OPTIDENS : a simulation model to explore the sustainable forms of accessibility for the urban territories

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Abstract

High levels of jobs and population accessibility are the main qualities characterising urban areas. These qualities represent the essence of cities favouring the emergence of agglomeration economies. In epoch of slow transportation means, activities and population densities were the only way to reach high levels of accessibility. Then, after the second war, the high speed travel provided by car allowed people to choose their home and jobs locations in larger areas, while keeping constant their daily transport time and budget. It leads to urban sprawl and automobile dependency and environmental and social consequences. Recently, in a sustainable perspective, a revival of urban density has been often promoted. However, high density and compactness has its challenges: they negatively impact the environment (e.g. heat islands, air pollution) and they are not well accepted by the residents.

In this context, we develop Optidens, which is a simulation model, to explore urban forms that are able to meet the contradictory goals: lower levels of local density and compactness, higher levels of population and jobs accessibility. Optidens reallocates residences and jobs in order to meet these criteria while minimising a car travel speed, which is a strategic aspect in limiting the automobile dependency. In this paper, we present first the context of the problem, followed by the qualitative formulation of the model. Next, we apply the model to analyse the impact of different parameters on urban form and travel speed.

Keywords: Optidens, Urban form, Accessibility, Social Interaction Potential, Density, Travel Speed, Mixed-Integer Model

1 Introduction

High levels of jobs and population accessibility are the main qualities characterising urban areas. Accessibility can be defined as a number of jobs or people accessible from a given location in a given time by a given transportation mean. Accessibility depends both on spatial distribution of population or jobs and travel conditions, and more precisely on the travel speed.

High accessibility level appears to be the essence of cities, because it allows the emergence of agglomeration economies (mainly related to the limitation of travel costs), innovation and therefore, competitiveness [8, 11].

With slow transport, activities and population density were the only way to reach high accessibility. Therefore, the dense and compact city with a unique centre maximizing accessibility was prevailing. Then, after the second war, higher car speed allowed people to choose their home and job locations in larger areas in order to avoid density and its negative impacts (noise, lower access to natural activities, land prices etc.), while keeping constant (about one hour) their daily transport time and budget [13].

The problem of such an urban functioning is that it makes people strongly reliant on automobile [3]. Without car speed, due to the distance between activities and people, people may be no more able to perform their daily tasks. Moreover, automobile dependency raises a problem of inequality, as the unmotorised people do not have access to many activities reachable only by car. Also, it raises an environmental problem as travelled distances (in kilometers) increase, resulting in higher energy consumption, noise, pollutant emissions, etc.

Thus a revival of urban density is often promoted in a sustainable perspective [9]. However, high density and compactness of the built-up environment has its challenges [1, 2]: it may lead to environmental issues (e.g. heat islands, air pollution) and it is not well accepted by the population that specifically choose the periphery to avoid it.

In this context, between the two extreme forms of dense and compact city with low travel speed and urban sprawl allowed by higher speed, we propose to explore urban forms with the simulation model Optidens that can meet contradictory goals such as : low levels of local density and compactness to meet people’s and environmental expectations *versus* high levels of accessibility to population and job in the attempt to meet the planners' expectations.

To do that, Optidens reallocates residences and jobs while minimising travel speed by car, which is a strategic goal in limiting automobile dependency in a sustainable perspective [3]. Indeed, the higher the car speed, the less competitive is the public transport, and the higher the possibility for people to organize their daily life in large areas. That leads in turn to automobile dependency and environemental issues [5, 14].

Besides, searching suitable urban forms by relocating activities is also justified by the fact that approximately every 20 years, about 20% of a given urban zone undergoes functional changes (e.g. a residence area into a shopping center), which gives the possibilities to the planners to transform the city [10].

Thus, Optidens is a decision-aid tool for urban planners designing the planning urban documents. It allows to explore different scenarios for an urban territory in terms of density, compactness and accessibility and to know the consecutive relevant travel speed.

The paper is organized as follows. We start with a presentation of the basics of the optimization model. Next, we present numerical results for the study area to illustrate the capacities of Optidens and to discuss the relative weight of the parameters on urban form and travel speed. Finally, we provide some overall conclusions and present the future work agenda.

2 OPTIDENS description

2.1 The used method

Optidens consists in coupling a geographical information system and a model of mixed-integer programming (MIP) which is a widely used tool in location-allocation problems. The idea originates from the ”Quadratic assignment problem” [7] where there is a set of *m* activities and a set of *n* locations. The objective is to assign activities to locations to minimize the assignment cost, which can be distance, time, travel cost, etc. Among the possible techniques to deal with this type of problems, we use a linearisation technique [6]).

Using Optidens requires the entry data describing the current territory, to set the expectations of the user and to choose the objective function. Resolving the model means to find the values of the decision variables (the quantity of people and / or jobs to be locate in each place and travel speed) in such a way, that all expectations and objective function are satisfied.

2.2 The entry data

In Optidens the study area is divided in square cells. The smaller the cell, the more precise will be the location of the population and jobs, but it increases the model complexity and the resolution time. The centers of the cells are the measurement points.

For each cell, using a GIS:

- we collect:
  - the current population
  - the current number of jobs
- we set if the cell is constructable or not according to the current urban plans (PLU in France). In unconstructable cells we consider that it is impossible to locate population or jobs, in constructable cell we locate population and activities.
- using a network analyst tool we compute on the current road network a matrix on travel time by car (in minutes) and travel distance (in kilometers) between all the measurement points. For the shortest paths in time, we take into account the different speeds allowed on the different types of roads and the one-way streets. The calculations are made under free-flow condition as we do not consider the traffic.

2.3 The user’s expectations

The user has to fix several parameters:

- the level of population accessibility, called Social Interaction Potential (SIP) [4], and/or jobs accessibility, i.e. population or number of jobs it should be possible to reach in 15 minutes by car from the measurement points. These levels may be the same for all the measurement points or different. Setting different levels of SIP implies spatial differentiation, which can correspond e.g. to the preference to preserve a part of the current urban structure.
- the maximum threshold for population density. The local density of population is measured in a radius of 1000 meters around each measurement point. We choose the threshold of 1000 meters as a compromise between a very local view and a too large view of the density if using higher thresholds, which will tend to smooth the spatial differentiations. Again the user may set the threshold same or different for all the measurement points.
- the maximum threshold for cell compactness. Compactness is a maximum share of the cell surface, where we can locate populations and jobs. Consequently, the higher this share the higher is probability for a more dense area in the output.
- optionaly : the minimum and the maximum quantity of people and jobs that each cell can receive in order to avoid to locate all the jobs and population in the same cell. This option also allows to favour particular locations when choosing high minimum of population, for example for cells close to the public transport infrastructures.

2.3 The objective function

Optidens seeks to verify all the user expectations while minimizing the travel speed by car to tackle the problem of automobile dependency. This link between urban form and transport conditions is a major asset of Optidens. There are two possible options:

- From a set of discrete speeds (20km/h , 30km/h, etc.) Optidens selects the minimum worst value (the higher) which allows to verify all the expectations. It means that we are sure that with the selected speed, all the expectations for each measurement point are satisfied, but it doesn't mean, that all people need absolutely to travel with this speed in order to access the requested level of SIP or a number of jobs: the travel speed can be lower for some areas but can never exceed the obtained value.
- Optidens searches the minimum relative change value (decrease or increase) from the current speeds on different sections in the road network, so that all the expectations are verified. This change value is measured in %, e.g. the resulted change value being 10% means, that the current speed will be reduced by 10%. Therefore, at the end we obtain a change value for the whole studied area. As previously mentioned, the obtained value describes the worst possible scenario. All the roads don’t need necessarily to apply exactly this value, lower speeds might be locally sufficient. With this option the initial hierarchy in terms of speed between the sections is maintained.

2.4 The reallocation of population and jobs

Regarding the reallocation of population and jobs, two possibilities exist:

- All the population and jobs can be reallocated
- We set the share of the current population and jobs that could be reallocated. This case is much closer to the planning reality because in practice planners obviously can't consider that it is possible to change everything at the same time. However, the results of this option are not developed in this short paper.

3 Study area

The studied area, denoted as "entire area" is a part of Vaucluse in the south-east of France. It contains one main urban area in the middle (Carpentras with 28000 inhabitants) and smaller neighbouring villages. The current total population counts 327000 inhabitants and 107000 jobs. A smaller area inside the entire area represents the reaffectable area (83000 inhabitants and 21000 jobs), where we consider that the decision-maker is authorized to reallocate. This differentiation between the reaffectable area and the rest of the entire zone is necessary to avoid a side effect. Indeed, in reality people of a given area can also access to facilities in the surrounding areas, so it is necessary to take these facilities into account (when computing accessibility and density) even if the user of Optidens might be not authorized to reallocate their activites. The entire area is divided in 6095 square cells (500m x 500m), with 1304 cells in the reaffectable area, corresponding to the administrative current planning area for the agglomeration of Carpentras. The current mean SIP of the reaffectable area is of 51000 (but with a high standard deviation), the density is 225 residents per 1 km2 and the average travel speed from cells to each other is 53 km/h.

4 Results

In this paper we present some preliminary results to illustrate the capacities of Optidens. For fair comparisons, we set different parameters equal for the different simulations. The required surface per person and job is respectively 90.5m2 per person, and 54.75m2 per job, which represents average values observed in the study area. The compactness fixed here by 70% for all the simulations (i.e. we allow 70% of cell surface to be reallocated). Thus, we can deduct, that population per cell can't surpass 1933 inhabitants. The travel time is limited by 15 minutes by car which allows us to simulate urban forms suitable for an urban functioning based on proximity. The idea is to achieve a territory providing an appropriate mix of urban functions at the scale of 15 minutes of travel, what is not the case currently as the same mix requires the duration of 40 minutes.

4.1 The higher the SIP the higher is the required speed, but not proportionally

First we consider the level of SIP and the compactness (70%) and observe the respective speeds. For a range of SIP from 30 to 70 thousands the required speed varies from 30 to 50 km/h.

Table 1: SIP level and corresponding speed

SIP (in thousands)	30	40	50	60	70
Speed (in km/h)	30	30	40	40	50

Spatially it appears [Figure 1] that the relocation process favours the cells with low population. Thus, the three dark blue clusters in the right part of the map represent the surplus in allocation of population compared to the original situation. The centre in yellow and dark yellow represents the areas with less population than originally. However, there is still a notably densely populated cluster in the middle of the small zone.

If we run the simulations with different SIP level for the different locations, it logically requires higher speeds as there are less achievable reallocations.

According to the current Plan of Urbanism, reallocation is possible only in a part of cells (representing only 13% of the surface of the reaffectable area due to the natural risks: flood, fire). In this case, we can notice that the levels of SIP previously mentioned require speed in average by 20 km/h higher. If we use the second objective function giving the relative change of the current speeds, the speed requires a 30% increase (in the worst case) [Table 2].

Table 2: SIP level and corresponding speed in conformity with Local Plan of Urbanism

SIP (in thousands)	30	40	50	60	70
Speed (in km/h)	60	60	60	70	70
Speed in %	100	100	110	120	130

Next, we add the constraint of density. The maximum density in a radius of 1000m around each measurement point is fixed to 615 residents per 1 km2. This parameter becomes critical, when SIP is greater than 50 thousands with higher required speed. Thus, for a SIP of 50 thousands the travel speed requires an increase of 10 km/h compared to the situation without density criterion. Therefore, avoiding high densities while aspiring for the high level of SIP results in higher car speed.

4.2 Jobs accessibility : an essential criterion

While adding job accessibility as an additional criterion, we can notice that the threshold with over 20000 jobs reachable in 15 minutes, impacts significantly the resulted speed.

Indeed, as the current jobs are concentrated in the central urban cluster of Carpentras, adding this criterion requires jobs to scatter more (to the benefit of areas with few jobs) and results in higher speed [Figure 2]. However, the respective impact of job accessibility is less significant when the required SIP is high, because in this case high SIP is a deciding factor, causing the high speed [Table 2].

Table 2: Required speed for different SIP and job accessibility thresholds

Job accessibility	Required speed for SIP 60	Required speed for SIP 70
0	40	50
15	40	50
30	50	50
45	60	60
Compactness 70%, all cells are constructable, no density constraint		

4.3 It is not always possible to meet all the criteria

Finally, we consider simultaneously all the criteria: high SIP, and accessibility to jobs, low density, and unconstructable areas (in conformity with the Urban Plan). In this case it appears that it may be impossible (when the thresholds are set to the extremely high levels) to find a reasonable travel speed to meet all the criteria [Table 2].

Table 2: Required speed for a combination of all criteria

SIP	Job accessibility	Required speed All cells are constructable	Required speed Taking into account unconstructable cells
30	0	30	60
30	15	30	60
30	30	50	**120**
30	45	60	**>120!**
60	0	40	70
60	15	40	70
60	30	50	**120**
60	45	60	**>120!**

This finding shows that planning in a sustainable perspective is a question of choice, and that it is not always possible to fully respect all the demands and interests. In this case, both people and planners have to find a suitable compromise to their expectations.

5 Conclusion

These first results suggest that Optidens is a useful tool to explore the link between urban forms and travel speed for efficient policy-making. This ability to link expectations for urban forms and the respective travel speed is the main advantage of the model in comparison with other types of simulations as LUTI models (Land Use Transport Interaction) [12] which mainly simulate the effects of changes in accessibility (due to the given travel conditions) on the urban form.

Planners can use Optidens as a collaborative tool to work on the future of urban forms. It allows to analyse which urban forms are feasible (criteria values) and under which conditions (required speed), which may be useful e.g. for a public debate. It doesn't provide *the* solution, but indicates if a solution exists.

However, several improvements remain necessary to increase the operationality of Optidens:

- to enable to allocate optimally only the additional population or jobs rather than reallocating the current amenities;
- to minimize the speed according to the types of road, for example imposing certain speed decrease for highways ;
- to consider contiguities between the land-use types in the process of re-allocation. The idea is to limit scattered shapes of built-up areas (in order to keep the reasonable complexity of infrustructures like water, energy networks, etc. At the same time it is essential to prevent some types of contiguities. For example, the contiguity between built-up and green areas has to be favored contrary to the contiguity between a built-up areas and polluting or risk-related activities.

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Figure 1: Population reallocation for a SIP of 70000.

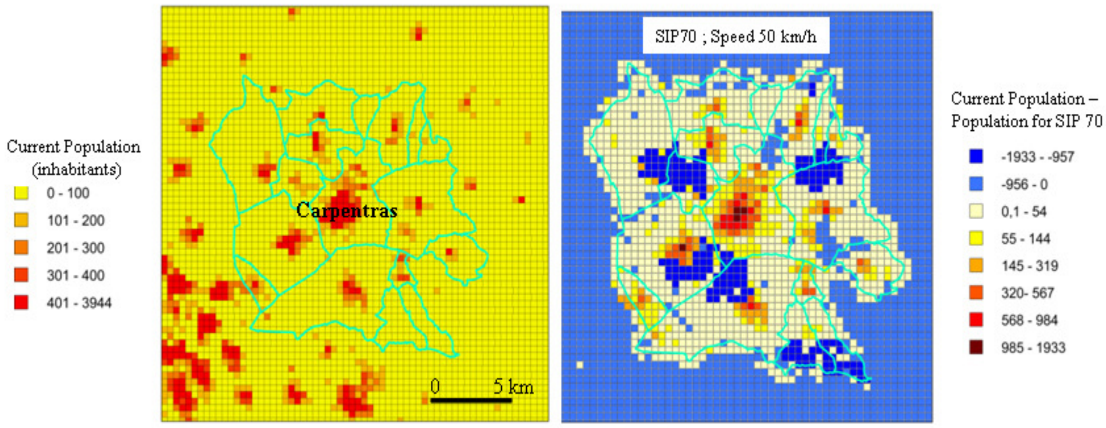

Figure 2: Required speed for different SIP and job accessibility thresholds