An Agent for Supporting and Simulating Locations Decisions of Firms

Gustavo G. Manzato, Theo A. Arentze, Harry J. P. Timmermans and Dick Ettema[1]

Eindhoven University of Technology
PO Box 513
5600MB Eindhoven
The Netherlands
Email: G.G.Manzato@tue.nl, T.A.Arentze@tue.nl, H.J.P.Timmermans@tue.nl

[1] Utrecht University
PO Box 80115
3508TC Utrecht
The Netherlands
Email: D.Ettema@geo.uu.nl

Key words: Design & Decision Support Systems, Firm Location Decisions

Abstract: The objective of this paper is to present the scope and the contents of an agent for supporting and simulating location decisions of firms. An application of one of its features, which is related to finding a location for a given firm, is developed here as an illustration of the approach. We can conclude that the agent is able to perform an evaluation of suitable locations in space given a set of firm's characteristics or requirements. Other features may also be derived, for example, finding firms that meet the environmental characteristics and also an attempt to simulate the allocation of firms, seeking a location, to the set of available locations.

1. INTRODUCTION

Since decades, there has been an overwhelming interest in location decisions of firms and organizations, especially in disciplines such as (economic) geography and regional science. Early theories of location were heavily based on principles of the *Homo economicus*. Location theories developed by Christaller, Weber, Losch and many others, based on distance minimizing consumers and profit maximizing firms, given isotropic conditions, led to appealing (symmetric), distinctive location patterns of firms. While these theories did increase our understanding of the organization of space, the assumptions underlying these theories were too restrictive to use these theories for developing policies or to predict location decisions of firms.

In fact, these criticisms about the lack of face validity of traditional theories led to the formulation of so-called behavioral theories, based on concepts of *Homo psychologicus*. Principles of distance-minimizing and profit-maximizing behavior were replaced with concepts such as preferences, limited information, evaluation, cognitive maps etc. They articulate that location decisions are based on preferences of decision makers applied to limited and perhaps biased information that decision makers have about the choice options and their characteristics. Consequently, formal theories with clear location patterns were difficult to derive. Instead, operational models were built, which were supposed to represent the location decision making process. Typically, value judgments about individual characteristics of locations were combined according to some combination rule to arrive at an overall preference. Location choice in turn was systematically related to these preferences.

These behavioral models typically assumed that location preferences were time-invariant or, more specifically, were not related to the characteristics and the lifecycle of the firms. It led to the development of an institutional or organizational approach, claiming that location decisions were nothing but another strategic business decision. Location choices should therefore be understood in the context of the larger organization, its lifecycle, and the timing of other strategic decisions of the organization.

Discussion of the concepts of location theory can be found, for example, in Witlox, 1998, Witlox and Timmermans, 2000, Pellenbarg, van Wissen, et al., 2002, Brouwer, Mariotti, et al., 2004, van Dijk and Pellenbarg, 2000.

Based on this trend in location theories and associated location choice models, we decided to develop an agent to support and simulate location decisions of firms. This agent allows inclusion of domain knowledge and contains a set of concepts and mechanisms to support and simulate location decisions. Dependent on the specific application, the agent can be embedded in different user interfaces to develop a decision support tool with a specific application in mind.

In this paper, we will outline the scope and contents of this agent and illustrate its potential using an example of location decision for offices. The paper is completed with a discussion of an application of this tool and possible extensions.

2. PRINCIPLES

Let i (i=1,…, I) be a subscript indicating the set of locations in a study area. Similarly, let j (j=1,…, J) be a subscript for the set of firms investigated. Assume that each location i can be described in terms of N physical characteristics X_{in} and each firm j in terms of M firm characteristics Y_{jm} (e.g., type of activity, size, etc.). Assume that decision makers, representing firms, have a set of minimum requirements formulated for a set of K performance characteristics Z_{jk}^{D} (e.g., accessibility by car, availability of workers, visibility of the site, etc.). The demands are a function of the firm's characteristics:

$$Z_{jk}^{\mathrm{D}} = f(\mathbf{Y}_j) \tag{1}$$

where $\mathbf{Y}_j$ is the set of Y_{jm} firm characteristics (m = 1, …, M). On the other hand, the performance provided by a location i on each criterion k is denoted by Z_{ik}^{S} and modeled as a function of the location's physical characteristics:

$$Z_{ik}^{\mathrm{S}} = g(\mathbf{X}_i) \tag{2}$$

where $\mathbf{X}_i$ is the set of X_{in} location characteristics (n = 1, …, N). We assume that for each combination of location i and firm j the agent is able to evaluate the degree of match represented by the following function:

$$Q_{ijk} = h(\mathbf{Z}_i^{S}, \mathbf{Z}_j^{\mathrm{D}}) \tag{3}$$

where Q_{ijk} represents a matching score between supplied and demanded performance on criterion k and $\mathbf{Z}_i^{S}$ and $\mathbf{Z}_j^{D}$ are K-vectors of offered and demanded performance scores. Finally, we assume that the agent maps the matching characteristics into an evaluation space and then applies some value judgment V (satisfaction, utility etc.) to the overall match of location and firm. Hence:

$$V_{ij} = r(\mathbf{Q}_{ij}) \tag{4}$$

where V_{ij} is s suitability score for housing firm *j* at location *i* and $\mathbf{Q}_{ij}$ is a *K*-vector of match scores. This basic information can be stored in a set of basic matrices:

i. An *I* x *N* matrix **X** describes the characteristics of the various locations;
ii. An *J* x *M* matrix **Y** describes the characteristics of the various firms in the study area;
iii. An *I* x *K* performance matrix $\mathbf{Z}^S$ of locations;
iv. An *J* x *K* requirement matrix $\mathbf{Z}^D$ of firms;
v. An *I* x *J* x *K* matching matrix **Q;**
vi. An *I* x *J* suitability matrix **V**.

In summary, using this set of functions the agent is able to perform a role of an intermediate between, on the one hand, a supply set of locations for accommodating a firm and, on the other, a demand set of firms looking for locations to accommodate their activities. Eventual value judgments *V* relate to a comparison between performances offered and performances required which the agent derives through a series of steps including judgments *f* (performances demanded on relevant criteria), *g* (performance supplied on the same criteria), *h* (match between supply and demand on these criteria) and *r* (overall suitability of the location for the firm). This set-up relies on the following assumptions:

1. Performance characteristics of locations can be determined independently of the firm looking for a location;
2. Performance requirements by firms can be formulated independently of the location offering accommodation.

As argued in a functional approach to modeling site selection (Reitsma, 1990, Lucardie, 1994, Witlox, 1998), the first assumption is not always warranted. An example where the first assumption is violated is a case where a firm requires that a (new) location is well accessible for the current clients of the firm. The extent to which a location meets this requirement can be evaluated only in relationship to the specific firm imposing the requirement. Note, however, that if the requirement would be posed in generic terms, such as for example, the location should be accessible for potential clients for a certain service, the assumption is not restrictive. In that case the performance of each location can be evaluated without reference to a specific firm imposing the requirement. The second assumption seems to violate the phenomenon of conditional relevance. For example, conditional relevance occurs if a firm would impose a particular requirement conditional upon a characteristic of the location (e.g., visibility of the location is relevant only in an urban area). Clearly, such interactions between location characteristics and requirements are numerous. However, arguably, they can be captured by allowing substitution relationships at the levels of function *h* or *r*.

A rationale of the approach is twofold. First, matching functions allows the agent to take overperformance as well as underperformance into account (Arentze, Lucardie, et al., 1996). If rent price is not explicitly represented, then overperformance is generally undesirable as it tends to raise costs of a firm without giving value in return. Keeping that in mind, it is important to derive demanded performances carefully. Second, the agent can be used for different types of applications.

The first type of application will involve an individual firm looking for a satisfactory or optimal location. In this case, $J = 1$ and the relevant matrices are collapsed into vectors. The agent would then generate a set of locations meeting minimum requirements or a list of feasible locations, sorted in terms of overall value judgment/evaluation/preference. If the various functions are operationalised by the researchers or experts, the agent would be a decision support tool, very similar to multicriteria evaluation approaches to site selection (Malczewski and Ogryczak, 1995, Jankowski, 1995). If these functions are calibrated using empirical data, the purpose of the agent would shift into a model of actual decision making, which could be used in more complex, large scale simulations (e.g., Waddell, Borning, et al., 2003, Wagner and Wegener, 2007). A second type of application would not start with the firm, but rather with the location. In that case, the problem would be to find the firm or set of firms which would match or be most suitable for any given location. This could be relevant for project managers. Technically, the matrices would again collapse into vector, but now into the other dimension. Thirdly, the focus could also be on the full matrix *V* in an attempt to simulate the allocation of firms, seeking a location, to the set of available locations. In principle, this mechanism could be based on any specific allocation model, based on some optimality criteria (Cromley and Hanink, 1999). In this case, the agent could be used in dynamic land use simulations, either aggregate simulations such as cellular automata (White and Engelen, 1993) or integrated land use-transport simulations (Mackett 1985, Timmermans, 2003) or in multi-agent simulation systems (Ma, Arentze, et al., 2006, Saarloos, Arentze, et al., 2005, Arentze and Timmermans, 2007). In the latter case, rules to define the interactions between agents (firms) need to be defined.

Functions *f*, *g*, *h* and *r* in any applied context require further operational decisions. Function *g* derives performance scores from physical location characteristics. This may involve a psycho-physical operator which maps physical characteristics into the psychological concept of interest. Empirical research has overwhelmingly indicated that such functions are a non-linear, monotonically decreasing function of continuous physical variables, but in principle any continuous or stepwise function can be used. Function *f* derives performance demands from characteristics of a firm. Generally, such functions are based on expert knowledge accumulated in practices of agents acting as intermediates in real-estate markets. Considerations mentioned with regard to *g* and *f* also apply to the function *h*: it can be formulated as an algebraic function, based on similarity or as a set of logical Boolean operators, or as some mixed specification in case of a combination of quantitative and qualitative characteristics. Finally, function *r* represents a combination rule and has received a lot of attention in behavioral research. In many cases, *r* has been defined as a weighted average function, representing compensatory decision making in the sense that a low value judgment of one characteristic can at least partially be compensated by high value judgments on one or more of the remaining characteristics. Alternatively, a multiplicative function can be used which can represent or at least approximate non-compensatory decision making processes. These and other specifications of *r* find their theoretical foundation in multi-attribute decision theory. If theoretical underpinnings would be of lesser concerns, *r* could also be linked to the many multi-criteria evaluation methods which also *process* evaluation scores of choice options and weights attached to criteria (characteristics) in some particular way, but without making strong, if any, assumptions regarding the representation of actual decision making processes.

3. APPLICATION

A preliminary application of the agent was carried out here to illustrate the approach. This application is related to the first type of question, which involves an individual firm looking for a satisfactory or optimal location. This agent is based on decision tables which contain expert knowledge for evaluating location decisions given a set of firm requirements (demand) and set of environmental characteristics (supply) (Arentze, Lucardie, et al., 1996). From this comprehensive, multi dimensional set of decision tables we have selected a specific dimension to build the agent: the Location Quality at the Regional Level. This dimension also includes some sub-dimensions some of which we also have selected here for the illustration purpose. Figure 1 illustrates it highlighting the dimensions studied in this present work.

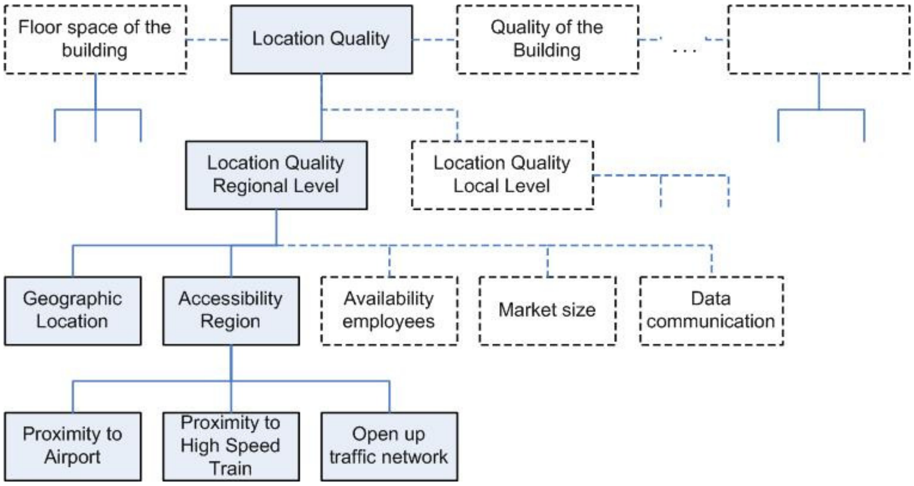

Figure 1. Dimensions of the decisions tables used for developing a preliminary agent

For each dimension, there are some input variables related both to demand and supply sides, these correspond to *X* and *Y* types of variables in our scheme. For example, for evaluating the dimension "Proximity to Airport", in the demand side, we need to know the level of service of the firm, i.e., whether the firm requires an airport close to the location and whether it should be regional or national airport. On the other hand, in the supply side, we need to know the travel time both to a regional and a national airport. Hence, concerning the dimensions studied here (highlighted in Figure 1), we have listed the variables for each side, as presented in Table 1.

The present application focuses on the demand for and supply of office space. The source of data of those variables related to the supply of office space was obtained from the Spatial Planning Agency, a branch of the Dutch Government, containing the locations of the actual offices in the Netherlands. Data about the transportation infrastructure and land-use was also obtained from national databases and/or were generated. All of these datasets were stored, managed, visualized and/or generated in a GIS-base system. Regarding the demands, for this illustration purpose we have assumed characteristics of two hypothetical firms as presented in Table 2.

Table 1. List of variables for deriving demanded and supplied performances

Demand	Level of urbanization
(Y_{jm})	Number of inhabitants
	Scale level of the firm
	Required airport
	Type of airport
	Required High Speed Train station
	Number of employees
	Number of employees who receive visitors
	Number of visits/employee/week
	Number of visitors per time
	Number of visits/employee/week to external customers
	Area scale where employees come from
	Percentage of car-dependent employees
	Percentage of car-dependent employees present in the office
Supply	Level of urbanization
(X_{in})	Number of inhabitants
	Travel time to regional airport
	Travel time to national airport
	Travel time to High Speed Train Station
	Distance to road network
	Presence of an Intercity Train Station

Hence, the agent performs an evaluation process for both demand characteristics (Y_{jm}) and supply characteristics (X_{in}) separately, generating performance scores for each of them, i.e., resulting in the vectors Z_{jk}^{D} and Z_{ik}^{S}. Also based on expert knowledge stored in decision tables, the performance matching scores are obtained for each dimension at the lowest level in each branch of the tree presented in Figure 1 (Geographic Location, Proximity to Airport, Proximity to High Speed Train and Open up Traffic Network). This results in a score matrix Q_{ijk} on the level of those sub-dimensions. A match is classified according to three classes: underperformance (when supplied is less than demanded), overperformance (when supplied is more than demanded) and match (when supplied equals demanded).

At a higher level of the tree (for example, aggregating the sub-dimensions related to "Accessibility Region"), an aggregation of the matching scores is carried out using the following rule. If there is an underperformance on at least one dimension, the overall result is underperformance. Otherwise, if there is an overperformance on at least one dimension, then the overall result is an overperformance. Finally, if there is a match on each dimension then the overall result is a match. In this way, an overall matching score (V_{ij}) is obtained for each location and firm. The results of this illustration are presented in thematic maps showing the evaluation performance scores (i.e., matching scores) in each dimension, on the different levels.

Table 2. List of variables for the demands and the supplies

Variables	Firm 1	Firm 2
Level of urbanization	Expanding city	4 Big cities
Number of inhabitants	More than 100.000	More than 100.000
Scale level of the firm	National	International
Required airport	Yes	Yes
Type of airport	Regional	National
Required High Speed Train station	No	Yes
Number of employees	20	100
Number of employees who receive visitors	5	20
Number of visits/employee/week	1	2
Number of visitors per time	2	5
Number of visits/employee/week to external customers	2	10
Area scale where employees come from	Regional	Higher than regional
Percentage of car-dependent employees	50 %	50 %
Percentage of car-dependent employees present in the office	75 %	90 %

4. RESULTS AND DISCUSSION

The results of the preliminary agent developed here are presented in Figures 2 and 3, which show thematic maps representing the evaluation performance in each dimension for both firms. In both figures, the locations are classified according to the classes: underperformance locations (represented in blue dots), matching locations (represented in black dots) and overperformance locations (represented in red dots). The thematic maps in each figure are labeled with capital letters which represent the dimensions studied here and are described as follows:

- Map “A”: Geographic Location;
- Map “B”: Proximity to Airport;
- Map “C”: Proximity to High Speed Train;

- Map “D”: Open up Traffic Network;
- Map “E”: Accessibility Region (aggregation of maps “B”, “C” and “D”);
- Map “F”: Location Quality Regional Level (aggregation of maps “A” and “E”).

Examining both Figures 2 and 3, we can observe that the agent really performs a plausible evaluation considering the requirements of the firms and the characteristics of the locations. The agent is able to indicate locations, represented in blue dots, that would not be satisfactory for a given firm requirements. Also, the agent can indicate suitable locations that match all the firm’s requirements (represented in black dots) and locations that present a higher level of supply related to the firm’s demand (represented in red dots). Comparing both figures, we can observe the degree of sensitivity of the agent to the characteristics of two different companies. In Figure 2, which represents firm 1, the generally lower level of requirements of this firm leads to finding locations with overperformance, matching and underperformance characteristics. In contrast, as firm 2 (represented in Figure 3) requires a higher level of demands, the agent only finds locations that match the requirements or give an underperformance.

Although we have considered only part of relevant dimensions here, the agent is already able to perform some evaluations. It gives us an indication of the behavior of the model proposed. However, extensions to include other relevant dimensions have yet to be developed and evaluated. In addition, other types of aggregation judgments at the higher level of the dimensions should also be implemented.

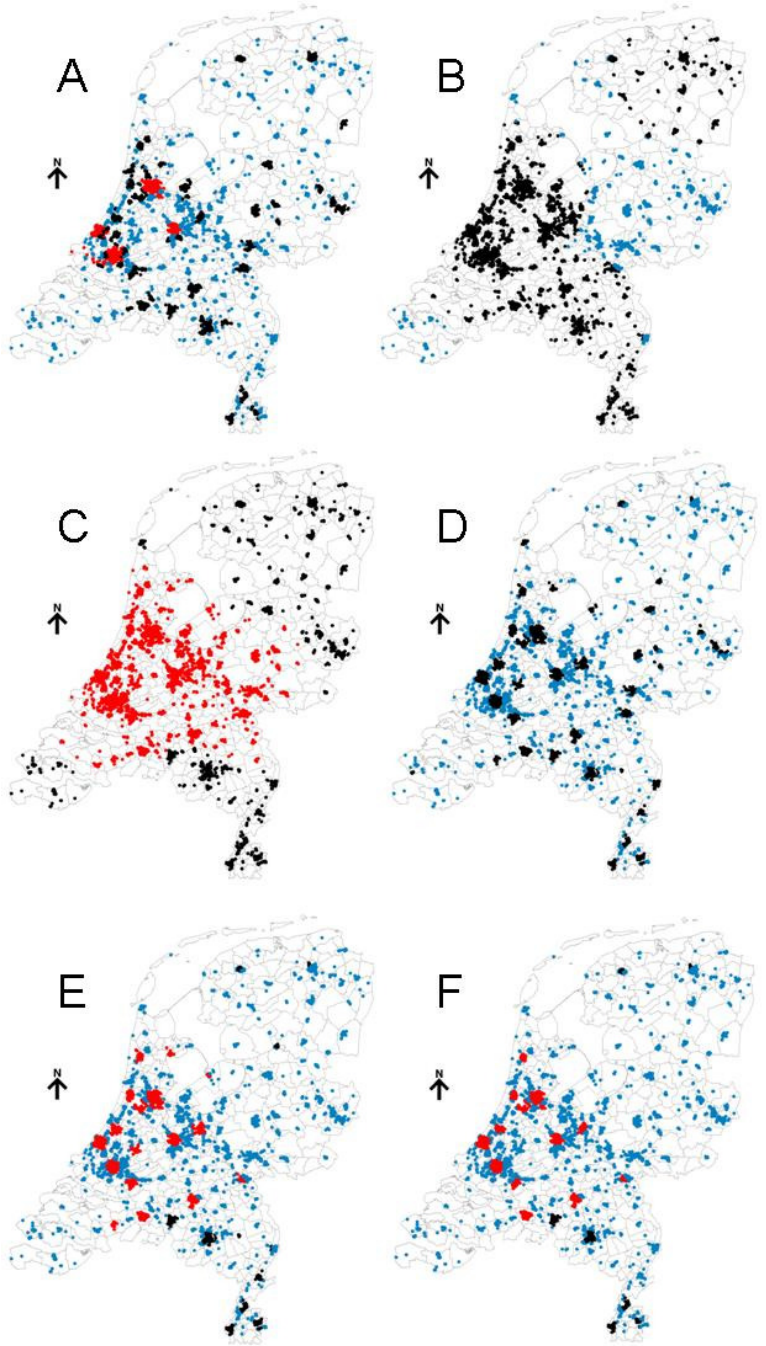

Figure 2. Thematic maps of firm 1

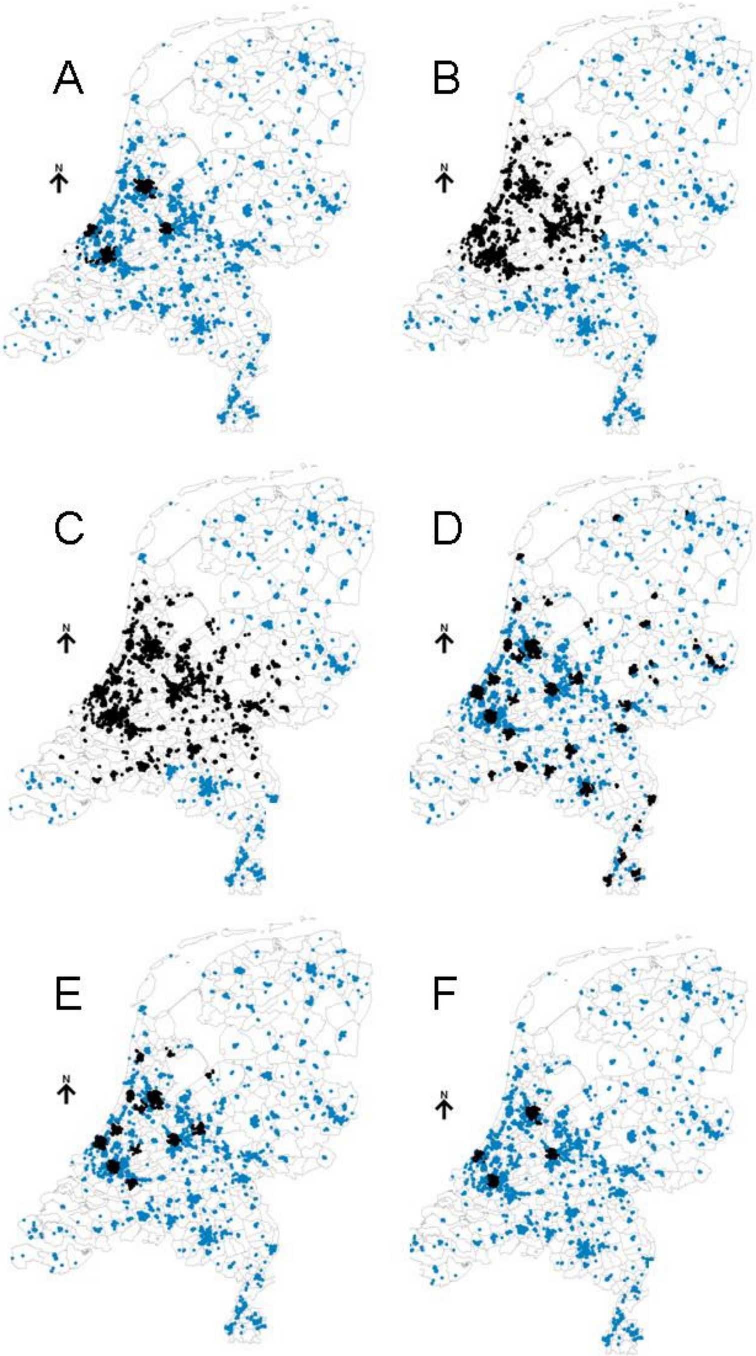

Figure 3. Thematic maps of firm 2

5. CONCLUSIONS

The objective of this paper was to present the scope and the contents of an agent for supporting and simulating locations decisions of firms. An application of one of its features was illustrated here. From the results of this illustration we can conclude that the agent is able to 1) derive performance demands from characteristics of a given firm, 2) evaluate actual performances from characteristics of a given location and 3) derive a suitability score based on the match between demanded and supplied performances for a given combination of firm and location. The agent displays plausible behavior when tested with different sets of demands, allowing the delineation of suitable location choice sets for each one of those sets of demands. Concerning this application, further studies will be carried out, developing an extension of the agent to include a full set of dimensions as well as alternative evaluation methods.

Such a knowledge-base supports various functions of the agent. These functions together with appropriate interfaces of the agent will also be developed. As described previously, one of them is the facility of finding firms that meet the environmental characteristics of a given location. Another is the delineation of location choice sets for a firm seeking a location. A final and most comprehensive one concerns the allocation of firms seeking a location to available locations offering accommodation in a study area. As those features allow inclusion of domain knowledge and contain a set of concepts and mechanisms to support and simulate location decisions, they can be useful in decision making processes related to urban and regional planning.

6. ACKNOWLEDGEMENT

Supported by the Programme Alβan (the European Union Programme of High Level Scholarships for Latin America, scholarship no. E07D400519BR) and RGI (Ruimte voor Geo-Informatie).

7. REFERENCES

Arentze, T.A., G.L. Lucardie, H. Oppewal, H.J.P. Timmermans, 1996, "A functional decision table based approach to multi-attribute decision making", *Proceedings: 3rd International Conference on Retailing and Consumer Services Science*, Telfs/Buchen, Austria.

Arentze, T.A. and H.J.P. Timmermans, 2007, "A multi-agent activity-based model of facility location choice and use", *DisP*, 170(3), p. 33-44.

Brouwer, A.E., I. Mariotti, J.N. van Ommeren, 2004, "The firm relocation decision: An empirical investigation", *The Annals of Regional Science*, 38(2), p. 335-347.

Cromley, R.G. and D.M. Hanink, 1999, "Coupling land-use allocation models with raster GIS", *Journal of Geographical Systems*, 1, p. 137-153.

Jankowski, P., 1995, "Integrating Geographical Information Systems and Multiple Critera decision-making methods", *International Journal of Geographical Information Systems*, 9, p. 251-273.

Lucardie, L., 1994, *Functional object types as a foundation of complex knowledge-based systems*, Technische Universiteit Eindhoven, Eindhoven.

Ma, L., T.A. Arentze, A.W.J. Borgers, H.J.P. Timmermans, 2006, "A multi-agent model for generating local land-use plans in the context of an urban planning support system", *Proceedings: 8th International Conference on Design & Decision Support Systems in Architecture and Urban Planning*, Eindhoven, The Netherlands.

Mackett, R.L., 1985, "Integrated land use-transport models", *Transportation Reviews*, 5, p. 325-343.

Malczewski, J. and W. Ogryczak, 1995, "The multiple criteria location problem: a generalized network model and the set of efficient solutions", *Environment and Planning A*, 28, p. 1931-1960.

Pellenbarg, P.H., L.J.G. Wissen, J. van Dijk, 2002, Firm relocation: state of the art and research prospects, University of Groningen, Groningen.

Reitsma, R.F., 1990, *Functional classification of space: aspects of site suitability assessment in a decision support environment*, Dissertation, International Insititute for Applied Systems Analysis, Laxenburg, Austria.

Saarloos, D., T.A. Arentze, A.W.J. Borgers, H.J.P. Timmermans, 2005, "A multi-agent model for alternative plan generation", *Planning and Design*, 32, p. 505-522.

Timmermans, H.J.P., 2003, "The saga of integrated land use-transport modeling: how many more dreams before we wake up?" *Proceedings: IATBR Conference*, Lucerne, Switzerland.

van Dijk, J. and P.H. Pellenbarg, 2000, "Firm relocation decisions in The Netherlands: An ordered logit approach", *Papers in Regional Science*, 79(2), p. 191-219.

Waddell, P., A. Borning, M. Noth, N. Freier, M. Becke, G. Ulfarssons, 2003, "Microsimulation of urban development and location choices: design and implementation of UrbanSim", *Networks and Spatial Economics*, 3, p. 43-67.

Wagner, P. and M. Wegener, 2007, "Urban land-use, transport and environment models: experiences with an integrated microscopic approach", *DisP*, 170(3), p. 45-56.

White, R. and G. Engelen, 1993, "Cellular automata and fractal urban form: a cellular modeling approach to the evolution of urban land use patterns", *Environment and Planning B: Planning and Design*, 25, p. 1175-1199.

Witlox, F.J.A., 1998, *Modelling site Selection: A relational matching approach based on Fuzzy decision tables*, Technische Universiteit Eindhoven, Eindhoven.

Witlox, F.J.A. and H.J.P. Timmermans, 2000, "MATISSE: a knowledge-based system for industrial site selection and evaluation", *Computers, Environment and Urban Systems*, 24(1), p. 23-43.

Witlox, F.J.A., A.W.J. Borgers, H.J.P. Timmermans, 2004, "Modeling locational decision making of firms using multidimensional fuzzy decision tables: an illustration", *Electronic Journal of Mathematics*, 15, p. 1-17.