing the educational system as a complex system, we have described a framework for modeling the interactions between the different agents of the system. This analysis which integrates the sub-models of the system, throughout multi-formalism modeling, makes it possible to take into account different existing models in the various components of the education system (demographic and growth, diffusion of information, choice of schools). These models are related to various modeling approaches (mathematical, spatial, and agent-based).
The prototype developed on the choice of schools gives results corroborated by previous studies on the inequality of the school offer in Ouagadougou.
In the future, the prototype will integrate different sub-models as well as parameters from recent data to simulate different scenarios.

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