A Multi-Agent Model for Generating Local Land-Use Plans in the Context of an Urban Planning Support System

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Abstract: In a multi-player urban planning process, the outcome of any individual decision of the actors is uncertain until a state where the plan is satisfactory for all. To support the plan generation phase, this paper develops a generic multi-agent system, in which agents represent particular land-uses. In the system, agents higher in the hierarchy have priority over agents lower in the hierarchy to claim units of land. This one-direction claim process may result in a plan that is not optimal for every agent. The system, therefore, allows agents to revise their plans in an iterative procedure. A case study illustrates centralized, semi-centralized and decentralized solutions for a plan area based on the outcomes of different strategies used by facility agents (retail, green, schools) and a housing agent. The results show that the proposed system is able to generate rational and realistic plan alternatives for new residential areas.

1. INTRODUCTION

Various urban planning actors operate in a highly complex, dynamic and uncertain environment to achieve a set of collective goals regarding the future location of the various land uses. This multi-player planning process is influenced by various objectives that may partly conflict, counteract, or synchronize because decisions are subject to interdependencies of land uses

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from different individual actors' needs and desires, which may be competitive or cooperative. A major difficulty in this context is that actors are unable to determine which responses and actions will and will not be effective until the end of the planning process. They are often confronted with uncertainty about other actors' decisions and their own individual contributions to the collective decisions in the interactive planning process. Most of the interactions between actors in a planning process are based on their personal (subjective) beliefs (*i.e.,* expectations), desires (*i.e.,* goals), preferences, and heuristic rules, attempting to minimize the uncertainty to achieve a set of outcomes satisfied by each of them at an aggregate level.

In order to represent and simulate the interactions (e.g. action and reaction) of multiple actors, we use multi-agents to represent the multiple actors of particular land uses. The authors have explored the land use decision of individual agent under the uncertain outcome of other land use agents in previous studies (see Ma, *et al*., 2004, 2005). In this paper, we develop a generic multi-agent system to generate land use plan alternatives in an interactive environment of multi-agents, building on Arentze, *et al.* (2006). The goal of the planning support system is to generate meaningful plan alternatives for a given land-use allocation problem. A set of plan alternatives is considered meaningful if it varies in terms of the strategies which the different agents could adopt.

This paper is organized as follows. After this introduction section, the second section describes the proposed multi-agent system. Next, the third section describes an application of the system in a case study to illustrate its properties. Finally, the last section summarizes the major discussions and discusses issues for further research.

2. METHOD TO GENERATE PLAN PROPOSALS

2.1 Assumptions

Consider the decision problem that a retail agent, a green agent, a school agent and a housing agent can expand their land-uses in the same administrative plan area. They may be either present in the existing area or they may be newly introduced. Assume that the size of the expansion is known and fixed (*i.e.,* as the outcome of earlier plan decisions) for each agent. In the following we will use the term 'Task Size' to refer to the size of the expansion of a land-use. Let the plan area be represented by a raster of grid cells. The size of the cells is small enough to assume that a single land-use exists in each cell. The existing land-use of each cell is given as well as the nature of new developments, if any, allowed in each cell. The latter is represented as a binary variable for each alternative land-use indicating whether or not the existing land-use may be converted to a new land-use.

The decision problem varies from one agent to another. For example, depending on given task sizes, the retail agent wants to develop new shopping centres, the green agent wants to develop new green parks, etc. For the so-called 'facility' agents, *i.e.,* retail agent, green agent, and school agent, the decision problems can be generalized as: 1) how many new facilities are to be located in this area? 2) what is the area size of each facility? 3) where should each new facility be located in the plan area? The housing agent differs from the facility agent in that it differentiates between different housing types. In the case study, we assume that the housing agent considers four types of houses, *i.e.,* detached houses, semi-detached houses, row houses and apartments in the plan area. The distribution of his Task Size across these different types is given and fixed at the moment of land-use planning. His decision problem involves: 1) what is the total size of each type of houses? 2) where to locate each type of houses in the plan area?

2.2 General procedure

In this proposed system, each agent first generates a set of alternatives so-called macro-strategies for his own land-use independently of the other agents and Task-size independently of the other agents. A macro-strategy is here defined as a strategy for allocating the total size of land for a particular use in the plan area. Later, we detail the strategies each agent may consider. For the planning support system, generating different macro-strategies is important as it provides the basis for the ability of the system to generate different (overall) plan alternatives for the area. A strategy never changes during the process, thus to guarantee resulting plan representing some optimum within the specific combination of strategies adopted by the agents. The agents involved are arranged in a sequence. Agents earlier in the sequence have priority over agents later in the sequence in claiming units of land (i.e., cells in the grid). This means that once the units of land are claimed by an earlier agent, other later agents cannot claim these units any more.

For each combination of alternative strategies across agents a plan is generated, as follows. The first agent in line uses its specialised knowledge to generate his plan and passes the initiative over to the second agent in line. Given the claims made by the first agent, the second agent then generates his plan for his land use and passes the initiative to the third agent, and so on. This sequential process results in a plan that may not be optimal from the viewpoint of every agent individually because earlier agents may wish to change their claims given the land-use plans of the later agents. Therefore, the system invokes a new cycle in which each agent is able to revise his plan in the same sequence. The cycles of revision are repeated until none of the agents wishes to make a change in his claims anymore. As stated above, agents are not allowed to change strategy when they revise a current plan.

The procedure is schematically summarized in Figure 1. We emphasize that each agent at each moment in the planning procedure can override the land use of cells of other agents lower in the hierarchy, as long as the land is available for the agent's land-use, whereas the reverse direction is not feasible. The interactions between agents happen through the environment of the multi-agent system, where agents operate in a hierarchical order of *R*-*G*-*RG*-*H*-*S* denoted 'Retail, Greenspace, RestGreen, Housing and School' agents. This structure is feasible in the practice but may not optimal.

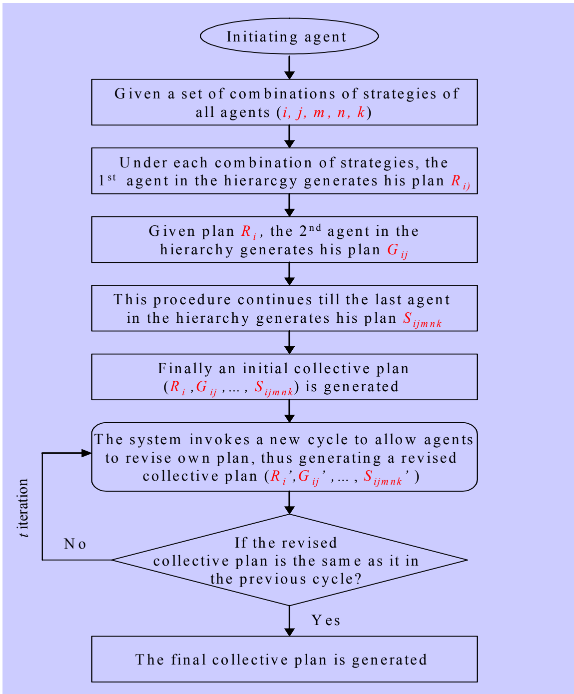

Figure 1. Interaction of multi-agents in the plan generation.

An agent needs the following abilities to fulfil its role in the above procedure: 1) a method to generate a set of strategies for his land-use; 2) a method to generate a plan for his land-use; 3) a method to reset his current plan for his land-use. Revising an existing plan does not require additional knowledge compared to generating a plan. A revision is the result of successive application of the resetting and generating methods.

2.3 The components of the system

2.3.1 Plan generation methods and land-use types

In the proposed system, each agent first generates a set of alternative macro-strategies of his land-use independently of the other agents. The methods used to generate the strategies can differ from one agent to another agent. In this regard, we distinguish two types of agents. On the one hand, agents concerned with retail, green-space and school facilities are referred to as 'facility' agents and, on the other hand, the housing agent is classified as an 'area' agent. Facility and area agents use different methods to evaluate the suitability of locations for their land-uses. Facility agents try to optimize a network of facilities considering the spatial distribution of demand for the facilities. Location-allocation models are well-suited for solving this problem. On the other hand, area agents conduct a suitability analysis of locations on a cell-by-cell basis whereby the overall suitability of a land-use plan is calculated as a sum of suitability scores across the cells occupied.

Although facility and area agents use different methods to generate a plan for their land-use, their methods also have a common feature. Both types of agents distinguish between a macro-strategy and a micro-strategy (Ghosh and McLafferty, 1987). A macro-strategy represents a specific setting of the parameters of the method used to spatially allocate the land-use, whereas the micro-strategy represents this allocation solution itself. In other words, a micro-strategy is embedded in a macro-strategy and determines how the macro-strategy is realized in terms of a land-use plan. At both micro and macro levels, the facility agents and area agent(s) use different concepts and methods, as we will explain below.

Macro-strategies of facility agents

A macro-strategy of a facility agent defines the number of new facilities and the size of each new facility. In line with central-place theory, we classify possible macro-strategies in terms of a hierarchy of facility locations. In the case study (as well as most Dutch facility systems), we assume a three-level system. In a three-level system we can distinguish the following strategies: a maximally centralized strategy, a semi-centralized strategy and a decentralized strategy. In a maximally centralized strategy, the facility-agent realizes as many first-order facilities as possible given his Task Size. In a semi-centralized strategy, the facility-agent does not develop first order*, i.e.,* city-level, facilities, but develops as many district-level facilities as his Task Size allows. Finally, in a decentralized strategy, the facility-agent only develops neighborhood-level facilities. Because the size of the facilities decreases with descending order of facilities, the centralized strategy results in a few large facilities, the semi-centralized in some more semi-sized facilities and the decentralized in many small sized facilities. Note that the macro-strategies assume a standard size for each facility order as given.

A given Task Size is not necessarily an exact multitude of a standard size used. The size remaining after having developed the maximum number of facilities of the preferred size is used for facilities of smaller size. In this way, for example, a city-level strategy may include lower-level facilities as well as the city-level facilities.

Macro-strategies of area agents
In formulating his alternative macro-strategies, an area agent could take many parameters of his method to generate a land-use plan into account. However, given the objective of the system to generate meaningful plan alternatives for planning support, we suppose that only the weight of accessibility of different kinds of facilities (*i.e.,* retailing, green space and school) relative to the weight of distance and adjacency to other land uses is relevant here. The lower the relative weight, the less sensitive the area agent is to the plans of facility agents and the higher the probability that the land-use of area agents is located relatively distant from facilities. Then, in the revision stage, the facility agents are likely to respond and change the locations of their facilities to better cover the spatial distribution of demand. Thus, depending on his macro-strategy, an area-agent either acts as a follower or as a leader. Thus, even if, for example, the housing agent appears last in the sequence, his preferences may still have a dominant impact on the final plan.

Micro-strategies of facility agents: the interchange algorithm
In the system, facility-agents use the interchange algorithm as a heuristic to find an optimal or good solution at the micro level. Recall that a micro-strategy is embedded in a macro-strategy. Since the macro-strategy defines the number and size of facilities only location decisions are left and, therefore, the interchange algorithm is a suited method for this stage. The interchange algorithm is a widely used heuristic to solve the *p*-median location-allocation problem. The heuristic is very efficient and appears to be robust and effective in the sense that it tends to produce the global optimum or near-global optimum with high probability (Rosing, *et al.*, 1979). The first step in this method involves generating an initial solution randomly and this is followed by an iterative procedure of trying to improve the solution by substituting (*i.e.,* interchanges) locations in the solution by candidate locations not in the solution. Although the interchange algorithm was developed originally for the *p*-median model (Teitz and Bart,1968) it has been shown to be useful for a larger class of location-allocation model as well (Hilsman, 1984).

In the context of the present system, a facility agent may consider several models as alternatives. First, the maximum-covering model seeks to maximize the total demand covered by the facilities. Hereby, a demand is covered if it falls within the catchment area of at least one facility. The radius of the catchment area of a facility is the maximum distance where people can be attracted to visit the facility. It is set dependent on the size (*i.e.,* order) of that facility: the larger the facility (*i.e.,* the higher it orders) the larger the catchment area will be and vice versa. Thus, in maximizing the total coverage, the maximum covering model seeks the set of locations that minimizes the overlap in catchment area between the facilities. At the same time, the model is sensitive to the size of the demand available within cells. In case of retail, green-space and school facilities, demand for the facilities originate from households at origin locations. The higher the density of housing, which may vary between the housing types considered by the housing agent, the larger the weight of the cell in the function that calculates the total demand covered. Therefore, apart from minimizing the overlap, the model seeks to maximize the housing cells and in particular high density housing cells within catchment areas of facilities.

Second, the *p*-median model minimizes the total weighted distance to the nearest facility across the origin locations of demand. Since households are the users of the facilities, housing density within cells is used as weight. Thus, the model searches for the locations that maximize the accessibility of the facilities for the population served by the facility system.

A number of observations are worth making. First, the interchange algorithm treats facility locations as point locations. Therefore, we take the locations (*i.e.,* cells) found as the centroids of the areas occupied by the new facilities. Having identified the centroid of each new facility, facility-agent claims all the land (*i.e.,* cells) in the surrounding of each centroid available for his land-use and needed to realize the size of the new facility.

Second, the interchange algorithm requires that all candidate locations are pre-defined. In the context of our system, each facility-agent considers all cells available for his land-use as the set of candidate locations. Note that the size of the candidate set will be smaller for agents later in the sequence, since the cells claimed by agents earlier in the sequence are no longer available as candidates.

Third, the facility agents face a problem of estimating the size of the demand for their facilities in each cell in the plan area. In the initial stage of the procedure, the housing plan is unknown at the moment when each facility agent generates a plan, given the sequence that we assume in the system. Therefore, the facility agents count cells with a *potential* housing development as well as cells with existing housing development as demand locations. Since housing density is unknown, an average density is assumed for potential housing cells.

Fourth, it is important to note that the agents also take the location and size of existing facilities into account (e.g., shopping centers, green spaces and schools). Existing facilities have the same catchment area definition as the new facilities. The only difference is that it is not possible for them to change location, *i.e.,* they are fixed in the solution.

Finally, the *p*-median as well as maximum covering model are rather restrictive in terms of the assumptions about the spatial choice behavior of users of the facilities. In particular, they assume that people always choose the nearest facility (*p*-median model) or that a critical distance exists (the maximum covering model). In later versions of the model, we include more behavioral realism in the objective function such as that, for example, people may also make multi-purpose or multi-stop trips and that choice behavior is probabilistic. Such objective functions have been studied in previous work of Ma, *et al*. (2004, 2005).

Micro-strategies of area agents: the Hara algorithm

The housing agent uses the so-called '**Hara** (Housing-type Allocation in Residential Areas)' algorithm for the allocation of housing types to the plan area (see Arentze, *et al.,* 2006). The Hara-algorithm first allocates housing types to cells in the plan area based on the suitability of each cell for each housing type. The suitability of each cell depends on the land use of adjacent cells and the shortest distance to specific facilities. After allocating all housing cells, a total suitability score can be calculated. Due to the consecutive allocation of housing types to cells, the total suitability score might not be optimal. Therefore, a process of swapping housing cells will be start up: randomly selected pairs of different housing cells will be swapped if this will increase the total suitability score. This process continues until the total suitability score does not improve anymore.

3. ILLUSTRATION

3.1 The decision problem

As an illustrative case, we consider Meerhoven, which is an area designated for the expansion of Eindhoven, The Netherlands. Meerhoven is located in-between Veldhoven (a smaller city) and Eindhoven and experiences the influence of both cities at the same time. The area is currently being developed. For illustration purposes, we assume the stage where the task size of each land-use for the area is known and a land-use plan is yet to be determined.

The size of the larger study area is 1,250 hectares and is represented by a grid of 50 x 50 meter cells. This cell size is the largest size for which it is still reasonable to assume that cells can take on only a single land-use. Thus, the total area comprises 5,000 cells. The plan area, *i.e.,* the area designated for the new developments, covers a subset of 1,500 cells with an area size of 3,750,000 m^2 (375 hectares).

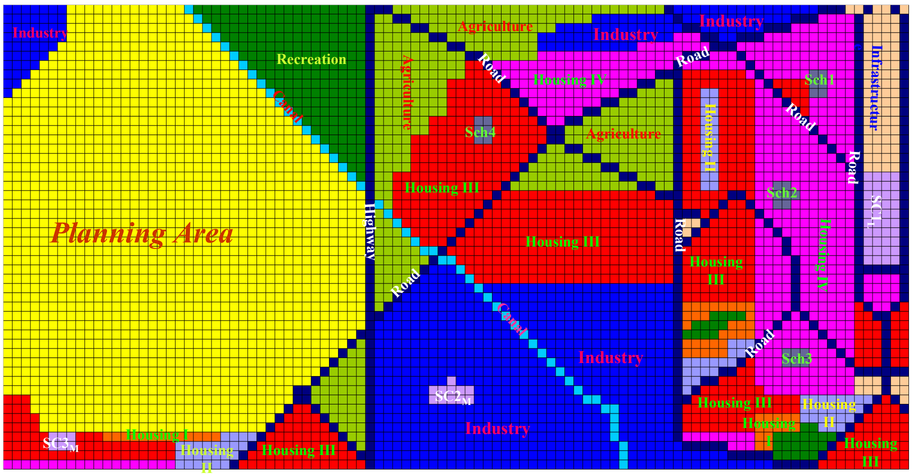

Figure 2. The study area.

Figure 2 shows the different land-uses in the study area: vacant land use (plan area), recreation, industry, landscape (canal), agriculture, schools (Sch1, Sch2, Sch3 and Sch4), shopping centres ($SC1_L$, $SC2_M$ and $SC3_M$), housing (housing I, housing II, housing III and housing IV), and transportation (highway and road) and other type of infrastructure. Specifically, the land use 'housing' is subdivided into four types of houses, *i.e.,* detached houses (housing I), semi-detached houses (housing II), row houses (housing III) and apartment (housing IV). Three shopping centres are located in the external area: a large shopping centre ($SC1_L$) and two medium-sized shopping centres ($SC2_M$ and $SC3_M$). In the plan area, approximately 6,000 new houses together with the necessary facilities need to be developed.

The system includes four agents: three facility agents (retail, green space, schools) and one area agent (housing). The area agent is responsible for the land-use planning of each housing type distinguished. Industry, agriculture and landscape play a role in the existing area, but are not involved as new developments in the plan area. Hence, a single area agent suffices in the present case study. A special land-use category that the system takes into account is called Restgreen (land use code '6'). Restgreen is the land-use that remains if no specific development is specified for a plan-area cell. Thus, in the existing situation all plan-area cells have a Restgreen land use.

Table 1 shows parameters for the facility agents relevant for determining macro-strategies. For the retail agent the task size equals 10,000 m^2. Based on this Task Size and standard sizes of shopping centres that are representative for the Dutch situation, the macro-strategies available include a maximally centralized strategy (one big shopping centre), a semi-centralized centre (two district-level shopping centres) and a decentralized strategy (four neighbourhood-level shopping centres). In a similar way, the green agent has as options: one big green park (of 200 cells), 5 district parks and 12 neighbourhood parks. Finally, the school agent considers one large school, two smaller schools and four small schools.

Table 1. Task size and available macro-strategies of facility agents.

Agent	Land use code	Task size (m^2)	Hierarchical orders	Criteria		Macro-strategy	
				Required inhabitants (10^3)	Size of a facility (10^4 m^2)	No. of facilities	No. of cells per facility
Retail	4	10,000	City (section)	Approx. 20	1.0	1	4
			District	10~20	0.5	2	2
			Neighborhood	6~10	0.3~0.4	4	1
Green	5	500,000	City (section)	Approx. 20	14~1,35	1	200
			District	10~20	4,25~14	5	40
			Neighborhood	6~10	< 4,25	12	17
School	7	9,600	City (section)	800 households	–	1	4
			District	800 households	–	2	2
			Neighborhood	800 households	–	4	1

Table 2 shows the task sizes and available macro-strategies of the housing agent. The plan area should accommodate a total of 6000 new households distributed across housing types as follows: 600 detached houses, 1500 semi-detached houses, 2700 row houses and 1200 apartments. Using standard figures for housing densities for the different types, these quantities lead to 215, 268, 386 and 130 cells for the housing types respectively.

Table 2. Task sizes and available macro-strategies of the housing agent.

Housing types	Land use code	Task size		Criteria	No. of new houses/cell	No. of cells
		Proportion of house types	No. of houses	Space per house type (m^2)		
Detached	1	10%	600	900	2,8	215
Semi-detached	2	25%	1500	450	5,6	268
Row houses	3	45%	2700	360	7,0	386
Apartment	8	20%	1200	270	9,3	130

3.2 Plans generated by the system

In this section, we will discuss the results of an application of the system to this case. Each facility-agent has three macro-strategies, *i.e.,* centralized, semi-centralized and decentralized. Thus, in terms of the facility agent alone, the system can generate as many as 27 collective plan alternatives. If we add to this the macro-strategies the housing agent may consider, the number of options is a multitude of this figure. In this paper, we discuss the results of only three cases as examples. These include: each facility agent uses a centralized strategy, each facility agent uses a semi-centralized strategy and each facility agent uses a decentralized strategy. The housing agent does not vary the parameters of his behaviour across cases, *i.e.,* does not adopt any specific strategy. As an illustration, the retail and school agents use the maximum covering model and the green agent uses a p-median model for determining a micro-strategy in each case.

Table 3 summarizes the settings of facility-agent parameters that were kept constant across cases. The parameters α and β are used in a MNL model to predict the demand attracted to each facility under the condition of a plan. The MNL models do not play a role in the planning process, but are used for analysing the performance of a plan in terms of travel demands and the economic performance of facilities in the system. The parameters are defined for each size category and each facility type respectively and indicate a constant and a distance coefficient respectively. The radii of catchment areas were calibrated such that the maximum covering model displayed the maximum sensitivity and produced unique solutions. The number of trips per household per month per facility type represents an average. These parameters are used to calculate travel demands in the system as part of a performance analyse of plans generated.

Table 3. Settings of parameters of the facility agents.

Agent	Facility size	β	α	No. of trips per household per month	No. of cells per facility size	Radius of a catchment area (m)
	Large size	-0.003	2.7		4	900
Retail	Medium size	-0.003	1.65	12*	2	550
	Small size	-0.003	1.2		1	400
	City (section)	-0.003	3.0	0.4	200	1,000
Green	District	-0.003	1.5	0.8	40	500
	Neighbourhood	-0.003	1.05	2.0	17	350
	Large size	-0.003	2.7		4	900
School	Medium size	-0.003	2.1	4.5*	2	700
	Small size	-0.003	1.35		1	450

*Assumption: no difference in trip purpose between facility sizes in case of retail and school.

Figures 3, 4 and 5 show the three plan alternatives resulting from the centralized, semi-centralized and decentralized macro-strategies of facility agents respectively. The figures show only the left part of the study area to highlight the plan area indicated by the same legend of land-use codes shown in Figure 3, but we emphasize that the solutions generated are sensitive to the situation in the right part of the study area as well. Several patterns are visible in these results. First, in each plan housing types are clustered in more or less homogeneous areas reflecting a preference to develop the same housing type in adjacent cells. Second, Restgreen tends to be arranged as buffer zones around clusters of housing types and between housing and industry in all solutions. Third, as a tendency, high density housing (apartments and row houses) is centred around facilities such as retail and green spaces. Lower density housing is concentrated in more peripheral layers around high density areas. As a result the plans vary in the extent to which they give rise to a single-centric versus a poly-centric structure of the area.

Table 4 shows the results of a performance analysis of the plans under the different strategies. The indicators calculated relate to accessibility (average and maximum distance to the nearest facility across households, average trip length across households) and economic performance of facilities (total and minimum demand attracted across facilities) and are expressed per facility type (retail, school, green). Predicted trip length and predicted demand are derived from an MNL model for each facility type. As expected, the accessibility increases with increasing decentralization. For example, for retailing the average distance to the nearest facility decreases from 834 meter (centralized), to 793 meter (semi-centralized) to 745 meter (decentralized). Perhaps more surprisingly, also the total demand attracted to *new* facilities in the solution increases for all facilities except green space. Note that the total demand for as well as the total size of facilities in the study area stay constant across the plans. Hence, an increase in demand attracted by the new facilities means a decrease in the demand attracted by the existing facilities in the area. Therefore, the new retail and school facilities as a set appear to be more competitive in less centralized solutions. The reason why this does not hold for green space relates to an assumption that we made regarding the type of this facility (see Table 3). In case of green space we assumed that larger green spaces have more to offer than small green spaces and therefore attract green-space trips of a higher order as well. In other words, for green-space demand is elastic and larger green spaces generate additional demand.

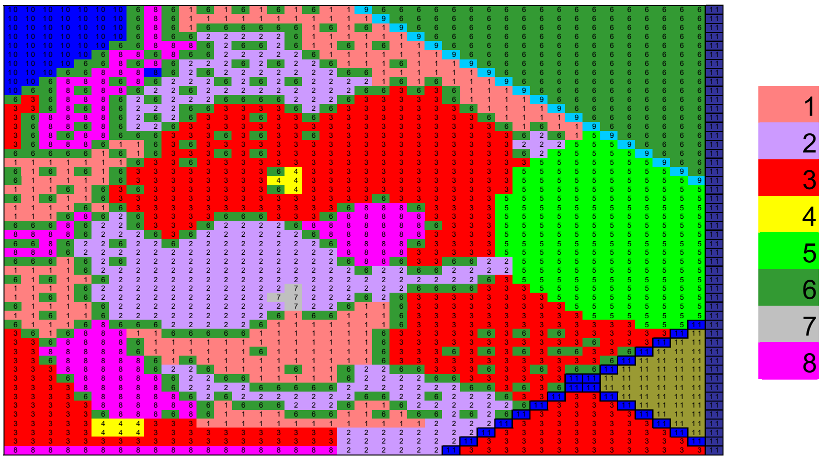

Figure 3. The plan alternative of the centralized macro-strategy.

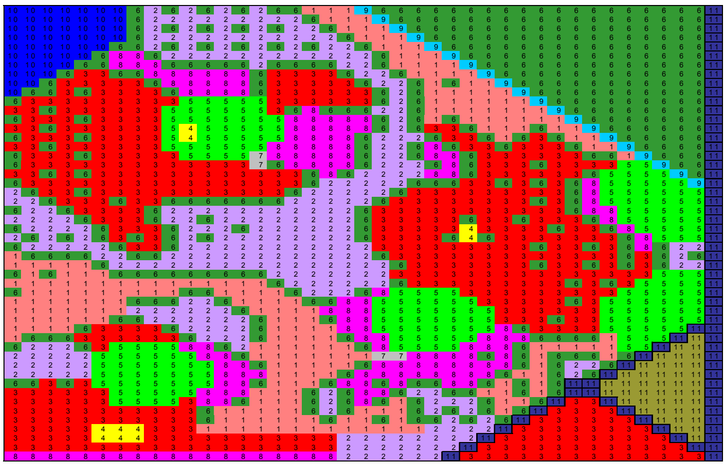

Figure 4. The plan alternative of the semi-centralized macro-strategy.

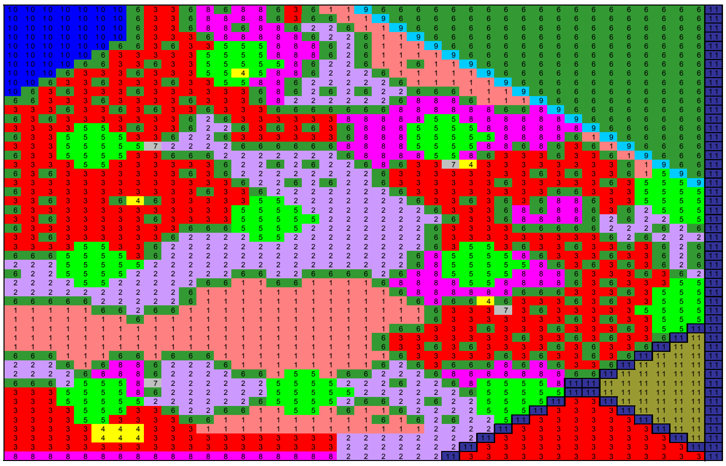

Figure 5. The plan alternative of the decentralized macro-strategy.

Table 4. Performance indicators.

Strategy	Agent	Distance to the nearest facility (m)		Distance of trips (predicted) (m)	Total demand new facilities (visits/month) (predicted)	
		Average	Maximum	Average	Total	Minimum
Centralized	Retail	834	1,914	900	54,734	54,734
	Green	1,712	3,250	1,712	55,781	55,781
	School	585	1,649	668	30,363	30,363
Semi-centralized	Retail	793	1,914	888	56,621	26,770
	Green	1,305	3,092	1,437	48,808	4,846
	School	499	1,230	607	30,564	15,228
Decentralized	Retail	745	1,901	875	61,598	13,954
	Green	1,232	3,105	1,468	34,863	1,352
	School	433	1,063	579	30,746	7,243

Finally, Table 5 shows a summary of the land-use suitability scores for each land-use in each plan. As it appears and in line with the earlier findings, the total suitability score across cells increases with decreasing centralization in case of each land-use. The increase is due to the distance component of the suitability scores, as the adjacency component stays approximately the same across the plans. The explanation is straightforward: in more decentralized solutions distances to nearest facilities tend to be shorter by which the suitability scores increase.

In sum, the results of this analysis indicate that a decentralized strategy yield a better performance in terms of the accessibility, economic performance and suitability indicators considered here. We emphasize, however, that this reflects limitations of the performance measurements used. As the green-space case shows, a centralized solution may outperform a less centralized solution in economic performance of the facility system, if demand is assumed to be elastic such that larger facilities evoke more demand. At the same time, the performance measures used did not take into the possibility of decreasing economic costs that result from economies of scale. Larger centres may reduce the costs per unit floor space and in that way increase the profitability of centres.

Table 5. Suitability scores for three macro-strategies.

Land use	Centralized (10^3)			Semi-centralized (10^3)			Decentralized (10^3)		
	Dist.	Adja.	Total	Dist.	Adja.	Total	Dist.	Adja.	Total
Detached	32,9	14,5	46,4	33,7	14,5	48,2	34,9	14,8	49,7
Semidetached	36,1	18,3	54,4	39,8	18,2	58,0	42,2	18,5	60,7
Row house	89,6	60,5	149,6	96,0	60,8	156,8	95,8	60,9	156,3
Retail	0,8	-	0,8	0,8	-	0,8	0,8	-	0,8
Green	1,4	-	1,4	2,5	-	2,5	2,8	-	2,8
Restgreen	5,4	14,4	19,7	5,4	14,4	19,8	5,8	14,8	20,6
School	-	0,4	0,4	-	0,4	0,4	-	0,4	0,4
Apartment	38,9	30,9	69,8	43,0	30,9	73,9	43,5	30,9	74,4
Landscape	-	-	-	-	-	-	-	-	-
Industry	-	0,3	-	-	0,3	-	-	0,3	-
Total	203,6	139,3	342,9	221,2	139,4	360,5	225,8	140,2	366,0

4. CONCLUSION

In this paper, we have developed and illustrated a generic multi-agent system to generate land use plan alternatives in an interactive environment of multi-agents. Each agent in the system is specialized in a certain land-use (*i.e.,* facility agents, e.g., retail, green park and school and area agents, e.g., housing agents). The different agents may use different methods to generate plans for their land-use. Particularly, facility agents use the interchange algorithms and formulate their location problem as a maximum covering model or *p*-median model, whereas area agents use a different heuristic based on suitability analysis. Apart from the methods used, each agent in addition may consider different (macro) strategies in the problem solving process. As illustrated in a case study, centralized, semi-centralized and decentralized macro-strategies may be varied to generate alternative plans that are interesting from a planning support point of view. We conclude, therefore, that the approach provides a promising framework for a planning support system that allows users to generate land-use plan alternatives.

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